J Shoulder Elbow Surg (2023) 32, 1231–1241

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Factors associated with functional improvement after posteriorly augmented total shoulder arthroplasty

Michael J. Gutman, MD[a,*], Eitan M. Kohan, MD[a], Benjamin A. Hendy, MD[a], Christopher D. Joyce, MD[a], Jacob M. Kirsch, MD[b], Arjun Singh, MD[a], Matthew Sherman, BS[a], Luke S. Austin, MD[a], Surena Namdari, MD, MSc[a], Gerald R. Williams Jr, MD[a]

[a]*Department of Orthopaedic Surgery, Rothman Orthopaedic Institute at Thomas Jefferson University Hospital, Philadelphia, PA, USA*
[b]*Department of Orthopaedic Surgery, New England Baptist Hospital, Tufts University, Boston, MA, USA*

Background: Posteriorly augmented glenoid components in anatomic total shoulder arthroplasty (TSA) address posterior glenoid bone loss with inconsistent results. The purpose of this study was to identify preoperative and postoperative factors that impact range of motion (ROM) and function after augmented TSA in patients with type B2 or B3 glenoid morphology.
Methods: This was a retrospective review of all patients who underwent TSA with a step-type augmentation performed by a single surgeon between 2009 and 2018. Patients with Walch type B2 or B3 glenoids were included. Outcomes included forward elevation (FE), external rotation (ER), internal rotation (IR), Single Assessment Numeric Evaluation (SANE) score, and visual analog scale pain score. Preoperative imaging was reviewed to assess glenoid retroversion and posterior humeral head subluxation relative to the scapular body and midglenoid face. Postoperative measurements included glenoid retroversion, subluxation relative to the scapular body, subluxation relative to the central glenoid peg, and center-peg osteolysis. Measurements were performed by investigators blinded to ROM and functional outcome scores.
Results: Fifty patients (mean age, 68.1 ± 8.0 years) with a mean follow-up period of 42.0 months (range, 24-106 months) were included. Glenoid morphology included type B2 glenoids in 41 patients and type B3 glenoids in 9. One patient had center-peg osteolysis, and 1 patient had glenoid component loosening. Average preoperative FE, ER, and IR were 110°, 21°, and S1, respectively. Average postoperative FE, ER, and IR were 155°, 42°, and L1, respectively. The mean postoperative visual analog scale score was 0.5 ± 0.8, and the mean SANE score was 94.5 ± 5.6. Type B3 glenoids were associated with better postoperative IR compared with type B2 glenoids (T10 vs. L1, $P = .024$), with no other differences in ROM between the glenoid types. Preoperative glenoid retroversion did not significantly impact postoperative ROM. Postoperative glenoid component retroversion and residual posterior subluxation relative to the scapular body or glenoid face did not correlate with ROM in any plane. However, posterior subluxation relative to the glenoid face was moderately associated with lower SANE scores ($r = –0.448$, $P = .006$).
Conclusion: Patients achieved excellent functional outcomes and pain improvement after TSA with an augmented glenoid component. Postoperative ROM and function showed no clinically important associations with preoperative or postoperative glenoid retroversion or humeral head subluxation in our cohort of posteriorly augmented TSAs, except for worse functional scores with increased humeral head subluxation in relation to the glenoid surface.

Thomas Jefferson University Institutional Review Board approved this study (no. 20E.194).

*Reprint requests: Michael J. Gutman, MD, Shoulder & Elbow Surgery, Rothman Institute–Thomas Jefferson University, 925 Chestnut St, Fifth Floor, Philadelphia, PA 19107, USA.
E-mail address: michaelgutman@gmail.com (M.J. Gutman).

https://doi.org/10.1016/j.jse.2022.12.004

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Augmented glenoid; glenoid bone loss; glenoid retroversion; StepTech; total shoulder arthroplasty; range of motion; functional outcomes

Primary glenohumeral arthritis is the most common indication for anatomic total shoulder arthroplasty (TSA) in the United States and can result in asymmetrical bone loss on the posterior glenoid as described by Bercik et al.[1] The Walch classification system classifies a patient with posterior bone loss, glenoid biconcavity, and a posteriorly subluxated humeral head as having a type B2 glenoid, whereas a patient who has $\geq$70% posterior subluxation relative to the scapular axis or $\geq$15° of retroversion with monoconcavity is classified as having a type B3 glenoid.[1] Patients with Walch type B2 and B3 glenoids present challenges for surgeons during the management of glenohumeral arthritis. Increased posterior bone loss and increased retroversion are associated with increased complication rates in patients undergoing anatomic TSA.[17,37] Walch et al[37] found that patients with posterior bone loss undergoing TSA had a glenoid loosening rate of 20.6% in their series. The higher clinical failure rate in these patients is believed to be due to the altered biomechanics, resulting in polyethylene edge loading, ultimately resulting in component loosening and failure.[4,6]

Common strategies for managing posterior bone loss in TSA are asymmetrically reaming the anterior glenoid, leaving the glenoid component in native retroversion, performing bone grafting of the posterior glenoid, and implanting posteriorly augmented glenoid components. Asymmetrically reaming the anterior glenoid to correct glenoid retroversion increases joint-line medialization, may violate strong subchondral bone, and may lead to peg perforation.[2,9,16] Failure to correct glenoid retroversion can lead to increased rates of glenoid component loosening and osteolysis of the center peg when >15° of glenoid retroversion remains.[2,6,13] Bone grafting allows for correction of the native joint line and retroversion. However, the clinical outcomes of bone grafting are mixed. This method has been shown to correlate with high rates of hardware loosening and failure owing to difficulties with bone graft incorporation.[8,11,15,19,24,25,29,32,37] Posteriorly augmented glenoid components theoretically restore the native joint line and preserve the remaining glenoid bone stock.[29] Previous studies have observed mixed results using augmented glenoid components.[7,12,27,28,33,40] However, recent studies have shown excellent outcomes with augmented glenoid components.[7,12,27] Even with the use of an augmented glenoid component, concerns remain that patients may still have persistent posterior subluxation after the procedure.[28] However, the clinical impact of residual posterior subluxation after TSA on functional outcomes is still unknown.[10,12,13,23,27,30,33,40]

Prior studies have assessed outcomes in patients treated with augmented glenoid components during TSA. However, those studies commonly focused on functional outcomes and the rates of center-peg osteolysis associated with this procedure. The purpose of this study was to identify preoperative and postoperative factors that impact range of motion (ROM) and function after augmented TSA in patients with type B2 or B3 glenoid morphology.

