J Shoulder Elbow Surg (2018) 27, e1–e8

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ONLINE ARTICLES

Structural glenoid grafting during primary reverse total shoulder arthroplasty using humeral head autograft

Robert Z. Tashjian, MD, Erin Granger, MPH, Peter N. Chalmers, MD*

Division of Sports Medicine, Department of Orthopaedic Surgery, University of Utah Medical Center, Salt Lake City, UT, USA

Background: Large glenoid bone defects in the setting of glenohumeral arthritis can present a challenge to the shoulder arthroplasty surgeon. The results of large structural autografting at the time of reverse total shoulder arthroplasty (RTSA) are relatively unknown.
Methods: This retrospective case series describes the clinical and radiographic results of large structural autografting from the humeral head to the glenoid during primary RTSA.
Results: Of 17 patients who met inclusion criteria, 14 (82% follow-up) were evaluated postoperatively at a mean of 2.6 years (range, 2.0-5.4 years). Mean inclination correction was 19° ± 12° (range, 3°-35°). Complications occurred in 3 patients, including 1 transient brachial plexus palsy, 1 loose baseplate, and 1 dislocation treated with closed reduction. Radiographic images showed 100% of grafts incorporated. Active forward elevation improved from 80° ± 40° to 130° ± 49° ($P = .028$). The visual analog scale score for pain improved from 8.1 ± 1.3 to 2.5 ± 3.1 ($P = .005$). The Simple Shoulder Test improved from 1.8 ± 1.1 to 6.5 ± 4 ($P = .012$). The American Shoulder and Elbow Surgeons score improved from 22 ± 10 to 66 ± 25 ($P = .012$). All patients (100%) were satisfied, and all patients (93%) but 1 stated that they would undergo the procedure again if given the chance.
Conclusions: RTSA incorporating structural grafting of the glenoid with humeral head autograft results in significant improvements in active forward elevation, pain, and function, with a low complication rate. This technique can reliably be used to achieve correction of large (up to 35°) glenoid defects with a 93% chance of baseplate survival and a 100% chance of graft incorporation in the short-term.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Reverse total shoulder arthroplasty; glenoid bone loss; bone grafting; shoulder arthroplasty; shoulder replacement; outcomes studies

Glenoid bone defects in the setting of glenohumeral arthritis pose a significant challenge to the shoulder arthroplasty surgeon.[20,21,23] Glenoid bone defects create multiple potential issues, including compromised glenoid component stability, component impingement with resultant instability and notching, decreased bone stock for future revisions, and inadequate soft tissue tensioning.[2,3,14,29] Multiple techniques have been

The University of Utah Institutional Review Board approved this study (protocol #46622).

*Reprint requests: Peter N. Chalmers, MD, Department of Orthopaedic Surgery, University of Utah Medical Center, 590 Wakara Way, Salt Lake City, UT 84105, USA.

E-mail address: p.n.chalmers@gmail.com (P.N. Chalmers).

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https://doi.org/10.1016/j.jse.2017.07.010

developed to address these defects, including eccentric reaming,[20] augmented glenoid components,[10,24,29] and bone grafting.[2-5,7-13,16-19,26,28] Reports of glenoid bone grafting in the setting of hemiarthroplasty and total shoulder arthroplasty have been mixed,[5,8,19] with subsidence rates ranging from 20%[19] to nearly 50%.[8]

Glenoid bone grafting in the setting of reverse total shoulder arthroplasty (RTSA) remains incompletely understood. Glenoid bone defects are common with RTSA: glenoid bone grafting may be necessary in up to 40% of primary procedures[13] and in up to 78% of revision procedures.[16] The optimal bone graft source and technique for placement and stabilization remain controversial.[13,17,18,26,28] Glenoid bone defects vary in their extent and location, and the optimal graft choice and surgical technique likely differ depending on the specific defect.[21,25,26] Specifically, central (contained and uncontained) and peripheral defects exist,[1] with the most commonly encountered wear patterns including posterior wear in glenohumeral osteoarthritis,[27] superior wear in rotator cuff tear arthropathy,[21] anterior defects in the setting of chronic anterior dislocations,[28] and global defects in the setting of revision shoulder arthroplasty.[12,18,26]

