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Outcomes of anatomic total shoulder arthroplasty in patients with excessive glenoid retroversion: a case-control study

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Background: Ideal management of severe glenoid retroversion during anatomic total shoulder arthroplasty (TSA) remains controversial, as previous reports have suggested that severe retroversion may negatively impact clinical outcomes. The purpose of this study was to evaluate the impact of severe glenoid retroversion on clinical and radiographic TSA outcomes using a standard glenoid component, as well as to compare outcomes among patients with less severe retroversion.

Methods: A case-control study was performed comparing 40 patients treated with TSA with more than 20° of glenoid retroversion preoperatively (average follow-up, 53 months) vs. a matched cohort of 80 patients with less than 20° of retroversion (average follow-up, 49 months). In all patients, the surgical technique, implant design, and postoperative rehabilitation protocol were identical. Patients were matched based on sex, age, indication, and prosthetic size. Comparisons were made regarding patient-reported outcome measures (PROMs), motion, postoperative radiographic loosening, and the presence of medial calcar resorption.

Results: Preoperatively, both groups demonstrated similar PROMs and measured motion, except for preoperative Single Assessment Numeric Evaluation scores and American Shoulder and Elbow Surgeons total scores, which were higher for the severe retroversion group (44.4 vs. 31.3 [$P = .012$] and 34.9 vs. 29.4 [$P = .048$], respectively). Postoperative PROMs and motion were also similar between the 2 cohorts. No significant differences were observed for postoperative radiographic findings. Medial calcar resorption was identified in 74 patients (61.7%). Calcar resorption and individual resorption grades were not found to differ significantly.

Conclusion: At midterm follow-up, preoperative severe glenoid retroversion does not appear to influence clinical or radiographic outcomes of TSA using a standard glenoid component.

Level of evidence: Level III; Case-Control Design; Treatment Study

Keywords: Corrective; eccentric; asymmetrical; reaming; retroversion; TSA

All work was performed at the Holy Cross Orthopedic Institute and Holy Cross Hospital.

This study was approved by the Western Institutional Review Board (study no. 1179001) prior to its conduction.

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Glenoid retroversion is commonly observed in the arthritic shoulder,[6] with reports suggesting an average of 15° of retroversion in the arthritic shoulder compared with 7° in the normal shoulder.[19] With the introduction of 3-dimensional measurements and virtual planning software, there has been a growing appreciation of the challenges in managing glenoid retroversion with anatomic total shoulder arthroplasty (TSA).[13,28]

Management of severe retroversion during TSA has remained controversial, as authors have advocated various treatment strategies including partial version correction,[17,24] minimal correction,[21] and use of augmented glenoid components.[4,7,13,24] Although some have advocated correction of glenoid version to within 5° of a plane perpendicular to the plane of the scapula,[13] this can be challenging in cases of severe retroversion in part because of difficulties with exposure, limitations of implant design, the risk of losing subchondral bone support, and the implications of joint medialization. Advocates of partial correction have demonstrated early outcomes with low rates of glenoid loosening, humeral head subluxation, and dislocation, although these complications certainly occur.[4,7,10,13,22] However, there remains a paucity of data available in the literature on the various treatment methods for managing excessive glenoid version.

Although it has been suggested that implantation of a glenoid component in excessive glenoid retroversion may lead to worse outcomes,[10,25,33] data comparing the results of patients with severe preoperative retroversion and those with less retroversion remain limited. The purpose of this study was to evaluate the impact of severe preoperative glenoid retroversion (>20°) on clinical and radiographic outcomes of TSA through a case-control comparison with patients with less glenoid retroversion using the same glenoid preparation technique (reamed to match the backside of the glenoid component with partial correction of eccentric wear when present), implant, and rehabilitation protocol. The hypothesis was that patients with severe retroversion would have worse clinical outcomes and higher rates of glenoid loosening.

Materials and methods

A retrospective query of our institutional shoulder arthroplasty repository was performed to identify patients treated with an anatomic TSA using a single implant system (Turon; DJO, Austin, TX, USA) with complete preoperative and minimum 2-year postoperative patient-reported outcome measures (PROMs). Preoperative mid-glenoid 2-dimensional axial computed tomography (CT) scans were used to calculate glenoid retroversion using the technique described by Friedman et al.[6] A total of 40 patients with greater than 20° of retroversion (average, 24° of retroversion; range, 20°-38° of retroversion) comprised the study group.

A case-control analysis was performed by identifying a matched set of patients with less than 20° of preoperative retroversion. Patients were matched at a ratio of 2:1 based on sex, age (within 5 years), surgical indication, and glenoid component size (within 1 size). A total of 80 patients with less than 20° of preoperative retroversion (average, 7.45° of retroversion; range, 16° of anteversion to 19° of retroversion) were included in the control group.