Methods

Study design

A retrospective query was performed, identifying 1044 consecutive anatomic TSAs performed by the senior author (G.R.W.). The majority were performed using a standard glenoid component. A total of 121 TSAs were performed with posteriorly augmented stepped glenoid components (StepTech APG; DePuy Orthopaedics, Warsaw, IN, USA) between September 2009 and February 2018. The inclusion criteria required use of a stepped component in anatomic TSA performed by a single surgeon during this time frame. Patients were excluded because they had glenoid morphologies other than Walch type B2 or B3 (n = 24) or underwent revision surgery (n = 9) owing to posterior dislocation (n = 2), nickel allergy (n = 1), periprosthetic fracture (n = 1), or postoperative rotator cuff tear (n = 5). These patients were excluded from ROM, radiographic, and functional outcome evaluation. In each case, the operative report from the revision surgical procedure indicated that the glenoid component was well fixed without any signs of loosening. Of the 88 patients meeting the initial inclusion criteria, 50 patients (56.8%) with a minimum of 24 months' radiographic and clinical follow-up or failure due to glenoid loosening were included in this study (Fig. 1).

Surgical technique

All patients underwent anatomic TSA via a Global StepTech Anchor Peg Glenoid (DePuy Orthopaedics) with either a Global AP or Global Unite humeral stem (DePuy Orthopaedics). In all patients, the procedure was performed through a deltopectoral approach. The humerus was prepared in a standard fashion with lesser tuberosity osteotomy. All patients underwent removal of the anteroinferior capsule during the operation, and none underwent posterior capsulorrhaphy. After glenoid exposure, specialized sizer disks with posterior augmentations were used to place the central guide pin. An attempt was made to slightly inferiorly tilt the pin. A concentric

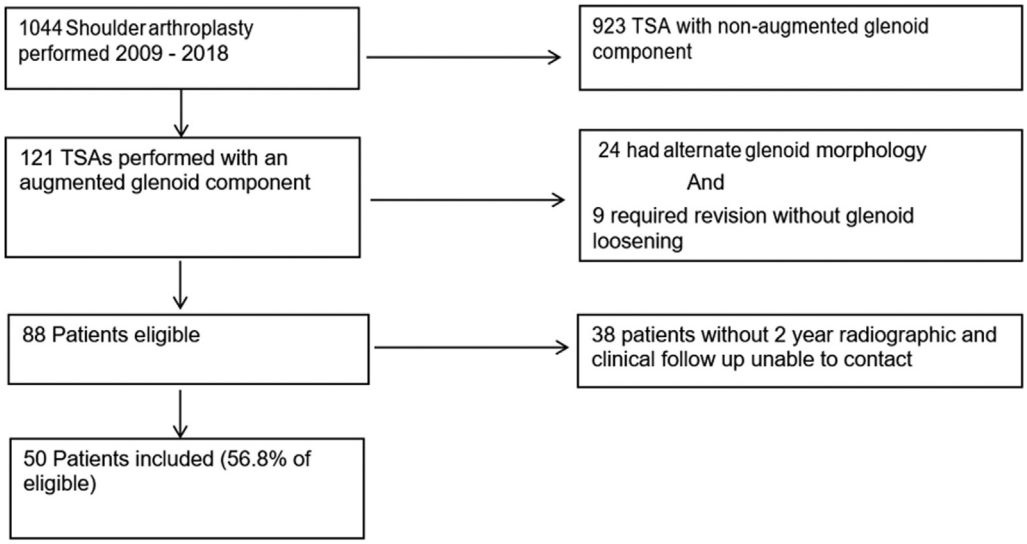

Figure 1 Inclusion and exclusion criteria. *TSA*, total shoulder arthroplasty.

reamer was used to prepare the anterior half of the glenoid, a cannulated drill was used over the central guide pin, the pin was removed, and the appropriate anterior preparation guide was impacted into position and secured in place with 2 pins. A vibratory rasp was used to prepare the posterior neo-glenoid. The anterior preparation guide was removed, and a peripheral drill guide appropriate to the size of the augmentation was placed. The 3 peripheral holes were drilled. The guide was removed, and a trial component was placed to confirm adequate preparation. The glenoid underwent pulse irrigation, the peripheral holes were filled with bone cement, and the glenoid component was impacted into position. The goal was to correct glenoid version to within 10° of neutral, correct humeral subluxation on the glenoid surface, and create a stable articulation. Patients began passive ROM 24 hours after surgery, with initiation of active motion at 6 weeks postoperatively.

Clinical evaluation and outcome variables

Patient charts were reviewed to document patient demographic information including age at the time of surgery, sex, body mass index, Charlson Comorbidity Index, and date of surgery. All office notes were reviewed from the final preoperative appointment to the final postoperative visit to document ROM including forward elevation (FE), external rotation (ER) at the side, and internal rotation (IR). Functional outcomes were assessed at the final office appointment using the Single Assessment Numeric Evaluation (SANE) score and visual analog scale (VAS) pain score. Patient charts were reviewed to document postoperative complication data (rates of reoperation including revision to address rotator cuff tears or revision to reverse shoulder arthroplasty).

Radiographic assessment

All preoperative axillary radiographs (n = 50) and advanced imaging (when available, n = 30) were reviewed independently by 2 shoulder and elbow fellowship-trained surgeons (C.D.J. and J.M.K.) to determine the modified Walch classification for each patient.[1] If the 2 reviewers disagreed on the Walch classification, consensus was achieved through consultation with the senior author (G.R.W.). The reviewers were blinded to patients' functional outcomes and ROM. Similarly, all final postoperative Grashey-view radiographs were reviewed by the same reviewers to assess the degree of center-peg osseous integration: grade 1, osteolysis; grade 2, bone growth to the edge of the flanges; or grade 3, osseous ingrowth between the flanges.[13,14]

In addition, preoperative and postoperative radiographs were reviewed and measurements were performed independently by 3 reviewers: 2 fellowship-trained shoulder and elbow surgeons (E.M.K. and B.A.H.) and a surgical resident (M.J.G.). Reviewers were blinded to patients' preoperative and postoperative ROM, pain, and functional scores. On preoperative radiographs, glenoid version, bone loss, joint-line medialization, and humeral head subluxation relative to both the scapular axis and the glenoid articular surface were measured by the reviewers.[12,20] The reviewers assessed humeral head subluxation relative to the scapular axis and the glenoid articular surface via 2 different methods to determine which had greater inter-rater reliability prior to assessing the effect of humeral head subluxation on postoperative ROM and function. This occurred because different methods of assessing humeral head subluxation relative to the scapular axis and the glenoid articular surface have been described in the literature, with limited data available on their inter-rater reliability. In the first method, posterior subluxation relative to the scapular axis and glenoid face was calculated by measuring humeral head–scapular alignment (HSA-AP) and humeral head–glenoid alignment (HGA-AP) on axillary radiographs using the best-fit circle method described by Ho et al[12,14] (Fig. 2). In the second method, posterior subluxation was calculated using the percentage of the head diameter that remained posterior to the scapular axis (% subluxation in scapular plane) or glenoid articular axis (% subluxation in glenoid plane) as described by Ko et al[20] (Fig. 3). Additionally, when preoperative advanced imaging was available, glenoid version, posterior bone loss, and joint-line