Multiple sources exist for the bone graft, including humeral head autograft,[3,18] iliac crest autograft,[16-18] cancellous autograft,[2,16] cancellous allograft,[5] femoral neck allograft,[2,21] and femoral head allograft.[4,13] The results of glenoid bone grafting in RTSA have been encouraging.[13,17,18,26,28] However, midterm survival of RTSA may be decreased when performed in the setting of glenoid bone grafting compared with an RTSA without grafting.[26] In addition, although those studies published to date have demonstrated rates of graft incorporation of between 76%[16] and 98%,[3] graft incorporation or resorption can be difficult to judge on radiographs.[6]

In the largest series to date, Wagner et al[26] distinguished between structural glenoid bone grafts and corticocancellous bone grafts, noting that 75% of failures in their series were corticocancellous and thus that structural bone grafting may necessary in some cases to achieve sufficient baseplate stability.[25] Very few prior series have focused specifically on the outcomes of structural bone grafting in the setting of RTSA for severe glenoid erosion.[25,26,28] This study describes the short-term clinical and radiographic results of structural bone grafting for severe glenoid deficiency from the humeral head in the setting of primary RTSA. We hypothesized that RTSA with structural bone grafting with a humeral head autograft would result in significant improvements in range of motion and patient-reported outcomes with high rates of graft incorporation and low rates of revision.

Materials and methods

This retrospective study included all patients undergoing RTSA with humeral head structural autograft for severe glenoid erosion. The operative log of the senior author (R.Z.T.) was reviewed between May 2008 and January 2015. Overall, 28 patients underwent RTSA with structural bone grafting for glenoid erosion. The senior author made the decision to perform an RTSA with a structural graft based on the ability to correct baseplate inclination to at least neutral tilt on a standing true anteroposterior radiograph of the shoulder and to within 10° of retroversion on an axillary radiograph without significantly reaming beyond 5 mm to 10 mm of glenoid bone stock to gain correction. The goal of reaming was to correct to 100% baseplate seating. If these goals could not be achieved with reaming alone, then RTSA with structural bone grafting was selected.

Patients who underwent primary RTSA with concomitant structural glenoid bone grafting with autologous humeral head were included. The study excluded patients who underwent RTSA with a structural glenoid bone graft as a revision of a prior arthroplasty, with an allograft, or with an iliac crest autograft. A total of 17 of the 28 patients met the criteria and were contacted to return for a clinical and radiographic evaluation.

Operative procedure

A deltopectoral approach was used in all operations. The Trabecular Metal Reverse Total Shoulder Arthroplasty (Zimmer, Warsaw, IN, USA) and the Aequalis Reversed Shoulder Arthroplasty (Tornier, Bloomington, MN, USA) systems were both used. In all cases, the humeral head was cut using the cutting guide, and the humerus was prepared according to the manufacturer's recommendations. A thicker cut was performed than usual so grafting could be performed using the cut head. The typical thickness of the cut head was between 15 mm and 20 mm. The proximal humerus was cut between 0° and 10° of retroversion in all cases.

The glenoid was exposed and assessed. The defect was decorticated with a high-speed burr, and the glenoid was perforated with a 0.062-inch Kirschner wire multiple times. All remaining cartilage was removed from the humeral head, and a segment was cut with an oscillating saw to match the defect. The baseplate guide for the system was used to place the central pin for the glenoid was at the appropriate height and inclination. The pin was positioned to achieve neutral or inferior tilt on a standing true anteroposterior radiograph and between 0° and 10° of retroversion on an axillary radiograph.

A slot was created in the graft to slide over the central pin that had been previously placed. The bone graft was placed and provisionally secured at its periphery with multiple Kirschner wires (Fig. 1). The glenoid was prepared for the baseplate according to the manufacturer's recommendations, including reaming and the central drill. The baseplate was placed, and screws were placed through the baseplate and graft and into the native glenoid to stabilize the graft. The central baseplate post was 25 mm long in all cases, achieving at least 5 mm in native glenoid.

