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Mid-term results of the use of structural humeral head autograft to correct glenoid bone loss in reverse total shoulder arthroplasty

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ABSTRACT

Background: Native glenoid bone loss presents technical challenges in shoulder arthroplasty. The purpose of this study is to report the mid-term clinical and radiographic outcomes of patients treated with structural humeral head autograft reconstruction of glenoid bone loss in the setting of reverse total shoulder arthroplasty (rTSA).

Methods: Retrospective review of 30 shoulders in 28 patients undergoing rTSA with a structural humeral head autograft to correct glenoid bone loss. Demographics, comorbidities, anatomic details, and patient-reported outcome measures were collected for analysis.

Results: Range of motion and patient-reported outcome measures were all significantly improved postoperatively ($P < .001$). Bone grafts were found to incorporate into 100% of shoulders, with no protheses displaying signs of loosening or other structural concerns. No revision procedures were performed, and all patients were satisfied with their shoulder postoperatively. Two patients developed scapular notching on follow-up.

Discussion: The use of a humeral head autograft to reconstruct glenoid bone loss in patients undergoing rTSA is a safe and effective procedure. It allows for a local graft source to be utilized thus avoiding potential comorbidity and complications associated with the use of alternative site autografts or allografts and has the advantage of nearly congruent fit within the defect.

Reverse total shoulder arthroplasty is a proven technique to relieve pain and restore function in the arthritic, rotator cuff deficient and unstable shoulder. Anatomical studies of the arthritic shoulder have demonstrated several patterns of glenoid bone loss. Walch et al. developed a classification of glenoid morphology as unstable shoulders with deviations in glenoid axial plane geometry present a challenge to reconstructive surgeons. Type B2, B3, C2, and D all involve moderate to severe bone loss with glenohumeral subluxation.[8,13] These morphologies can also be associated with bone loss to the glenoid vault depth, precluding implantation of a cemented standard glenoid component in anatomical shoulder arthroplasty, and reduced bone stock for implantation of reverse total shoulder ingrowth componentry.[8,18] It has been reported that up to 40% of patients with rotator cuff arthropathy present with superior bone loss to the glenoid.[18] Favard et al. described the most common patterns of glenoid erosion attributed to rotator cuff tear arthropathy, with varying degrees of erosion in the coronal plane.[1,8]

The original reverse total shoulder arthroplasty design approved for use in the USA by the Food and Drug Administration (FDA) designed by Grammont utilized a cemented humeral component with a 155-degree neck shaft angle and an ingrowth glenoid component with a medialized center of rotation relative to the glenoid face.[4] This construct has been proven successful in the long term;[21] however, the medialized center of rotation combined with a valgus neck shaft angle has been associated with the radiographic phenomenon of scapular notching.[1] A technique termed “BIO-RSA” was developed in 2007 to lateralize the glenoid component using

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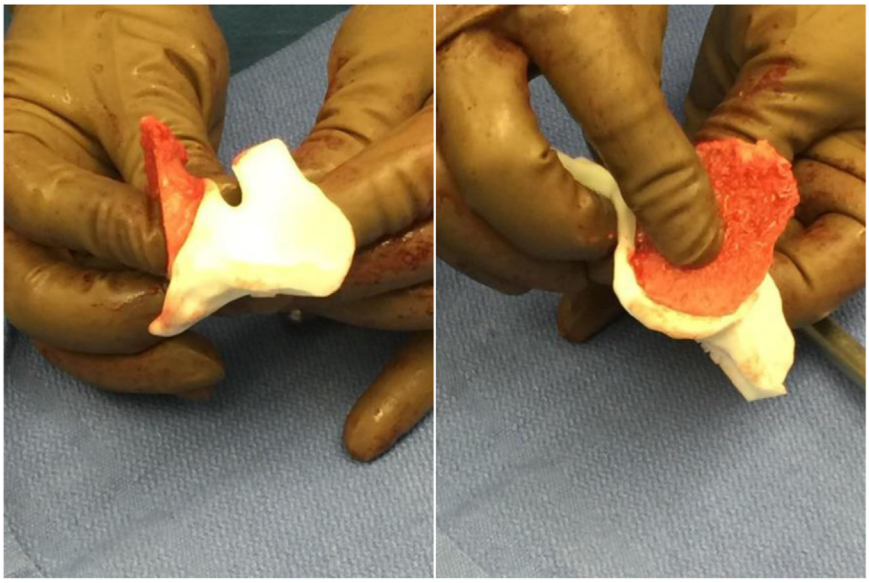