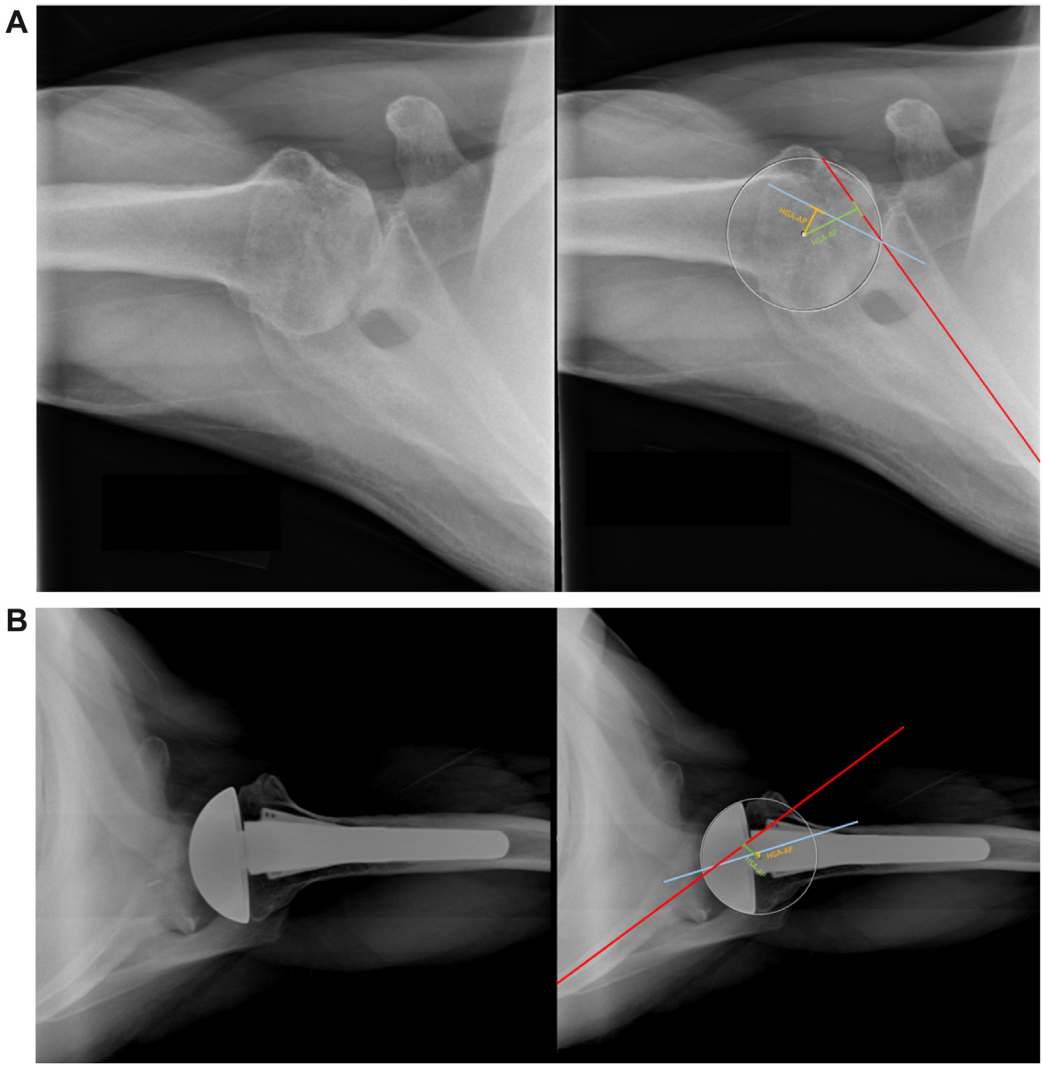

Figure 2 Measurement of posterior humeral head subluxation in relation to scapular axis *(HSA-AP)* and in relation to glenoid axis *(HGA-AP)* on preoperative imaging **(A)** and postoperative imaging **(B)** via method described by Ho et al.[12,14] *White circle*, humeral head; *yellow line*, HGA-AP; *green line*, HSA-AP; *blue line*, glenoid axis; *Red line*, scapular axis.

medialization were measured on either 2-dimensional (2D) computed tomography (n = 22) or magnetic resonance imaging (n = 8).[12,14,20] On postoperative radiographs, residual glenoid retroversion and residual subluxation of the humeral component relative to the scapular axis and relative to the glenoid face were measured as described by Ho et al[12,14] and Ko et al.[20] On postoperative radiographs, the radiopaque central-peg marker was used as the glenoid centerline.

Statistical analysis

To calculate *P* values for continuous data, *t* tests were used. Analysis of preoperative and postoperative ROM was performed with a 2-tailed dependent *t* test. Calculation of inter-rater reliability was performed to assess agreement between each individual rater and the respective preoperative and postoperative measurements. Inter-rater reliability was assessed using a 2-way mixed-effects intraclass correlation coefficient (ICC) model. The strength of agreement was classified as follows: 0-0.3, no relationship; 0.3-0.5, weak relationship; 0.5-0.7, moderate relationship; and 0.7-1.0, strong relationship. For any measurement variables that showed moderate or strong agreement among the 3 reviewers, the measurements of the 3 reviewers were averaged, with the average values used to perform correlation analysis. Correlation analysis was carried out via the Spearman ρ to assess the effect of patients' preoperative and postoperative radiographic measurements on postoperative ROM, pain, and function. The Spearman ρ was used for correlation analysis of nonparametric data, and the Pearson coefficient was used for parametric data. The level of statistical significance was defined as $P < .05$. All statistical analyses were conducted using RStudio software (version 3.6.1; RStudio, Boston, MA, USA).

Results

Fifty patients with a mean follow-up period of 42.0 months (range, 24-106 months) were included in this study.