Once the baseplate was secured, an additional 2.7-mm cortical screw was often placed superior to the baseplate from the graft into the glenoid. The glenosphere was then impacted into place. The humeral component was cemented in all cases, and a polyethylene spacer was chosen to achieve stability with minimal to no shuck and good tension in the conjoint tendon. The subscapularis was not repaired in any case.

Clinical data collection

Data collected from the preoperative documentation for each patient were operative side, side of dominance, gender, whether the patient had an active worker's compensation claim, whether the patient had

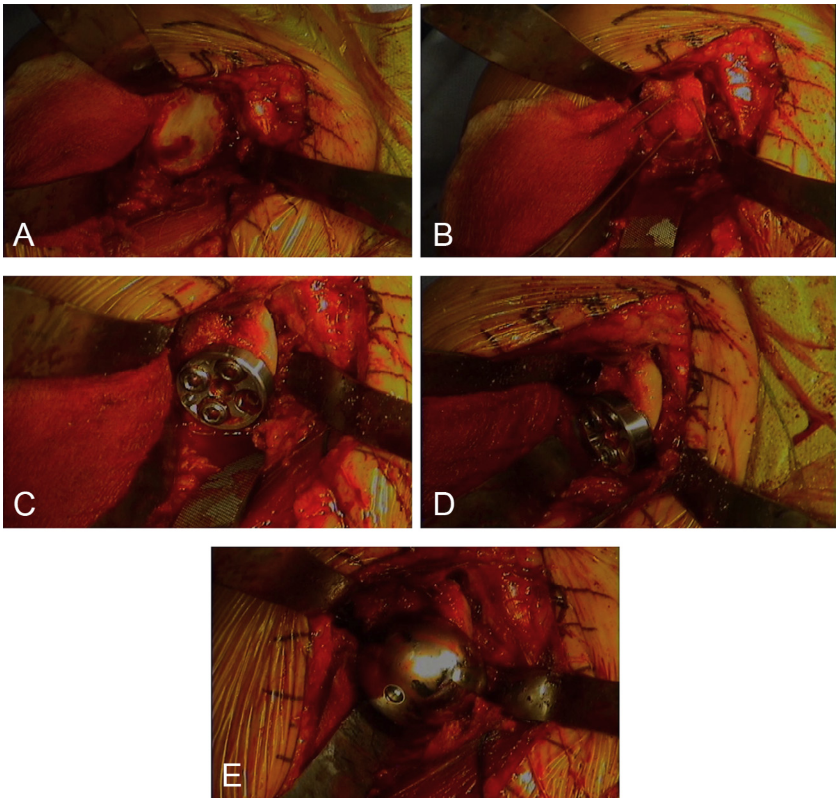

Figure 1 Intraoperative images of (**A**) exposed glenoid, (**B**) central guide pin and graft in position before glenoid preparation, (**C**) baseplate implanted top view, (**D**) baseplate implanted front view, and (**E**) final glenosphere construct.

a prior rotator cuff repair and whether this rotator cuff repair was performed through an open or arthroscopic approach, passive forward elevation, active forward elevation, external rotation in adduction, visual analog scale score for pain (VAS-pain), the Simple Shoulder Test (SST), and the American Shoulder and Elbow Surgeons (ASES) score. Data collected from the intraoperative documentation were diagnosis, procedure, whether a constrained polyethylene liner was used, the thickness of polyethylene used, the version of the humeral component, the glenosphere size, the glenoid baseplate peg length, and whether any intraoperative complications were noted. Data collected at final follow-up were whether any postoperative complications had occurred, whether the patient underwent revision, passive forward elevation, active forward elevation, external rotation in adduction, external rotation strength, internal rotation in adduction on both sides, VAS-pain, SST, ASES, whether the patient was satisfied, whether the patient would undergo the procedure again if given the chance, and length of follow-up.