The surgical technique, implant design, and postoperative rehabilitation protocol were identical in all patients. The senior author performed all TSA procedures using a deltopectoral approach. The glenoid was prepared using noncannulated reaming instrumentation with a goal of preparing the glenoid surface to create a minimum of 80% backside concentric support without violation of subchondral bone support.[17] In cases of eccentric wear, the glenoid was reamed to match the backside of the glenoid component, typically preferentially reaming the anterior glenoid and partially correcting glenoid version.

The standard all-polyethylene glenoid component was cemented in all cases with cement pressurization using a syringe, with additional cement placed on the backside of the glenoid component prior to implantation. Peg components were predominantly used unless the glenoid vault was determined to be narrow based on preoperative imaging. There were 2 keeled glenoid components used in the study group and 5 keeled glenoid components used in the control group. The humeral stem was implanted by a press-fit technique, with selection of the humeral size based on the smallest broach needed to achieve rotational stability. Morselized bone graft from the humeral head was impacted into the humeral canal prior to implantation of the stem.

The postoperative rehabilitation protocols were standardized for both cohorts. A shoulder immobilizer was worn for the initial 6 weeks, and patients were instructed to perform a self-administered exercise program beginning with pendulums for the initial 6 weeks, followed by active-assisted stretching for the subsequent 6 weeks. Strengthening and lifting were not initiated until 3 months.

Comparisons were made regarding PROMs, motion, and postoperative radiographic loosening. PROMs included the Simple Shoulder Test score, Single Assessment Numeric Evaluation score, visual analog scale score for function, American Shoulder and Elbow Surgeons total score, and visual analog scale score for pain. Patients graded satisfaction with the procedure as excellent, good, satisfactory, or unsatisfactory. In addition, they were asked whether they would undergo the same procedure again.

Range-of-motion measurements of active elevation and external rotation were routinely obtained by recording the patients' best effort with a manual goniometer. Internal rotation was measured based on the highest midline segment of the back that could be reached; this was converted to a numerical value.[27]

Preoperative mid-glenoid CT scans were used to classify glenoid wear as eccentric or concentric, and a glenoid-based subluxation index was calculated.[29] The most recent postoperative anteroposterior and axillary lateral radiographs were reviewed. Glenoid loosening (according to Lazarus et al[15]) and humeral loosening (according to Sperling et al[23]) were recorded. Any shift in position of the humeral component was also recorded. Consensus between at least 2 trained reviewers and a final confirmation by the senior author were required in the assessment