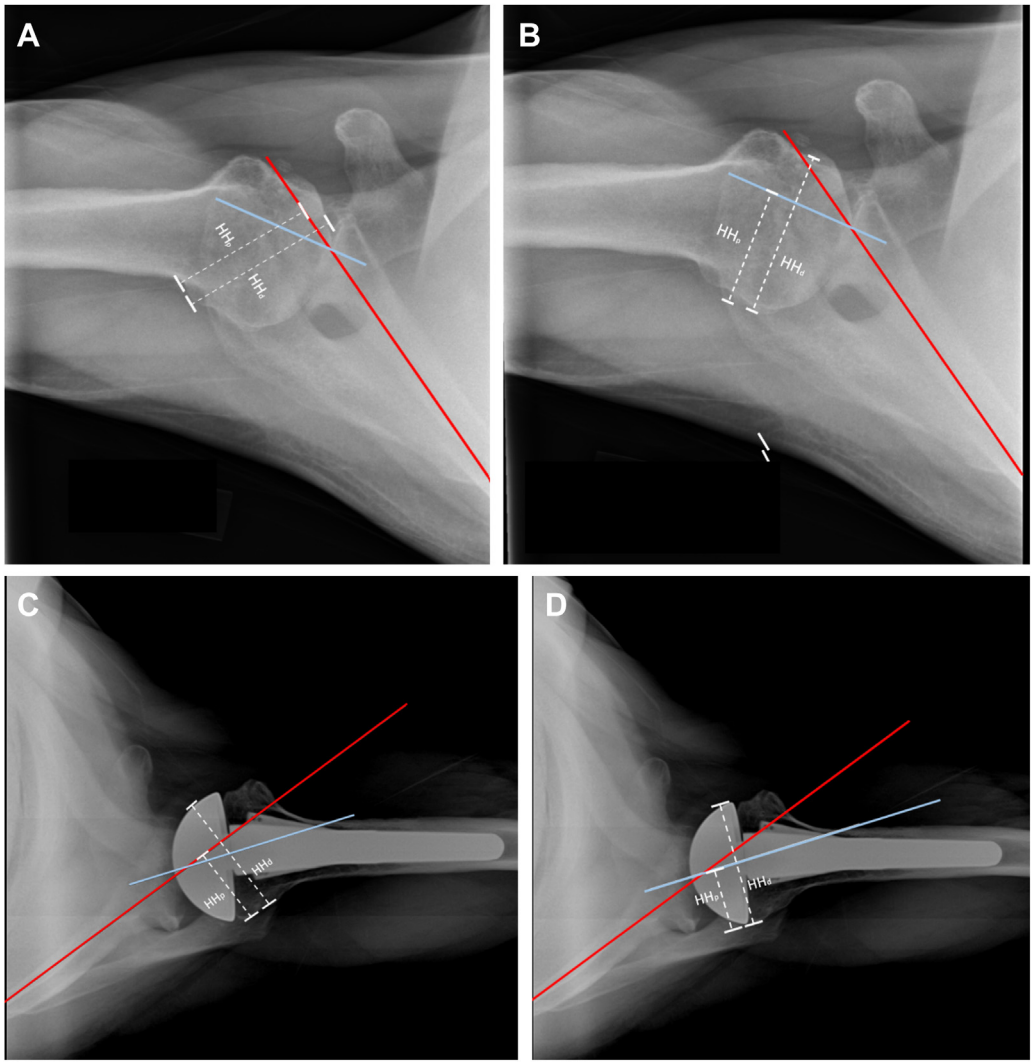

Figure 3 Measurement of posterior humeral head subluxation in relation to scapular axis *(red line)* (*HHp*/*HHd*) on preoperative **(A)** and postoperative **(C)** imaging and in relation to glenoid axis *(blue line)* (*HHp*/*HHd*) on preoperative **(B)** and postoperative **(D)** imaging via method described by Ko et al.[20] *HHd*, humeral head diameter; *HHp*, humeral head posterior subluxation.

Demographic variables, as well as preoperative and postoperative ROM, are included in Table I for the overall cohort, as well as for Walch type B2 and B3 glenoids individually. Patients with type B3 glenoids had better postoperative IR than patients with type B2 glenoids (T10 vs. L1, $P = .024$). Patients with type B2 glenoids had significantly better SANE scores (95.5 vs. 90.6, $P = .040$). One patient had center-peg osteolysis, and one patient underwent revision to reverse TSA owing to glenoid component loosening (Table II).

Revisions

Of 121 patients with augmented TSAs, 10 (7.4%) required revision to a reverse shoulder arthroplasty. Dislocation of the glenoid component occurred in 1 patient. This patient was included in our study and was the only patient in whom glenoid loosening was present at the time of revision arthroplasty. The other 9 patients who underwent conversion to reverse shoulder arthroplasty were excluded from our study because failure was not related to glenoid component loosening. One patient sustained a traumatic periprosthetic fracture of the humerus. One patient had a nickel allergy. Five patients had rotator cuff tears that occurred at 3-8 years postoperatively. Posterior dislocations developed in 2 patients at 4 and 6 years. We observed no difference in preoperative glenoid retroversion ($P = .640$), postoperative glenoid retroversion ($P = .622$), preoperative subluxation relative to the scapular spine ($P = .265$) or glenoid face ($P = .388$), and postoperative subluxation relative to the scapular spine ($P = .510$) or glenoid face ($P = .694$) between the 7 patients who were excluded because of rotator cuff tears or glenoid dislocation and the

Table I Demographic characteristics of patients meeting inclusion criteria

	All patients (N = 50)	Patients with type B2 glenoids (n = 41)	Patients with type B3 glenoids (n = 9)	*P* value
Age, yr	67.6 (8.01) [65.3-69.9]	66.5 (7.66) [64.1-69.0]	72.3 (8.25) [66.0-78.7]	.079
BMI	27.7 (4.90) [26.3-29.1]	27.8 (4.16) [26.4-29.1]	27.4 (7.71) 27.4 [21.4-33.3]	.885
Height, cm (SD) [CI]	174.5 (10.36) [171.5-177.3]	173.5 (10.64) [169.9-176.8]	178.8 (8.15) [172.7-185.2]	.105
Weight, kg (SD) [CI]	84.8 (18.3) [79.4-89.8]	83.9 (16.9) [78.5-89.4]	87.5 (24.6) [68.5-106.6]	.695
Sex, n (%)				.317
Female	12 (24)	11 (26.9)	1 (11.1)	
Male	38 (76)	30 (73.1)	8 (88.9)	
CCI	0.61 (0.95) [0.33-0.89]	0.62 (0.94) [0.31-0.92]	0.57 (1.13) [0.48-1.62]	.925
Preoperative FE, °	110 (27.3) [102-118]	112 (27.7) [104-121]	100 (24.5) [81.2-119]	.200
Preoperative ER, °	21.2 (13.1) [17.5-25.0]	21.9 (13.0) [17.7-26.0]	18.3 (13.7) [7.81-28.9]	.494
Preoperative IR, mean [95% CI]	S1 [L5-S1]	S1 [L5-S1]	S1 [L5-S2]	.439
Postoperative FE, °	155 (11.3) [152-158]	156 (11.6) [152-160]	150 (9.01) [143-157]	.103
Postoperative ER, °	41.6 (6.34) [39.8-43.4]	41.9 (6.57) [39.8-44.0]	40.3 (5.34) [36.2-44.4]	.467
Postoperative IR	L1 [T12-L2]	L1 [T12-L2]	T10 [T8-L1]	.024*
Postoperative VAS pain score	0.57 (0.91) [0.29-0.86]	0.52 (0.91) [0.19-0.84]	0.78 (0.97) [0.03-1.52]	.480
Postoperative SANE score	94.5 (5.64) [92.7-96.2]	95.5 (5.17) [93.7-97.3]	90.6 (5.83) [86.1-95.0]	.040*