Radiographic data collection

Preoperative and final follow-up radiographs, including anteroposterior, Grashey anteroposterior, scapular-Y lateral, and axillary lateral views, were independently evaluated by an attending surgeon fellowship-trained in shoulder and elbow surgery (P.N.C.) but who did not perform the index procedures. Glenoid deficiency was classified on preoperative radiographs and computed tomography (CT) scans using the Walch classification for patients with glenohumeral osteoarthritis[27] and the Favard system for patients with rotator cuff tear arthropathy.[21] The β-angle[15] and the reverse shoulder angle[21] were measured on the preoperative true anteroposterior radiographs (Figs. 2 and 3). The β-angle was measured as the angle between a line along the floor of the supraspinatus fossa and a line connecting the superior and inferior glenoid rims.[15] The reverse shoulder angle was measured as the angle between the a line along the floor of the supraspinatus fossa and a line connecting the inferior glenoid rim and the intersection between the previously drawn supraspinatus fossa floor line and the glenoid.[21]

Postoperative radiographs were evaluated for incorporation and resorption of the bone graft, migration or subsidence of the baseplate, and scapular notching as graded using the Nerot-Sirveaux system.[22] Baseplate inclination was measured relative to the floor of the supraspinatus fossa on the postoperative true anteroposterior radiographs (Figs. 4 and 5). This inclination measure is the equivalent of the preoperative β-angle or reverse shoulder angle in the postoperative setting.

Statistical analysis

Descriptive statistics were calculated for preoperative, intraoperative, and postoperative variables, and the Kolmogorov-Smirnov test was used to assess data normality. Preoperative and postoperative variables were compared using Fisher exact tests and paired Student t test or Wilcoxon signed-rank tests, as appropriate. P values of <.05 were considered statistically significant. Because this is an uncommon procedure examined with a retrospective design, no power analysis was conducted, and all available subjects were included.

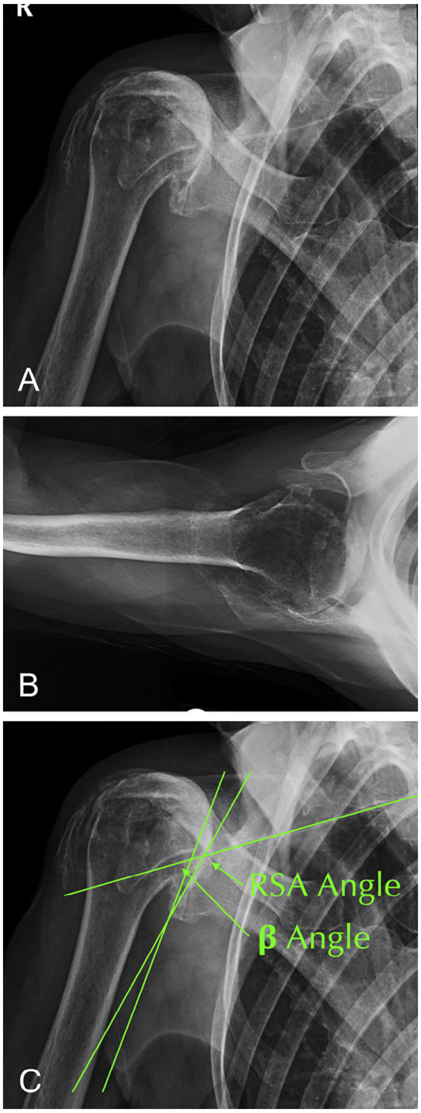

Figure 2 These preoperative (**A**) true anteroposterior and (**B**) axillary radiographs demonstrate severe superior and posterior wear. (**C**) The mean preoperative reverse shoulder angle (*RSA*) was 108° ± 20° (range, 73°-131°), and the mean preoperative β-angle was 79° ± 14° (range, 56°-106°).