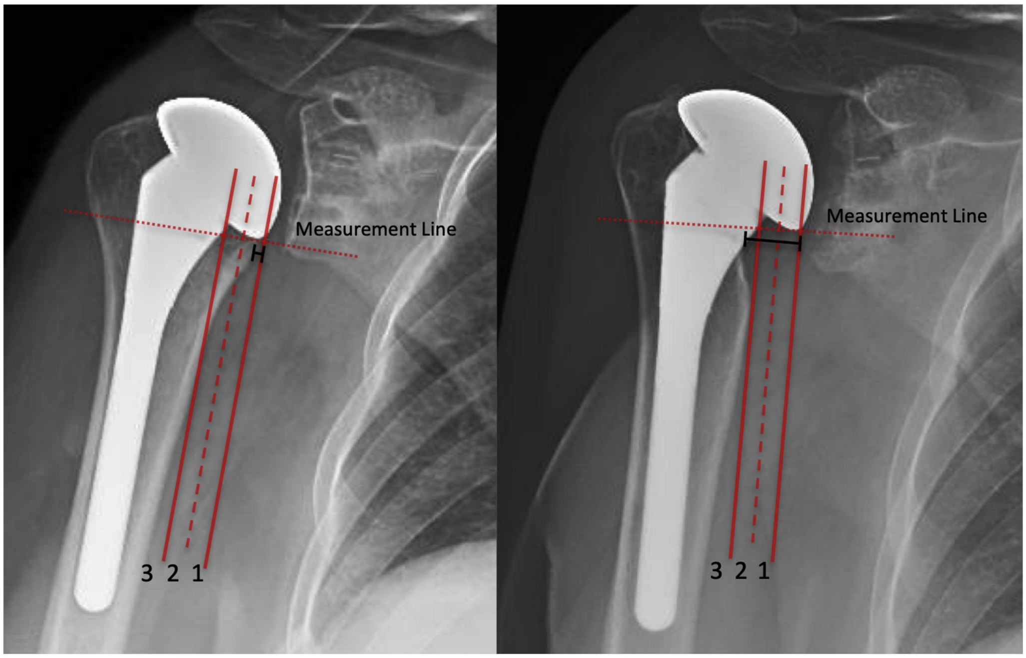

Figure 1 Calcar resorption grading system using anteroposterior radiographs. Calcar height is measured at the inferior level of the humeral head. As the calcar resorption progresses, the grade increases. Grade 1 denotes the zone between the *solid medial line* and the *dashed line*. Grade 2 denotes the zone between the *dashed line* and the *solid lateral line*. Grade 3 denotes the zone medial to the *solid medial line*. This patient shows significant progression from grade 1 at 3 months *(left)* to grade 3 at final follow-up *(right)*.

of all radiographic imaging. The opinion of the senior author was used in cases of dissent.

Calcar resorption was evaluated on the most recent postoperative anteroposterior radiographs using a newly devised grading system to quantify the degree of medial calcar resorption (Fig. 1). Calcar resorption of less than 50% of the medial head width corresponded to grade 1, resorption of 50% to 100% of the medial head width corresponded to grade 2, and resorption past the head-neck junction with exposure of the humeral stem corresponded to grade 3.

Appropriate descriptive statistics including frequencies and percentages, along with means and standard deviations, were calculated for all variables. Because each case had 2 controls, conditional logistic regression was performed to evaluate bivariate associations. Paired *t* tests were used to measure the efficacy of treatment, stratified by cases and controls. Data analysis was conducted using SPSS software (version 23; IBM, Armonk, NY, USA). All statistical tests were 2-tailed, and $P < .05$ was used to determine significance.

Results

The 2 cohorts were well matched, with a similar average age of 71 years ($P = .762$) and a similar sex distribution ($P = .480$), glenoid size ($P > .999$), and humeral head size ($P = .686$). The average clinical follow-up period was 53 months (range, 24-129 months) for the severe retroversion group and 49 months (range, 24-112 months) for the control group ($P = .344$). The average radiographic follow-up periods for the treatment (36 months; range, 3-100 months) and control (35 months; range, 3-111 months) cohorts were comparable ($P = .790$). Furthermore, preoperative comparisons between the 2 cohorts identified no significant differences in preoperative CT-based measurements other than glenoid version (Table I), which averaged 24° for the retroversion group and 7° for the control group. Similarly, baseline outcome scores (Table II) and measured range of motion (Table III) were similar for the 2 groups, except for preoperative Single Assessment Numeric Evaluation scores and American Shoulder and Elbow Surgeons total scores, which were higher for the severe retroversion group (44.4 vs. 31.3 [$P = .012$] and 34.9 vs. 29.4 [$P = .048$], respectively).

At most recent follow-up, postoperative PROMs (Table II) and range of motion (Table III) were similar between the 2 cohorts. Both cohorts had similar satisfaction with surgery (97.5%) and a similar desire to undergo the same procedure again (Table II).

TSA was effective at improving motion and PROMs for both cohorts. Significant improvements from preoperative to postoperative levels were observed in all motion measurements and all PROMs (Table IV).

Postoperative radiographs identified calcar resorption in 61.7% of the entire combined cohort, with no difference in incidence between the 2 cohorts (Table I). Further classification based on grade found similar rates of grade 1, grade 2, and grade 3 resorption between the 2 cohorts.

Although gross loosening was identified only among patients with severe retroversion, no significant

Table I Preoperative CT and postoperative radiographic findings

	>20° of retroversion (n = 40), n (%) or mean ± SD	<20° of retroversion (n = 80), n (%) or mean ± SD	*P* value
Preoperative findings			
Version, °	24 ± 4.3	7 ± 7.9	<.001*
Levine classification†			.242
Concentric	27 (67.5)	62 (77.5)	
Eccentric	13 (32.5)	18 (22.5)	
Subluxation index, %	52.2 ± 7.6	51.5 ± 9.0	.662
Postoperative findings			
Calcar resorption	26 (65)	48 (60)	.593
Calcar resorption grade			.662
1	1 (3.9)	9 (18.8)	.261
2	18 (69.2)	34 (70.8)	.582
3	7 (26.9)	5 (10.4)	.366
Glenoid loosening			
Any loosening	8 (20)	9 (11.3)	.194
Gross loosening	3 (7.5)	0 (0)	.340
Revision	0	0	—

CT, computed tomography; *SD*, standard deviation.
* Statistically significant (P < .05).
† Missing data for 1 patient.