BMI, body mass index; *CCI*, charlson comorbidity index; *FE*, forward elevation; *ER*, external rotation; *IR*, internal rotation; *VAS*, visual analog scale; *SANE*, single assessment numeric evaluation; *CI*, confidence interval.
Data are presented as mean (standard deviation) [95% CI] unless otherwise indicated.
* Statistically significant.

Table II Center-peg grading and glenoid component characteristics

	All patients (N = 50)	Patients with type B2 glenoids (n = 41)	Patients with type B3 glenoids (n = 9)	*P* value	Glenoid component failure or radiographic risk of failure (grade 1 osteolysis) (N = 50)
Center-peg grading				.183	
1	1 (2)	0 (0)	1 (11.1)		
2	23 (46)	19 (46.3)	4 (44.4)		
3	25 (50.0)	21 (51.2)	4 (44.4)		
Component loosening	1 (2)	1 (2.4)	0 (0)		
Step size				.698	
3 mm	27 (54)	23 (56.1)	4 (44.4)		0 (0)
5 mm	20 (40)	16 (39.0)	4 (44.4)		0 (0)
7 mm	3 (6)	2 (4.9)	1 (11.1)		2 (66.6)

Data are presented as number (percentage).

rest of the patients included in the study. Moreover, the augmented component size was not associated with an increased risk of rotator cuff tear or chronic dislocation. Of the 8 patients who underwent revision for rotator cuff tears or chronic dislocation, 4 received a 3-mm stepped component, 3 received a 5-mm stepped component, and 1 received a +7-mm stepped component.

Demographic characteristics, preoperative variables, and component variables associated with postoperative ROM and function

Age, sex, and Charlson Comorbidity Index were not associated with postoperative FE, ER, IR, VAS pain score, or SANE score. However, higher body mass index ($r = –0.302$, $P = .033$) and shorter height ($r = –0.400$, $P = .004$) were associated with decreased IR postoperatively. Similarly, preoperative FE, ER, and IR did not correlate with postoperative ROM, VAS pain score, or SANE score (Table III). Finally, there was no difference in postoperative ROM, SANE score, or VAS pain score based on the size of the augmented component used (Table IV).

Agreement among reviewers

The 3 reviewers showed strong agreement when measuring preoperative and postoperative glenoid retroversion and humeral head subluxation relative to both the scapular spine and the glenoid articular surface on radiographs. The reviewers showed superior agreement when assessing

Table III Demographic and preoperative variables associated with postoperative range of motion and function

Variable	Spearman ρ				
	Postoperative FE	Postoperative ER	Postoperative IR	Postoperative VAS pain score	Postoperative SANE score
Age	−0.114	0.213	0.053	−0.249	−0.086
BMI	0.013	−0.128	0.302*	0.128	−0.031
Height	−0.124	−0.013	−0.400*	0.118	−0.137
Weight	−0.037	−0.083	−0.072	0.101	−0.086
Sex	−0.115	−0.129	−0.188	0.211	−0.130
CCI	−0.015	−0.011	−0.090	−0.138	0.200
Preoperative FE	0.172	−0.099	0.076	0.027	0.042
Preoperative ER	0.089	0.069	0.122	−0.215	−0.044
Preoperative IR	0.0005	0.006	0.034	0.091	−0.050

FE, forward elevation; *ER*, external rotation; *IR*, internal rotation; *VAS*, visual analog scale; *SANE*, Single Assessment Numeric Evaluation; *BMI*, body mass index; *CCI*, charlson comorbidity index; *CI*, confidence interval.
* Statistically significant.

posterior subluxation relative to the humeral-scapular axis and humeral-glenoid axis using the method described by Ho et al[12,14] compared with the method described by Ko et al[20] (Table V). As a result, humeral head–scapular alignment percentage (HSA-AP %) and humeral head–glenoid alignment percentage (HGA-AP %) were selected to evaluate the effect of preoperative and postoperative posterior subluxation relative to the scapular axis and glenoid axis on postoperative ROM.[12,14]

Radiographic predictors of ROM and function

Neither preoperative glenoid retroversion nor posterior subluxation relative to the scapular axis and glenoid axis showed significant associations with postoperative ROM, pain, or function (Table VI). Postoperative glenoid component retroversion and residual posterior subluxation relative to the scapular axis or glenoid axis did not correlate with ROM in any plane. Posterior subluxation relative to the glenoid articular surface was almost entirely corrected during surgery using an augmented glenoid component (Table VII). However, residual posterior subluxation relative to the glenoid face was moderately associated with lower SANE scores ($r = –0.448$, $P = .006$).

Discussion

Surgical management of patients with glenohumeral arthritis with Walch type B2 and B3 glenoids is challenging. In this study, we present 50 patients with glenohumeral arthritis and Walch type B2 or B3 glenoids treated with a stepped augmented glenoid component with a minimum 2-year radiographic and clinical follow-up. Patients had durable results and excellent ROM and function at most recent follow-up. However, residual posterior subluxation relative to the glenoid face was associated with lower SANE scores. Additionally, higher body mass index and shorter height were associated with worse postoperative IR. Moreover, type B3 glenoids were associated with greater IR than type B2 glenoids (T10 vs. L1). Although this difference may not appear to be clinically significant, such a difference affects patients' activities of daily living and can have a large impact on patients' abilities to live independently. Although type B2 glenoids were associated with better function via the SANE score, there was no clinical difference between the cohorts based on the minimal clinically important difference in the SANE score reported in the literature for TSA patients.[3] Additionally, although only 9 type B3 glenoids were included in this study, patients with type B3 glenoids had excellent functional outcomes and type B3 glenoids were not associated with higher revision rates. The results of this study indicate that a stepped augmented component is a reliable option in patients with type B2 glenoids—and may be considered as an option in patients with type B3 glenoids.