Results

Of the 17 patients who met inclusion and exclusion criteria, 3 were lost to follow-up for a total of 14 patients evaluated (82% rate of follow-up). Mean length of follow-up was 2.6 years (range, 2.0-5.4 years). The mean ± standard deviation age was 75 ± 9 years. No patient had an open worker's compensation claim. No patients had a history of being treated for osteoporosis. Preoperatively, patients had significantly limited motion and function with significant pain (Table I). The mean preoperative reverse shoulder angle was 108° ± 20° (range, 73°-131°) and the mean preoperative β-angle was 79° ± 14° (range, 56°-106°). A 25-mm extended-length baseplate peg was used in all cases. Demographic, preoperative, and intraoperative variables are reported in Table II.

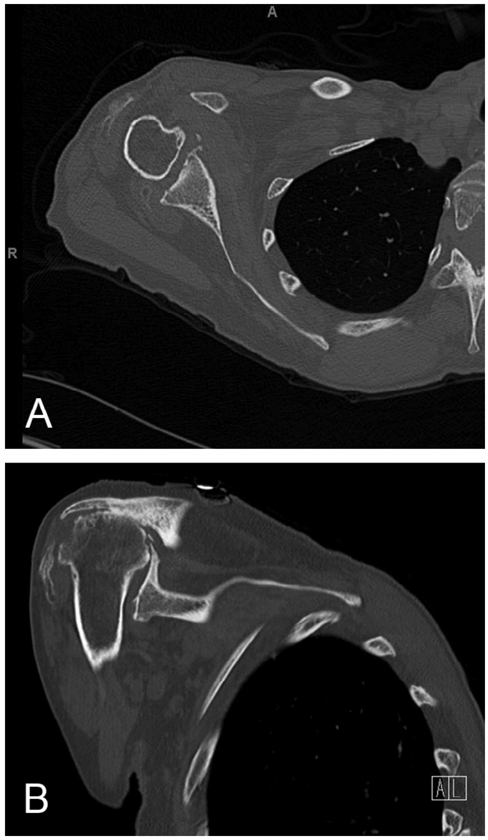

Figure 3 (**A**) Axial and (**B**) coronal images from a preoperative computed tomography scan of the patient shown in Fig. 1.

Postoperatively, active forward elevation, pain, and function were all significantly improved (Table I). Satisfaction with the procedure was also excellent (Table I). When satisfaction was assess with a "yes/no" question, 100% of patients were satisfied. All patients (93%) but 1 stated that they would undergo the procedure again if given the chance. When asked with a "yes/no" question, no patients reported persistent pain. Radiographs showed all grafts incorporated and all baseplates were stable in position except for the single revision described below. Mean postoperative inclination as measured by the β-angle was 96° ± 8° (range, 84°-110°). Mean inclination correction was 19° ± 12° (range, 3°-35°).

The only intraoperative complication was an anterosuperior glenoid fracture in 1 patient that occurred during reaming, with this portion of the glenoid being restored by the graft. A complete but transient brachial plexus palsy occurred in 1 patient postoperatively.

In addition, 1 patient was doing well until 6 months postoperatively when the patient began experiencing pain after a trauma to the arm, although functionally remained excellent. Although the initial radiographs were thought to be unchanged, over time the screws in the baseplate sequentially broke, and a CT scan showed the baseplate had migrated several millimeters superiorly. The patient underwent a