Figure 1 Humeral head autograft fits native glenoid defect perfectly. Glenoid defect modelled via 3D printed glenoid targeting guide (Matchpoint; Materialise, Leuven, Belgium).

an onlay intercalated cylindrical autograft from the humeral head using a long post Grammont RSA metaglene component. Intermediate studies have shown the graft incorporates 90-94% of the time and this can reduce the rate of notching.[3]

In 2004, one year after the Grammont design was approved, another reverse total shoulder arthroplasty design was approved for use in the USA by the FDA. This implant relied on a more anatomical humeral neck shaft angle of 135 degrees, and a lateral offset ingrowth glenoid component. This implant differed from Grammont, as the ingrowth glenoid component was a screw-in baseplate, rather than a press-fit post metaglene. Long term follow-up studies have also shown this design to be successful with the added benefit of markedly reduced rates of scapular notching thought to be a function of an anatomical neck shaft angle along with a lateral offset glenoid center of rotation.[6]

Regardless of implant chosen, a goal of reverse total shoulder arthroplasty is to restore glenoid version to 0-10 degrees of retroversion, and inclination from -10-0 degrees of inferior tilt in order to obtain a stable construct able to withstand shear forces long-term.[2,7,9,20] Because glenohumeral arthritis and rotator cuff arthropathy are associated with glenoid bone loss which can be severe, reconstructive techniques using metal augments, allograft, and autografts from the iliac crest have been utilized.[10,14,24] We observed that in many cases of glenoid bone loss the defect tends to mirror the shape of the humeral head, and that the humeral head seemed to fit the glenoid defect perfectly (Fig. 1). Because the glenoid component in our preferred RSA implant is screwed into position, it seemed intuitive that the patient's humeral head might serve as an ideal structural bone graft to correct severe bone loss and restore the native paleo-glenoid morphology.

The use of a humeral head autograft to augment glenoid bone loss in RTSA has been previously reported in 2 small case series using the same implant design from the BIO-RSA studies. Both studies demonstrated successful correction of large glenohumeral deficits and restoration of inclination and retroversion angles. No graft failures were reported in either study and patient outcome measures were significantly improved postoperatively. However, both studies reported high rates of scapular notching.[11,22]

The purpose of our study is to evaluate the feasibility, safety, and efficacy of using a structural humeral head autograft to correct glenoid bone loss in patients undergoing reverse total shoulder arthroplasty with radiographic and clinical outcomes. All cases utilized a screw-in baseplate with a lateralized center of rotation glenosphere and a 135-degree humeral stem. Our research hypothesis was that the patients native humeral head will correspond geometrically to the void present in the glenoid, and this anatomical relationship can be leveraged to the surgeon's advantage to reconstruct bone loss allowing for incorporation, restoration of anatomical alignment, and improved patient outcomes that are durable over the intermediate term. We also evaluated whether medical comorbidities influenced postoperative outcomes.

Methods

A retrospective review of all patients who underwent reverse total shoulder arthroplasty for glenohumeral arthritis associated with severe glenoid bone loss reconstituted with a humeral head autograft performed by a single surgeon at our institution from 2005 to 2019 was performed as approved by our institution's IRB. All patients treated surgically with the DJO/Encore Reverse Shoulder Prosthesis (DJO, Austin, TX, USA) augmented with a humeral head autograft were identified. These cases were further stratified according to the Walch classification (A2, B1, B2, B3, C1, C2, and D),[8,13] the Favard classification (E0, E1, E2, E3, and E4),[8,15] and whether they had concomitant rotator cuff insufficiency. The Walch and Favard classifications have only been validated for cases of primary osteoarthritis and massive rotator cuff tear, respectively. However, we describe the anatomy of each shoulder using both classification systems to allow the reader to better understand the three-dimensional (3D) deformity of each shoulder. Beginning in 2016, a commercially available custom 3D printed model of the glenoid and targeting guide for central screw placement in the glenoid (Matchpoint; Materialise, Leuven, Belgium) was used intraoperatively to aide in sizing and preparing the bone graft (Fig. 2).