Table II Preoperative and postoperative clinical outcomes (N = 120)

	>20° of retroversion (n = 40), n (%) or mean ± SD	<20° of retroversion (n = 80), n (%) or mean ± SD	*P* value
SST score			
Preoperative	3.7 ± 2.9	3.3 ± 2.5	.373
Postoperative	9.5 ± 2.8	9.1 ± 2.8	.432
Amount of improvement	5.7 ± 3.5	5.7 ± 3.1	.991
SANE score			
Preoperative	44.4 ± 24.6	31.3 ± 22.3	.012*
Postoperative	80.6 ± 22.5	78.3 ± 26.7	.642
Amount of improvement	37.3 ± 35.3	46.5 ± 37.0	.203
VAS score for function			
Preoperative	4.0 ± 2.0	3.4 ± 2.1	.167
Postoperative	8.4 ± 2.1	8.1 ± 2.3	.479
Amount of improvement	4.5 ± 3.0	4.7 ± 3.0	.664
ASES total score			
Preoperative	34.9 ± 15.4	29.4 ± 15.9	.048*
Postoperative	84.8 ± 18.9	78.8 ± 21.1	.116
Amount of improvement	50.5 ± 27.7	49.7 ± 23.0	.942
VAS score for pain			
Preoperative	6.3 ± 2.0	6.5 ± 2.5	.403
Postoperative	1.3 ± 2.5	1.8 ± 2.8	.300
Amount of improvement	−5.1 ± 3.3	−4.8 ± 3.2	.800
Satisfaction			.988
Excellent	33 (82.5)	59 (73.8)	.261
Good	6 (15)	13 (16.2)	.838
Satisfactory	0 (0)	6 (7.5)	.314
Unsatisfactory	1 (2.5)	2 (2.5)	>.999
Would undergo same procedure again	37 (92.5)	71 (88.8)	.525

SD, standard deviation; *SST*, Simple Shoulder Test; *SANE*, Single Assessment Numeric Evaluation; *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons.
* Statistically significant (*P* < .05).

difference was observed (Table I). Three patients were identified to have gross glenoid loosening at 89 (Fig. 2), 82, and 85 months after surgery. No cases of gross humeral loosening or shift in position of the humeral component occurred. There were no cases in which surgical revision was performed in either cohort following the index procedure.

Discussion

Severe glenoid retroversion remains a challenging problem in anatomic TSA, with several options available for the treating surgeon. Our study supports the use of a similar surgical technique for management of various degrees of glenoid retroversion using a standard cemented all-polyethylene glenoid component. By use of a similar surgical technique, no significant differences in outcome, satisfaction, or radiographic findings were observed at an average of 3 years' follow-up.

Although significant differences were not observed in glenoid loosening between the groups, the 3 cases of gross glenoid loosening occurred in the severely retroverted cohort and the observation of any degree of glenoid loosening was nearly twice as common in this group (Table I). Patients with severe retroversion are at risk of eccentric loading of the glenoid component, with preferential posterior forces that may result in glenoid loosening and/or asymmetrical glenoid wear.[1,4,18] Although the incidence of gross loosening in this series was low, the average radiographic follow-up period was 36 months and the 3 patients with gross glenoid loosening had undergone surgery nearly 7 years earlier. Longer radiographic follow-up will likely result in higher rates of gross glenoid loosening with the cemented all-polyethylene glenoid implant used in our patients. Modern glenoid components with enhanced fixation features and improved polyethylene wear characteristics may also help to lower the incidence of glenoid loosening.

The surgical technique used for glenoid preparation in this study emphasizes the creation of a concentric surface, often with partial correction of glenoid retroversion. In principle, this technique has a primary goal of implant

Table III Preoperative and postoperative motion

	>20° of retroversion (n = 40), mean ± SD	<20° of retroversion (n = 80), mean ± SD	*P* value
Active elevation, °			
Preoperative	92.5 ± 26.3	96.6 ± 33.0	.394
Postoperative	138.4 ± 18.6	136.3 ± 23.5	.594
Amount of improvement	49.7 ± 24.3	39.3 ± 33.2	.103
Active external rotation, °			
Preoperative	15.7 ± 16.3	21.3 ± 20.4	.114
Postoperative	47.5 ± 11.9	47.9 ± 11.7	.873
Amount of improvement	31.7 ± 17.6	26.6 ± 21.4	.192
Active internal rotation*			
Preoperative	3.3 ± 1.7	3.6 ± 2.3	.512
Postoperative	7.4 ± 1.7	6.8 ± 2.2	.148
Amount of improvement	4.1 ± 2.0	3.1 ± 2.8	.099

SD, standard deviation.
* Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

Table IV Efficacy of treatment (N = 120)