Prior studies have raised concerns that >15° of residual retroversion after anatomic TSA results in increased rates of glenoid component loosening and inferior clinical outcomes.[2,6,9,13,31] This question has been raised in terms of both treatment with standard glenoid components and treatment with augmented glenoid components.[12,13,23,30] The rate of center-peg osteolysis or glenoid loosening in this study (n = 2, 4%) is comparable to rates in prior studies showing that center-peg osteolysis occurs in 3%-12% of patients treated with non-augmented glenoid components.[23,26,30,38,39] Ho et al[12] found that 15% of patients with a stepped component experienced center-peg osteolysis whereas none experienced glenoid loosening. They reported that the presence of greater preoperative joint-line medialization and posterior bone loss was associated with increased rates of center-peg osteolysis. In the

Table IV Outcomes of range of motion based on augmented component size

	Postoperative FE	Postoperative ER	Postoperative IR	SANE score	VAS pain score	No. of revisions (%)
3 mm (n = 27)	158.1 ± 9.2	41.9 ± 4.9	13.56	93.8 ± 5.5	0.48 ± 0.85	0 (0)
5 mm (n = 20)	150.8 ± 13.1	41.5 ± 7.8	13	95.6 ± 6.1	0.47 ± 0.84	0 (0)
7 mm (n = 3)	155.0 ± 7.0	37.5 ± 10.6	12	92.5 ± 4.5	0.50 ± 0.71	1 (33.3)
P value	.233	.840	.609	.283	.283	

FE, forward elevation; *ER*, external rotation; *IR*, internal rotation; *SANE*, single assessment numeric evaluation; *VAS*, visual analog scale.
Data are presented as mean ± standard deviation unless otherwise indicated.

Table V Agreement on radiographs and advanced imaging between reviewers

Variable	ICC value	Agreement
Preoperative glenoid retroversion (radiography)	0.747	Strong
Preoperative retroversion (CT or MRI)	0.681	Moderate
Preoperative eccentric glenoid bone loss (radiography)	0.398	Weak
Preoperative eccentric bone loss (CT or MRI)	0.340	Weak
Preoperative joint medialization		
Radiography	0.362	Weak
CT or MRI	0.429	Weak
Preoperative HSA-AP % (radiography)	0.724	Strong
Preoperative HGA-AP % (radiography)	0.698	Strong
Preoperative % subluxation in scapular plane (radiography)	0.541	Moderate
Preoperative % subluxation in glenoid plane (radiography)	0.631	Moderate
Postoperative glenoid retroversion (radiography)	0.939	Strong
Postoperative HSA-AP % (radiography)	0.781	Strong
Postoperative HGA-AP % (radiography)	0.664	Moderate
Postoperative % subluxation in scapular plane (radiography)	0.690	Moderate
Postoperative % subluxation in glenoid plane (radiography)	0.421	Weak

ICC, intraclass correlation coefficient; *CT*, computed tomography; *MRI*, magnetic resonance imaging; *HSA-AP*, humeral head–scapular alignment; *HGA-AP*, humeral head–glenoid alignment.

setting of larger bony defects and posterior bone loss, there is a risk of glenoid failure due to the rocking-horse phenomenon and poor bone stock.[18,21,34-36] In our study, glenoid component loosening developed in 1 patient and central-peg osteolysis developed in 1 patient. In both patients, a +7-mm augmented glenoid component was used, signifying severe bone loss.

In this study, the surgeon attempted to correct glenoid retroversion and humeral subluxation relative to the scapular spine to within 10°. Although augmented glenoid components seek to restore posterior bone loss, patients do well postoperatively even without complete version correction. Our correlation analysis showed that residual retroversion and residual posterior humeral head subluxation relative to the scapular axis did not correlate with inferior functional outcomes or ROM. As a result, it appears that despite the fact that glenoid retroversion was not completely corrected, this did not affect functional outcomes. However, patients with residual posterior subluxation relative to the glenoid articular surface had worsened shoulder function. The findings of this study are similar to those of Matsen et al,[23] who reported excellent outcomes in 66 patients (40 with type B2 glenoids and 26 with type B3 glenoids) treated with anatomic shoulder arthroplasty via a non-augmented glenoid component without an attempt to correct glenoid version. The authors' goal was to ensure the centering of the humeral head on the glenoid face. The patients reported a mean SANE score of 85%,[23] which is similar to the results of our study. These findings may suggest that humeral head subluxation in relation to the glenoid surface is more important than its relation to the scapular axis in terms of short- to mid-term function.

Most commonly, the term ''subluxation'' is used to describe displacement of the humeral head relative to the plane of the scapular body, instead of displacement relative the glenoid articular surface.[22] One major difficulty that we encountered when trying to assess the impact of posterior subluxation on shoulder function is the lack of a universally accepted method for assessing posterior subluxation in patients with glenohumeral arthritis. There has been much debate regarding how to properly assess posterior subluxation in patients with glenohumeral arthritis, with many different methods described in the literature.[22] Both Ho et al[12,14] and Ko et al[20] described methods for measuring subluxation relative to both the humeral-scapular axis and the humeral-glenoid axis. Ho et al assessed posterior subluxation using the best-fit circle method to determine the amount of subluxation relative to the scapular axis and glenoid face, whereas Ko et al assessed posterior subluxation by measuring the percentage of the head diameter that remained posterior to the scapular axis or glenoid articular

Table VI Predictors of shoulder range of motion and function based on radiographic measurements as calculated by Spearman ρ correlation coefficient

Radiographic measurement	Spearman ρ				
	Postoperative FE	Postoperative ER	Postoperative IR	Postoperative VAS pain score	Postoperative SANE score
Preoperative					
Glenoid retroversion	−0.141	−0.250	−0.005	0.226	0.082
HSA-AP %	0.135	−0.243	0.031	−0.045	0.164
HGA-AP %	0.139	−0.157	0.074	−0.170	0.133
Postoperative					
Glenoid retroversion	−0.026	−0.298	−0.091	0.269	0.043
HSA-AP %	−0.033	−0.284	−0.226	0.312	0.006
HGA-AP %	0.042	−0.234	−0.103	0.052	−0.448*

FE, forward elevation; *ER*, external rotation; *IR*, internal rotation; *VAS*, visual analog scale; *SANE*, single assessment numeric evaluation; *HSA-AP*, humeral head–scapular alignment; *HGA-AP*, humeral head–glenoid alignment.
* Statistically significant.