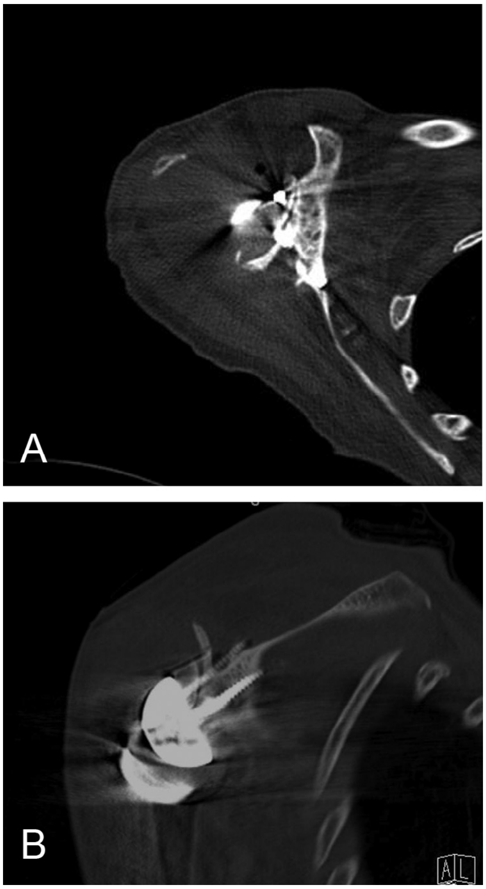

Figure 4 (**A**) Axial and (**B**) coronal images from an immediately postoperative computed tomography scan of the patient shown in Fig. 1 and 2.

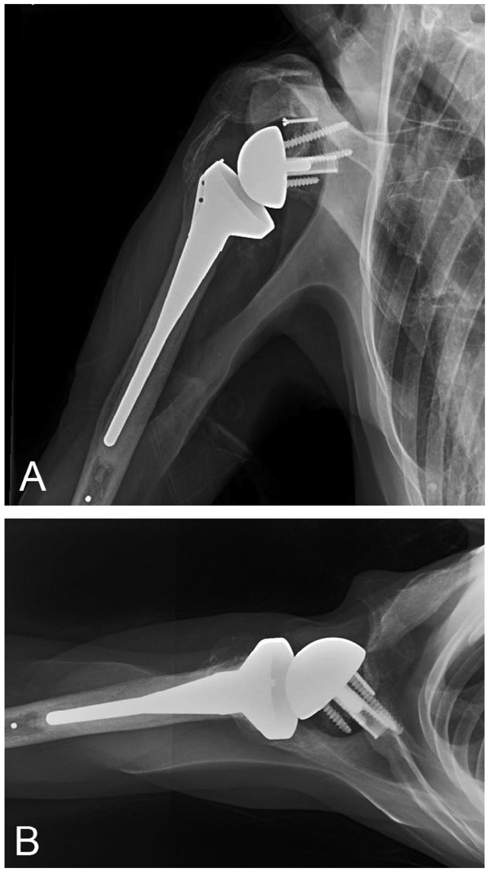

Figure 5 These postoperative (**A**) true anteroposterior and (**B**) axillary radiographs from final follow-up of the patient in Fig. 1, 2, and 3 demonstrate restoration of neutral alignment, with a final inclination (β angle) of 91° and a correction of 30°.

revision of the glenoid component. At the time of revision, most of the graft was healed, although the hole for the central post had ovalized. This hole was packed with an allograft femoral head structural graft. A new long-post baseplate was placed, with excellent stability intraoperatively. There were 2 postoperative instability events, 1 of which was reported as a "subluxation" event that was self-reduced by the patient and the other was a full dislocation requiring a closed reduction in the office.

Discussion

RTSA generally offers excellent glenoid fixation and allows the ability to improve glenoid bone stock via bone grafting.[13,17,18,26,28] These 2 factors have expanded the pathologies that can be successfully treated with a shoulder arthroplasty, especially in cases of severe glenoid erosion and revision arthroplasty.[12,16,26] The purpose of this study was to report specifically on the results of glenoid structural autografting with the humeral head during primary RTSA. Our results demonstrate that in the short-term, RTSA performed with a technique that incorporates structural autografting of the glenoid with the humeral head results in significant improvements in active forward elevation, pain, and function with a low complication rate. This technique can reliably be used to achieve correction even of large (up to 35°) glenoid defects with a 93% chance of baseplate survival and a 100% chance of graft incorporation in the short-term.