Surgery was performed under general anesthesia, in the beach chair position. A standard deltopectoral approach was utilized. A subscapularis peel, biceps tenodesis to the pectoralis major, and standard anterior humeral and glenoid releases were performed to gain access to the glenoid. The humeral head was resected using the standard 135 degree extra-medullary cutting guide in 20-30

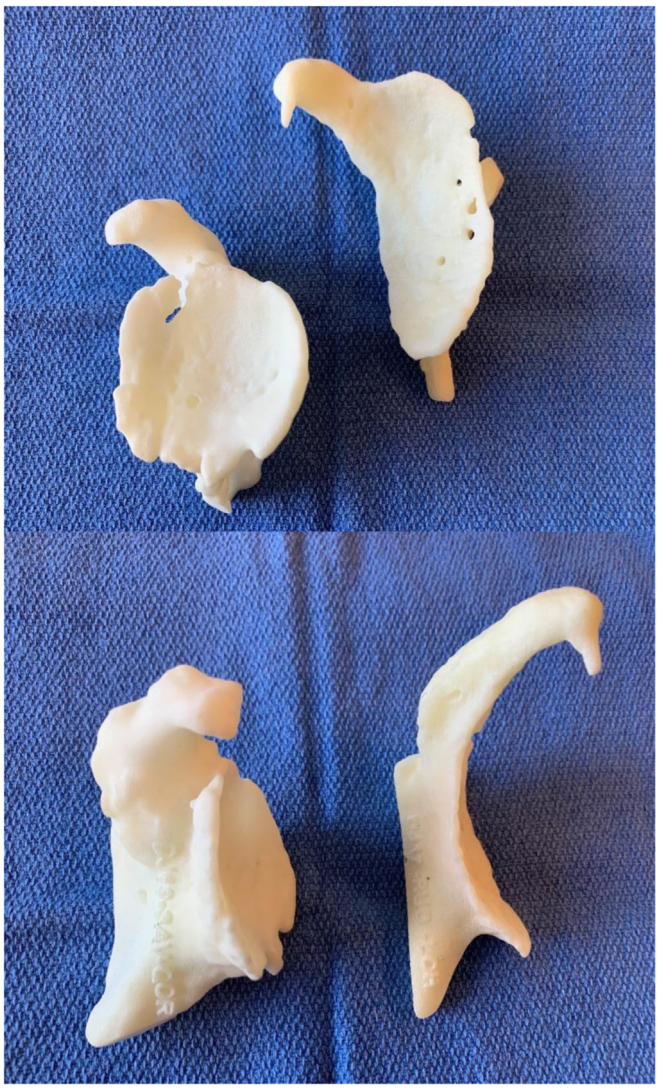

Figure 2 Two three dimentional (3D) printed models of the glenoid used to assist intraoperatively with reconstruction from patients in this study (Matchpoint; Materialise, Leuven, Belgium).