	Preoperative, mean ± SD	Postoperative, mean ± SD	*P* value
SST score			
>20° of retroversion	3.7 ± 2.9	9.5 ± 2.8	<.001*
<20° of retroversion	3.3 ± 2.5	9.1 ± 2.8	<.001*
SANE score			
>20° of retroversion	44.4 ± 24.6	80.6 ± 22.5	<.001*
<20° of retroversion	31.3 ± 22.3	78.3 ± 26.7	<.001*
VAS score for function			
>20° of retroversion	4.0 ± 2.0	8.4 ± 2.1	<.001*
<20° of retroversion	3.4 ± 2.1	8.1 ± 2.4	<.001*
ASES total score			
>20° of retroversion	34.9 ± 15.4	84.8 ± 18.9	<.001*
<20° of retroversion	29.4 ± 15.9	78.8 ± 21.1	<.001*
VAS score for pain			
>20° of retroversion	6.3 ± 2.0	1.3 ± 2.5	<.001*
<20° of retroversion	6.5 ± 2.5	1.8 ± 2.8	<.001*
Active elevation, °			
>20° of retroversion	92.5 ± 26.3	138.4 ± 18.6	<.001*
<20° of retroversion	96.6 ± 33.0	136.3 ± 23.5	<.001*
Active external rotation, °			
>20° of retroversion	15.7 ± 16.3	47.5 ± 11.9	<.001*
<20° of retroversion	21.3 ± 20.4	47.9 ± 11.7	<.001*
Active internal rotation†			
>20° of retroversion	3.3 ± 1.7	7.4 ± 1.7	<.001*
<20° of retroversion	3.6 ± 2.3	6.8 ± 2.2	<.001*

SD, standard deviation; *SST*, Simple Shoulder Test; *SANE*, Single Assessment Numeric Evaluation; *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons.
* Statistically significant ($P < .05$).
† Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

stability by creating a concentrically prepared surface to match the backside of the glenoid and avoiding violation of subchondral bone support. The secondary goal of this technique is the correction of glenoid version, which is accomplished by asymmetrically preparing the glenoid surface. In the setting of severe glenoid retroversion, corrective reaming to a "normal" range of glenoid risks joint medialization and violation of the important subchondral bone support, which makes soft-tissue balancing challenging and places the glenoid component at risk of subsidence[30-32] and early loosening.

Similar techniques have been reported in the literature. Orvets et al[17] retrospectively reviewed a series of patients with Walch type B2 glenoids wherein partially corrective reaming was used with standard glenoid component TSA; they found no significant PROM or radiographic differences between patients with more than 20° and patients with less than 20° of preoperative retroversion. Similarly, Service et al[21] evaluated outcomes of TSA patients with more or less than 15° of postoperative retroversion, finding no significant difference concerning PROMs and radiographic lucency. Hussey et al[12] retrospectively compared outcomes of TSA between preoperatively concentric and eccentric glenoids wherein a technique of glenoid preparation similar to that in our study was used; no difference in PROMs was found, whereas gross loosening was found to develop at a higher rate in patients with eccentric glenoids. Although the series by Service et al did not direct specific efforts at correcting glenoid version, the surgical technique for glenoid preparation in our series was similar to that used in the series reported by both Orvets et al and Hussey et al.

Critics of corrective reaming rightly emphasize a limited capacity in treatment of the severely retroverted glenoid. With average retroversion of 24° and cases as extreme as 38°, it would be challenging to expect that corrective reaming to neutral would have been successful in our severe retroversion cohort. Existing literature has noted that attempting to significantly correct version in these circumstances runs the risk of excessive anterior glenoid bone removal and/or component placement in residual retroversion and, consequently, an expectation of poor outcomes.[2,3,11,15,20] Furthermore, Gillespie et al,[7] Clavert et al,[2] and Nowak et al[16] have attempted to quantify the degree of correctable retroversion, suggesting an upper limit of 15° to 18° before inherent anatomy is compromised. However, our findings suggest that a technique that uses partial correction can be an effective technique in this challenging patient population with severe retroversion (>20°) without sacrificing radiographic outcomes (Table I), clinical outcomes (Table II), patient satisfaction (Table II), or range of motion (Table III) compared with patients with