Few prior reports are available regarding structural glenoid bone grafting during primary RTSA. Neyton et al[18] were the first to report use of the humeral head as a structural autograft at the time of primary RTSA in 3 patients with rotator cuff arthropathy. All grafts healed in this limited series. Werner et al[28] reported outcomes of 21 patients who underwent anterior glenoid structural grafting with RTSA using a central post for chronic anterior shoulder dislocations. Mean bone loss was 45% in their series. After a mean follow-up of 4.9 years, only 2 patients (10%) required revision, and the mean final Constant score was 57. The authors concluded that at least 10 mm to 15 mm of central peg must be secured within the native scapula to achieve baseplate stability.[28]

Mizuno et al[17] reported outcomes of 3 patients who underwent glenoid bone grafting using humeral head autograft at the time of RTSA with a central post in the setting of glenohumeral osteoarthritis with a B2 glenoid. All grafts healed without complication. Klein et al[13] reported outcomes of 21

Table I Patient data

Variable	Preoperative (Mean ± SD)	Postoperative (Mean ± SD)	*P* value*
Forward elevation			
Passive,°	106 ± 30	136 ± 45	.273
Active,°	80 ± 40	130 ± 49	**.028**
Adducted external rotation			
Active,°	18 ± 13	29 ± 16	.279
Passive,°	NA	32 ± 14	NA
Active adducted internal rotation†	1.3 ± 0.6	3.1 ± 1.2	.317
VAS score			
Pain	8.1 ± 1.3	2.5 ± 3.1	**.005**
Satisfaction	NA	8.3 ± 1.8	NA
Simple shoulder test	1.8 ± 1.1	6.5 ± 4	**.012**
ASES score	22 ± 10	66 ± 25	**.012**

ASES, American Shoulder and Elbow Surgeons; *NA*, not applicable; *VAS*, visual analog scale.
* Significant values ($P < .05$) are bolded.
† Active adducted internal rotation was coded as follows: 0 points = lateral thigh, 2 = buttock, 4 = lumbosacral junction, 6 = L3, 4 = sacrum; 8 = T12, 10 = interscapular region.

primary RTSAs that underwent concomitant structural glenoid bone grafting using humeral head autograft as a portion of a report on 143 RTSAs using a baseplate with a central screw. They were not able to demonstrate any difference in functional outcomes between those with and without glenoid bone abnormalities and did not observe any failure or resorption of the glenoid bone grafts. The average preoperative inclination angle was 19° in cases of grafting, but there was no mention of the corrected inclination.

The largest series of humeral head structural autograft for glenoid erosion during RTSA was by Jones et al,[11] who reported outcomes of 29 patients. The authors reported 59% of grafts fully incorporated, 31% partially incorporated, and 14% did not incorporate based on radiographic analysis. The 4 grafts that did not incorporate had radiographically loose baseplates, of which 2 required revision surgery. The Jones et al[11] series is the closest comparison to the current study because it was relatively large and used the same graft technique with a baseplate with a central post. The current series reports a higher incidence of full graft incorporation but an identical 7% rate of revision for a loose implant. No series to date has documented the amount of correction achievable using this grafting technique.

Several reports are available regarding bone grafting of the glenoid with RTSA in the revision setting.[12,16,26] In the largest series to date, Wagner et al[26] distinguished between structural glenoid bone grafts and corticocancellous bone grafts, noting that 75% of failures in their series were corticocancellous and that structural bone grafting may be necessary in some cases to achieve sufficient baseplate stability.[25] However, these authors did not describe structural vs. corticocancellous or autograft vs. allograft as predictors of failure. Their study may have been underpowered to make this specific comparison.[26]

In another large series, Melis et al[16] examined 37 patients who underwent revision from a total shoulder arthroplasty to an RTSA, 29 of whom underwent concomitant glenoid bone grafting with a 76% graft incorporation rate and an 8% glenoid loosening rate, but with somewhat disappointing clinical results with a mean final Constant score of 55. All grafts in these revision cases were iliac crest autograft or allografts, with none being humeral head autografts.