Table VII Preoperative and postoperative glenoid retroversion and humeral head subluxation

	Preoperative	Postoperative	Preoperative-to-postoperative change	*P* value
Glenoid retroversion	24.0 ± 8.7	17.2 ± 8.2	6.8	<.001
HSA-AP %	57.5 ± 15.1	34.0 ± 15.3	23.5	<.001
HGA-AP %	20.7 ± 9.9	2.8 ± 8.4	17.9	<.001

HSA-AP, humeral head–scapular alignment; *HGA-AP*, humeral head–glenoid alignment.

surface. We found that our reviewers showed more agreement when assessing subluxation using the best-fit circle method described by Ho et al.[12,14] Because multiple methods of assessing posterior subluxation relative to the scapular axis and glenoid axis exist, we believed that it was imperative to perform the measurements for this study in the most reproducible manner to properly correlate radiographic findings in this patient population with postoperative ROM and function.[22] To our knowledge, this is the first study to compare reviewer agreement when measuring posterior subluxation relative to the scapular axis and glenoid articular surface via 2 different methods.

In this study, we had hoped to assess the effect of eccentric bone loss and joint medialization on ROM. Ultimately, this could not be evaluated owing to the weak agreement among reviewers. This is a reflection of the fact that 2D computed tomography scans and radiographs are not the most reliable method of assessing posterior bone loss. A recent study by Cronin et al[5] found that 3-dimensional (3D) imaging was more accurate in measuring bone loss than 2D imaging. However, owing to the retrospective nature of this study and the recent development of 3D imaging to assist in preoperative planning, 3D imaging was not available to the reviewers for the measurement of bone loss and joint medialization. Future studies should use 3D imaging to assess the impact of posterior bone loss on functional outcomes in patients undergoing TSA with posteriorly augmented glenoid components.

This study is not without its limitations. First, its retrospective design leads to an inherent bias because a high number of patients were lost to follow-up. Additionally, a disproportionate number of patients with type B2 glenoids were included as compared with type B3 glenoids. Given the limited number patients with type B3 glenoids in this study, it is difficult to make a definitive conclusion regarding the use of augmented glenoid components in these patients. Similarly to Ho et al,[12] we excluded patients who underwent TSA revision to reverse shoulder arthroplasty owing to complications unrelated to the glenoid component. In this study, 9 patients were excluded because the revision operation was not directly related to glenoid failure. It is possible that the augmented glenoid component altered rotator cuff mechanics and predisposed patients to rotator cuff tearing or posterior shoulder instability. However, the revision rate in this study (7.4%, 10 of 121 patients) is similar to the revision rates for non-augmented anatomic TSAs found in the literature, especially in patients with severe glenoid deformity.[8,15,30] Furthermore, although axillary radiographs were obtained in a standardized fashion, there was some variability in the quality of radiographs. Although 3 different reviewers

independently performed the radiographic measurements, there were circumstances in which the reviewers showed weak agreement. Although the reviewers showed greater agreement when measuring preoperative glenoid retroversion on radiographs than on advanced imaging, advanced imaging was only available for 60% of patients. Additionally, preoperative shoulder SANE and VAS scores were missing from this study. Although ROM was determined by a single provider during clinical appointments for all patients, this method of determining ROM is less accurate than using a goniometer. Finally, all surgical procedures were performed by a senior surgeon with extensive experience using one type of augmented glenoid component; therefore, these results may not be generalizable to inexperienced surgeons.

Conclusion

Patients achieved excellent functional outcomes and pain improvement after TSA with an augmented glenoid component. The results of this study indicate that a stepped augmented component is a reliable option in patients with type B2 glenoids and may be considered in patients with type B3 glenoids. Given the limited number of patients with type B3 glenoids in this study, further research is required to make a definitive conclusion in this cohort. Residual glenoid component retroversion and humeral component subluxation do not appear to affect motion. Although augmented glenoid components seek to restore posterior bone loss, patients tend to do well postoperatively even without complete version correction.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Luke S. Austin receives intellectual property (IP) royalties from DePuy (A Johnson & Johnson Company) and Ignite Orthopaedics; is a paid consultant for DePuy (A Johnson & Johnson Company) and Ignite Orthopaedics; owns stock or stock options in Ignite Orthopaedics; and receives research support from Zimmer.
Surena Namdari receives IP royalties from Aevumed, DJ Orthopaedics, and Miami Device Solutions; owns stock or stock options in Aevumed, Force Therapeutics, MD Live, MD Valuate, Orthophor, Parvizi Surgical Innovations, RubiconMD, and Tangen; receives research support from Arthrex, DePuy (A Johnson & Johnson Company), DJ Orthopaedics, Integra, Wright Medical Technology, and Zimmer; is on the editorial or governing board of *Bone & Joint 360*; is a paid consultant for DJ Orthopaedics, Flexion Therapeutics, Miami Device Solutions, and Synthes; is a paid presenter or speaker for DJ Orthopaedics and Miami Device Solutions; is a board or committee member of Philadelphia Orthopaedic Society; and receives publishing royalties and financial or material support from Saunders/Mosby-Elsevier, SLACK, and Wolters Kluwer Health–Lippincott Williams & Wilkins.
Gerald R. Williams Jr receives research funding from DePuy and Tornier, receives royalties from DePuy and Innovative Medical Device Solutions (IMDS)/Cleveland Clinic, and is a paid consultant for DePuy on the subject of shoulder arthroplasty. He is also a consultant for DJO and receives product design royalties from DJO related to shoulder arthroplasty.
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.

References

1. Bercik MJ, Kruse K, Yalizis M, Gauci MO, Chaoui J, Walch G. A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. J Shoulder Elbow Surg 2016;25:1601-6. https://doi.org/10.1016/j.jse.2016.03.010
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. Cohn MR, Kunze KN, Polce EM, Nemsick M, Garrigues GE, Forsythe B, et al. Establishing clinically significant outcome thresholds for the Single Assessment Numeric Evaluation 2 years following total shoulder arthroplasty. J Shoulder Elbow Surg 2021;30:e137-46. https://doi.org/10.1016/j.jse.2020.07.011
4. Couteau B, Mansat P, Estivalèzes E, Darmana R, Mansat M, Egan J. Finite element analysis of the mechanical behavior of a scapula implanted with a glenoid prosthesis. Clin Biomech (Bristol, Avon) 2001;16:566-75.
5. Cronin KJ, Kirsch JM, Gates S, Patel MS, Joyce CD, Hill BW, et al. Three-dimensional measures of posterior bone loss and retroversion in Walch B2 glenoids predict the need for an augmented anatomic glenoid component. J Shoulder Elbow Surg 2021;30:2386-92. https://doi.org/10.1016/j.jse.2021.02.023
6. 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
7. 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
8. Gates S, Cutler H, Khazzam M. Outcomes of posterior glenoid bone-grafting in anatomical total shoulder arthroplasty a systematic review. JBJS Rev 2019;7:e6. https://doi.org/10.2106/JBJS.RVW.19.00005
9. 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
10. Grey SG, Wright TW, Flurin PH, Zuckerman JD, Roche CP, Friedman RJ. Clinical and radiographic outcomes with a posteriorly augmented glenoid for Walch B glenoids in anatomic total shoulder