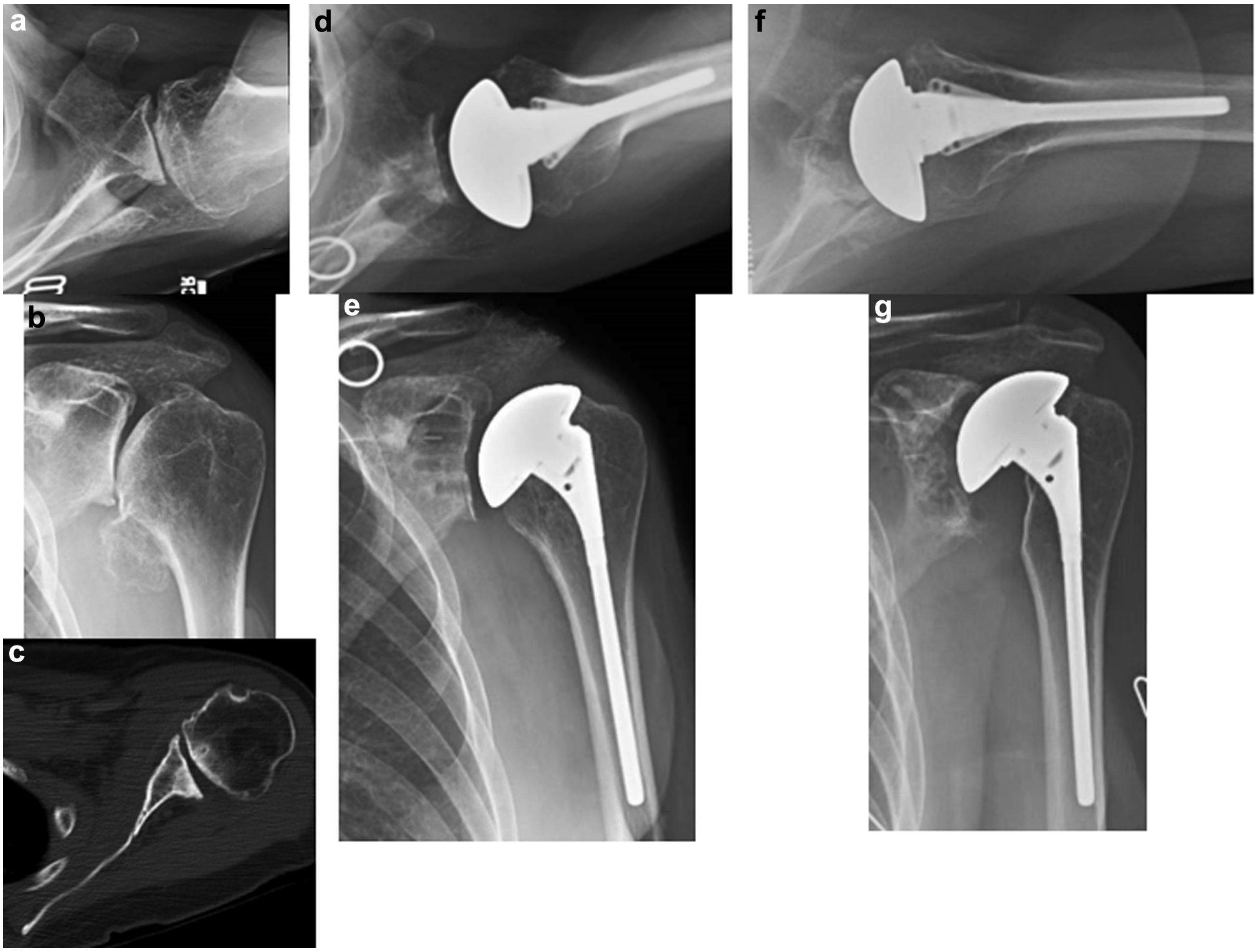

Figure 2 Imaging of a 66-year-old female patient with severe osteoarthritis. **(a)** Preoperative anteroposterior radiograph. **(b)** Preoperative axillary radiograph. **(c)** Preoperative mid-axial computed tomography scan, demonstrating 23° of retroversion. Comparison of the initial postoperative **(d, e)** and 89-month follow-up **(f, g)** anteroposterior and axillary radiographs demonstrates gross glenoid loosening and grade 3 medial calcar resorption.

more acceptable deformity. Although long-term studies are likely to provide further insight into the merits of this technique, our midterm data suggest this method is a viable option for patients.