An alternative technique of glenoid bone grafting places a ring of bone around the central post or screw taken from the humeral head rather than structurally grafting the defect, as described previously. Boileau et al[3] reported outcomes of 42 patients who underwent humeral head autografting during primary RTSA in which specially designed instruments were used to harvest and shape the graft. CT scans obtained 2 years postoperatively showed a 98% graft incorporation rate. Their technique, called the "Biologically-Increased Offset Reverse Shoulder Arthroplasty" or "BIO-RSA," works well to address contained defects and medialization of the joint line and may not be appropriate for uncontained or peripheral defects. Other authors have altered this technique to provide an asymmetric graft to better address asymmetric defects, including superior in rotator cuff arthropathy, anterior for fracture dislocations, or posterior for osteoarthritis with B2 glenoids.[7,17,21] The difference between the BIO-RSA technique and the structural filling technique described in our series is that the baseplate is frequently in contact with some native glenoid bone with the structural filling technique but never in the BIO-RSA technique.

A glenoid baseplate with 4 screws was used in all but 1 of the RTSAs included in our series because the senior author transitioned implants for all RTSAs, not just those with glenoid bone grafts, during the study period. Although the transition was driven by a variety of factors, the ability to stabilize the baseplate with more screws can be advantageous. However, our technique can be applied without alteration with either a 2-screw or 4-screw baseplate. To date, no clinical evidence

Table II Preoperative, intraoperative, and postoperative characteristics of the cohort

Variable	No. (%) (n = 14)
Right side	10 (71)
Dominant side	10 (71)
Female gender	10 (71)
History of fracture elsewhere requiring ORIF	2 (14)
Prior rotator cuff repair	4 (29)
Prior open rotator cuff repair	2 (14)
Diagnosis	
Rotator cuff tear arthropathy	7 (50)
Favard classification	
E2	3 (43)
E3	4 (57)
Glenohumeral osteoarthritis	5 (36)
Walch classification	
A2	1 (20)
B3	4 (80)
Anterior glenoid fracture	2 (14)
Implant	
Trabecular Metal Reverse*	1 (7)
Reversed Arthroplasty†	13 (93)
Polyethylene	
Constrained	2 (14)
3 mm	1 (7)
6 mm	3 (21)
9 mm	6 (43)
12 mm	4 (29
Humeral retroversion	
0°	3 (21)
5°	1 (7)
10°	7 (50)
15°	1 (7)
20°	2 (14)
Glenosphere size	
36	12 (86)
42	2 (14)
Notching	
None	4 (36)
Grade 1	7 (50)
Grade 3	1 (7)
Grade 4	1 (7)

ORIF, open reduction and internal fixation.
* Zimmer, Warsaw, IN, USA.
† Tornier, Bloomington, MN, USA.

exists to suggest that a 2-screw baseplate is inferior to a 4-screw baseplate, and the single failure in our study was in a 4-screw baseplate.

Strengths of the current study include a high rate of follow-up and the inclusion of validated patient-related outcome scores and radiographic outcomes, including the amount of correction achieved as a result of grafting.

Our study has several limitations. This is a single-center, retrospective review of a smaller sample with short-term follow-up without a control group. Given the relative rarity of structural bone grafting during RTSA, larger sample sizes are difficult to achieve, and insignificant differences may be a result of a lack of power. One significant limitation of the study is the ability to completely measure and characterize defect size. Our measurements of inclination allow partial characterization of this 3-dimensional process in 2 dimensions but do not allow complete volumetric defect measurement.

Conclusion

RTSA performed with a technique that incorporates structural grafting of large glenoid defects with humeral head autograft results in significant improvements in active forward elevation, pain, and function with a low complication rate. This technique can reliably be used to achieve correction even of large (up to 35°) glenoid defects with a 93% chance of baseplate survival and a 100% chance of graft incorporation in the short-term.

Disclaimer

Robert Tashjian is a paid consultant for Cayenne Medical and Mitek, has stock in Conextions, INTRAFUSE, and KATOR, receives intellectual property royalties from Imascap, Shoulder Innovations, and Zimmer, receives publishing royalties from *Journal of Bone & Joint Surgery*, and serves on the editorial board for the *Journal of Orthopaedic Trauma*. The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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