arthroplasty. J Shoulder Elbow Surg 2020;29:e185-95. https://doi.org/10.1016/j.jse.2019.10.008
11. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Joint Surg Am 2001;83:877-83.
12. Ho JC, Amini MH, Entezari V, Jun BJ, Alolabi B, Ricchetti ET, et al. Clinical and radiographic outcomes of a posteriorly augmented glenoid component in anatomic total shoulder arthroplasty for primary osteoarthritis with posterior glenoid bone loss. J Bone Joint Surg Am 2018;100:1934-48. https://doi.org/10.2106/JBJS.17.01282
13. Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg Am 2018;100:1934-48. https://doi.org/10.2106/JBJS.17.01282
14. Ho JC, Youderian A, Davidson IU, Bryan J, Iannotti JP. Accuracy and reliability of postoperative radiographic measurements of glenoid anatomy and relationships in patients with total shoulder arthroplasty. J Bone Joint Surg Am 2018;100:1934-48. https://doi.org/10.2106/JBJS.17.01282
15. Iannotti JP, Frangiamore SJ. Fate of large structural allograft for treatment of severe uncontained glenoid bone deficiency. J Shoulder Elbow Surg 2012;21:765-71. https://doi.org/10.1016/j.jse.2011.08.069
16. 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
17. Iannotti JP, Norris TR. Influence of preoperative factors on outcome of shoulder arthroplasty for glenohumeral osteoarthritis. J Bone Joint Surg Am 2003;85:251-8. https://doi.org/10.2106/00004623-200302000-00011
18. Karelse A, Van Tongel A, Verstraeten T, Poncet D, De Wilde LF. Rocking-horse phenomenon of the glenoid component: The importance of inclination. J Shoulder Elbow Surg 2015;24:1142-8. https://doi.org/10.1016/j.jse.2014.12.017
19. 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
20. Ko JWK, Syed UA, Barlow JD, Paxton S, Loeffler BJ, Thakar O, et al. Comparison of asymmetric reaming versus a posteriorly augmented component for posterior glenoid wear and retroversion: A radiographic study. Arch Bone Jt Surg 2019;7:307-13. https://doi.org/10.22038/abjs.2019.28430.1751
21. Matsen FA, Clinton J, Lynch J, Bertelsen A, Richardson ML. Glenoid component failure in total shoulder arthroplasty. J Bone Joint Surg Am 2008;90:885-96. https://doi.org/10.2106/JBJS.G.01263
22. Matsen FA, Hsu JE. Subluxation in the Arthritic Shoulder. JBJS Rev 2021;9(9). https://doi.org/10.2106/JBJS.RVW.21.00102
23. Matsen FA, Whitson AJ, Somerson JS, Hsu JE. Anatomic Total Shoulder Arthroplasty with All-Polyethylene Glenoid Component for Primary Osteoarthritis with Glenoid Deficiencies. JBJS Open Access 2020;5:e20.00002. https://doi.org/10.2106/JBJS.OA.20.000
24. Nicholson GP, Cvetanovich GL, Rao AJ, O'Donnell P. Posterior glenoid bone grafting in total shoulder arthroplasty for osteoarthritis with severe posterior glenoid wear. J Shoulder Elbow Surg 2017;26:1844-53. https://doi.org/10.1016/j.jse.2017.03.016
25. Norris TR, Iannotti JP. Functional outcome after shoulder arthroplasty for primary osteoarthritis: A multicenter study. J Bone Joint Surg Am 2003;85:251-8. https://doi.org/10.2106/00004623-200302000-00011
26. Parks DL, Casagrande DJ, Schrumpf MA, Harmsen SM, Norris TR, Kelly JD. Radiographic and clinical outcomes of total shoulder arthroplasty with an all-polyethylene pegged bone ingrowth glenoid component: Prospective short- to medium-term follow-up. J Shoulder Elbow Surg 2016;25:246-55. https://doi.org/10.1016/j.jse.2015.07.008
27. Priddy M, Zarezadeh A, Farmer KW, Struk AM, King JJ, Wright TW, et al. Early results of augmented anatomic glenoid components. J Shoulder Elbow Surg 2019;28:S138-45. https://doi.org/10.1016/j.jse.2019.04.014
28. 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
29. Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis with severe glenoid bone loss. J Bone Joint Surg Am 2013;95:1290-6. https://doi.org/10.2106/JBJS.L.00097
30. Service BC, Hsu JE, Somerson JS, Russ SM, Matsen FA. 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
31. 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:S90-5. https://doi.org/10.1016/j.jse.2006.07.010
32. Steinmann SP, Cofield RH. Bone grafting for glenoid deficiency in total shoulder replacement. J Shoulder Elbow Surg 2014;23:1066-72. https://doi.org/10.1016/j.jse.2013.09.017
33. 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
34. Suárez DR, Nerkens W, Valstar ER, Rozing PM, van Keulen F. Interface micromotions increase with less-conforming cementless glenoid components. J Shoulder Elbow Surg 2012;21:474-82. https://doi.org/10.1016/j.jse.2011.03.008
35. Walch G, Boulahia A, Boileau P, Kempf JF. Primary glenohumeral osteoarthritis: Clinical and radiographic classification. Acta Orthop Belg 1998;64:46-52.
36. Walch G, Mesiha M, Boileau P, Edwards TB, Lévigne C, Moineau G, et al. Three-dimensional assessment of the dimensions of the osteoarthritic glenoid. Bone Joint J 2013;95-B:1377-82. https://doi.org/10.1302/0301-620X.95B10.32012
37. 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
38. Wijeratna M, Taylor D, Lee S, Hoy G, Evans MC. Clinical and radiographic results of an all-polyethylene pegged bone-ingrowth glenoid component. J Bone Joint Surg Am 2016;98:1090-6. https://doi.org/10.2106/JBJS.15.00475
39. Wirth MA, Loredo R, Garcia G, Rockwood CA, Southworth C, Iannotti JP. Total shoulder arthroplasty with an all-polyethylene pegged bone-ingrowth glenoid component: A clinical and radiographic outcome study. J Bone Joint Surg Am 2012;94:260-7. https://doi.org/10.2106/JBJS.J.01400
40. Youderian AR, Napolitano LA, Davidson IU, Iannotti JP. Management of glenoid bone loss with the use of a new augmented all-polyethylene glenoid component. Tech Shoulder Elbow Surg 2012;13:163-9. https://doi.org/10.1097/BTE.0b013e318265354d