An alternative solution for this patient population is the augmented glenoid. Advocates of augmented glenoid components focus on the primary goal of restoring normal glenoid version without medialization of the joint line. Although the initial early experience using augmented glenoid components demonstrated satisfactory clinical results, patients experienced persistent posterior instability.[18] With little advantage over traditional glenoid components, this design was abandoned[18] until relatively recently with the advent of enhanced fixation features. Favorito et al[5] and Stephens et al[26] have since reported good to excellent improvements in pain and function at midterm follow-up using an augmented glenoid with enhanced fixation in the setting of glenoid retroversion. Depending on the glenoid morphology and wear pattern, preparation of the posterior glenoid to facilitate component placement risks removing substantial bone. Although this may not decrease the structural support, it can create challenges in revision surgery related to glenoid bone loss.[20] Additional augmented glenoid designs have focused on minimizing glenoid bone removal and use various forms of enhanced fixation, including hybrid glenoid components with metal osseous integration potential.[1,8]

An additional alternative advocated by a few authors is the use of bone graft to restore glenoid version during TSA. Bone grafting during TSA has been marked with challenges as high rates of nonunion, fixation failure, and inappropriate settling have been reported.[17,19] Moreover, although the literature has noted that bone graft techniques can produce moderate to good improvements in function,[9,14,24] this may come at the expense of a nearly 50% risk of radiographic loosening, failure, or otherwise unsatisfactory results.[9,17,20]

This study is not without limitations. With an average radiographic follow-up period of 36 months with some patients having only 3-month radiographs, higher rates of glenoid loosening will likely present over time. However, the clinical significance of such glenoid loosening may not become relevant until later, as clinical follow-up at an average of over 4 years supports maintained improvements in pain and function. In addition, the glenoid component used lacks a requirement for a large amount of glenoid bone removal for pegged or keeled fixation and lacks enhanced fixation features. Modern glenoid components with enhanced fixation and improved wear capacity may improve the longevity of the implants and produce even lower rates of glenoid loosening. Furthermore, postoperative CT scans were not used to assess postoperative glenoid version or radiographic loosening. Thus, it is not possible to know what the actual postoperative glenoid version was, and cases of component loosening may have been missed on standard radiographs. Finally, the results of this study, as a single-surgeon series, may not be able to be extrapolated to the general orthopedic community. The strengths of the study relate to the study design with well-matched cohorts. Nonetheless, with low rates of gross glenoid loosening and no cases of humeral loosening, the study may suffer from a lack of power to detect significant differences in component loosening.

Conclusion

Midterm results of TSA using a standard cemented all-polyethylene glenoid component, with a primary goal of creating a concentric glenoid surface for component placement with partial correction of glenoid retroversion, demonstrate similar findings for patients with severe glenoid retroversion and those with more normal glenoid retroversion.

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References

1. Allred JJ, Flores-Hernandez C, Hoenecke HR Jr, D'Lima DD. Posterior augmented glenoid implants require less bone removal and generate lower stresses: a finite element analysis. J Shoulder Elbow Surg 2016;25:823-30. https://doi.org/10.1016/j.jse.2015.10.003
2. Clavert P, Millett PJ, Warner JJP. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion? J Shoulder Elbow Surg 2007;16:843-8. https://doi.org/10.1016/j.jse.2007.03.015
3. Denard PJ, Walch G. Current concepts in the surgical management of primary glenohumeral arthritis with a biconcave glenoid. J Shoulder Elbow Surg 2013;22:1589-98. https://doi.org/10.1016/j.jse.2013.06.017
4. Farron A, Terrier A, Büchler P. Risks of loosening of a prosthetic glenoid implanted in retroversion. J Shoulder Elbow Surg 2006;15:521-6. https://doi.org/10.1016/j.jse.2005.10.003
5. Favorito PJ, Freed RJ, Passanise AM, Brown MJ. Total shoulder arthroplasty for glenohumeral arthritis associated with posterior glenoid bone loss: results of an all-polyethylene, posteriorly augmented glenoid component. J Shoulder Elbow Surg 2016;25:1681-9. https://doi.org/10.1016/j.jse.2016.02.020
6. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am 1992;74:1032-7.
7. Gillespie R, Lyons R, Lazarus M. Eccentric reaming in total shoulder arthroplasty: a cadaveric study. Orthopedics 2009;32:21. https://doi.org/10.3928/01477447-20090101-07
8. Hermida JC, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Augmented wedge-shaped glenoid component for the correction of glenoid retroversion: a finite element analysis. J Shoulder Elbow Surg 2014;23:347-54. https://doi.org/10.1016/j.jse.2013.06.008
9. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Joint Surg Am 2001;83-A:877-83.
10. Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg Am 2013;95:e82. https://doi.org/10.2106/JBJS.L.00336
11. Hsu JE, Ricchetti ET, Huffman GR, Iannotti JP, Glaser DL. Addressing glenoid bone deficiency and asymmetric posterior erosion in shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:1298-308. https://doi.org/10.1016/j.jse.2013.04.014
12. Hussey MM, Steen BM, Cusick MC, Cox JL, Marberry ST, Simon P, et al. The effects of glenoid wear patterns on patients with osteoarthritis in total shoulder arthroplasty: an assessment of outcomes and value. J Shoulder Elbow Surg 2015;24:682-90. https://doi.org/10.1016/j.jse.2014.09.043
13. Iannotti JP, Greeson C, Downing D, Sabesan V, Bryan JA. Effect of glenoid deformity on glenoid component placement in primary shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:48-55. https://doi.org/10.1016/j.jse.2011.02.011
14. Klika BJ, Wooten CW, Sperling JW, Steinmann SP, Schleck CD, Harmsen WS, et al. Structural bone grafting for glenoid deficiency in primary total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1066-72. https://doi.org/10.1016/j.jse.2013.09.017
15. Lazarus MD, Jensen KL, Southworth C, Matsen FA 3rd. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am 2002;84-A:1174-82.
16. Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, LU Bigliani, et al. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be corrected. J Shoulder Elbow Surg 2009;18:680-8. https://doi.org/10.1016/j.jse.2009.03.019
17. Orvets ND, Chamberlain AM, Patterson BM, Chalmers PN, Gosselin M, Salazar D, et al. Total shoulder arthroplasty in patients with a B2 glenoid addressed with corrective reaming. J Shoulder Elbow Surg 2018;27(Suppl):S58-64. https://doi.org/10.1016/j.jse.2018.01.003

18. Rice RS, Sperling JW, Miletti J, Schleck C, Cofield RH. Augmented glenoid component for bone deficiency in shoulder arthroplasty. Clin Orthop Relat Res 2008;466:579-83. https://doi.org/10.1007/s11999-007-0104-4
19. Scalise JJ, Codsi MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Shoulder Elbow Surg 2008;17:487-91. https://doi.org/10.1016/j.jse.2007.09.006
20. Sears BW, Johnston PS, Ramsey ML, Williams GR. Glenoid bone loss in primary total shoulder arthroplasty: evaluation and management. J Am Acad Orthop Surg 2012;20:604-13. https://doi.org/10.5435/JAAOS-20-09-604
21. Service BC, Hsu JE, Somerson JS, Russ SM, Matsen FA 3rd. Does postoperative glenoid retroversion affect the 2-year clinical and radiographic outcomes for total shoulder arthroplasty? Clin Orthop Relat Res 2017;475:2726-39. https://doi.org/10.1007/s11999-017-5433-3
22. Shapiro TA, McGarry MH, Gupta R, Lee YS, Lee TQ. Biomechanical effects of glenoid retroversion in total shoulder arthroplasty. J Shoulder Elbow Surg 2007;16(Suppl):S90-5. https://doi.org/10.1016/j.jse.2006.07.010
23. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg 2000;9:507-13.
24. Steinmann SP, Cofield RH. Bone grafting for glenoid deficiency in total shoulder replacement. J Shoulder Elbow Surg 2000;9:361-7.
25. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg Am 2015;97:251-9. https://doi.org/10.2106/JBJS.N.00566
26. Stephens SP, Spencer EE, Wirth MA. Radiographic results of augmented all-polyethylene glenoids in the presence of posterior glenoid bone loss during total shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:798-803. https://doi.org/10.1016/j.jse.2016.09.053
27. Triplet JJ, Everding NG, Levy JC, Moor MA. Functional internal rotation after shoulder arthroplasty: a comparison of anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:867-74. https://doi.org/10.1016/j.jse.2014.10.002
28. Van de Bunt F, Pearl ML, Lee EK, Peng L, Didomenico P. Glenoid version by CT scan: an analysis of clinical measurement error and introduction of a protocol to reduce variability. Skeletal Radiol 2015; 44:1627-35. https://doi.org/10.1007/s00256-015-2207-4
29. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty 1999; 14:756-60.
30. Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid. J Shoulder Elbow Surg 2012;21:1526-33. https://doi.org/10.1016/j.jse.2011.11.030
31. Walch G, Young AA, Boileau P, Loew M, Gazielly D, Molé D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than five years of follow-up. J Bone Joint Surg Am 2012;94:145-50. https://doi.org/10.2106/JBJS.J.00699
32. Walch G, Young AA, Melis B, Gazielly D, Loew M, Boileau P. Results of a convex-back cemented keeled glenoid component in primary osteoarthritis: multicenter study with a follow-up greater than 5 years. J Shoulder Elbow Surg 2011;20:385-94. https://doi.org/10.1016/j.jse.2010.07.011
33. Yongpravat C, Lester JD, Saifi C, Trubelja A, Greiwe RM, Bigliani LU, et al. Glenoid morphology after reaming in computer-simulated total shoulder arthroplasty. J Shoulder Elbow Surg 2013; 22:122-8. https://doi.org/10.1016/j.jse.2011.12.010