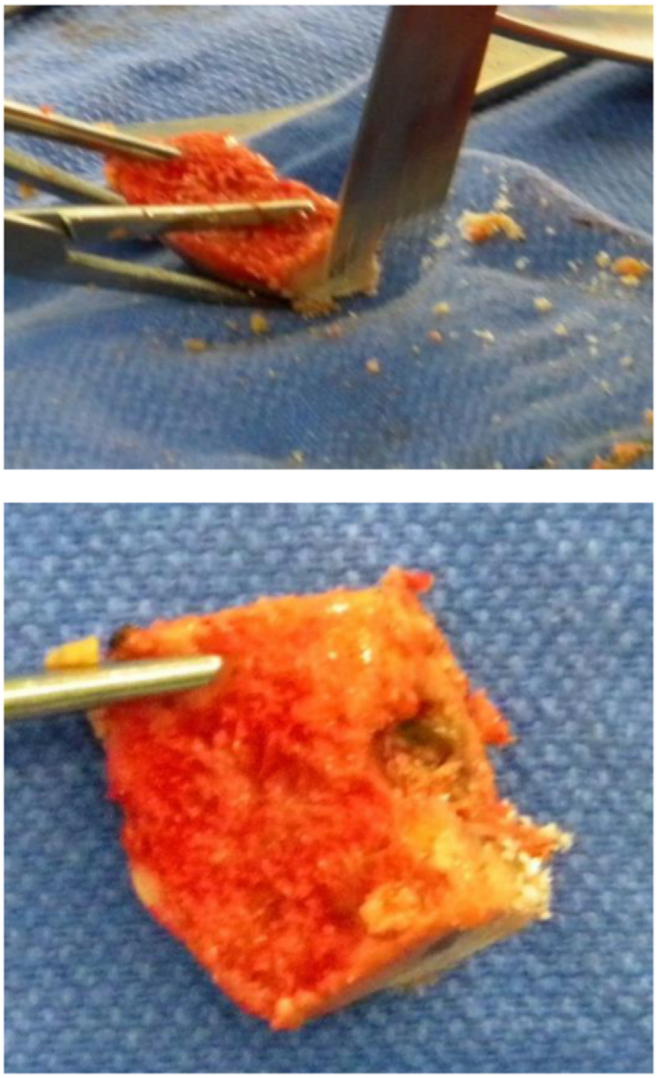

Figure 3 Humeral head autograft sizing intraoperatively.

degrees of retroversion. The humeral head articular surface was roughened using a manual rasp with care to preserve the subchondral bone and then saved on the back table. The glenoid face was then roughened with a manual rasp and the centerline for the central screw of the baseplate was identified with a 2.5 mm long drill using either the information gleaned from the preoperative CT scan or later, a custom targeting guide starting in 2016. The goal was to attain 0-10 degrees of retroversion and a minimum of 10 degrees of inferior angulation of the glenosphere. The centerline axis drill hole depth was measured using a depth gauge in an attempt to verify coordinates. A short 3mm drill bit was then placed into the centerline axis. The humeral head bone graft was then placed on the custom model (when available) with the best congruent match to the defect and best bone stock placed into a position to restore glenoid version to 0-10 degrees of retroversion. Graft thickness was aimed at restoring the paleoglenoid morphology, matching the premorbid joint line. The antero-inferior part of the glenoid could not always reliably be used as a landmark to determine the position of the premorbid joint line, such as in patients with inferior glenoid bone loss (for example, a Walch B1, Favard E4 glenoid). Preoperative CT scans were utilized to determine the exact glenoid morphology secondary to bone loss. A 3mm drill was passed through the model retrograde to recreate the centerline in the bone graft. From 2005-2016, before this model technology was available, the carpentry to size and fit the graft was all done by trial and error using the patient's native anatomy in situ.

Once the graft was sized (Fig. 3), the centerline axis hole was increased in diameter using a 5.0 mm drill. The graft was then inset over the 3 mm drill bit onto the glenoid face. A drift was used to gently impact the graft flush and two .045-inch smooth Kirshner wires were placed in the periphery of the graft holding it in position (Fig. 4*A*). The 3 mm drill bit was removed and the 6.5 mm tap was inserted with care not to disturb the graft. Using the starter cannulated reamer, the graft/native bone interface construct was further shaped. The small reamer followed to complete the graft shaping (Fig. 4*B*). Completion of reaming was determined with the aid of a 3D templating program after it became available in 2016, and by surgeon discretion with the assistance of 2D templating prior. The graft was not allowed to project beyond the highest point of the paleo-glenoid to prevent over-lateralization of the joint line which could hinder the ability to reduce or dislocate the shoulder implants as the case progressed. The 6.5 mm tap was removed carefully, and the DJO/Encore RSP Baseplate was screwed into

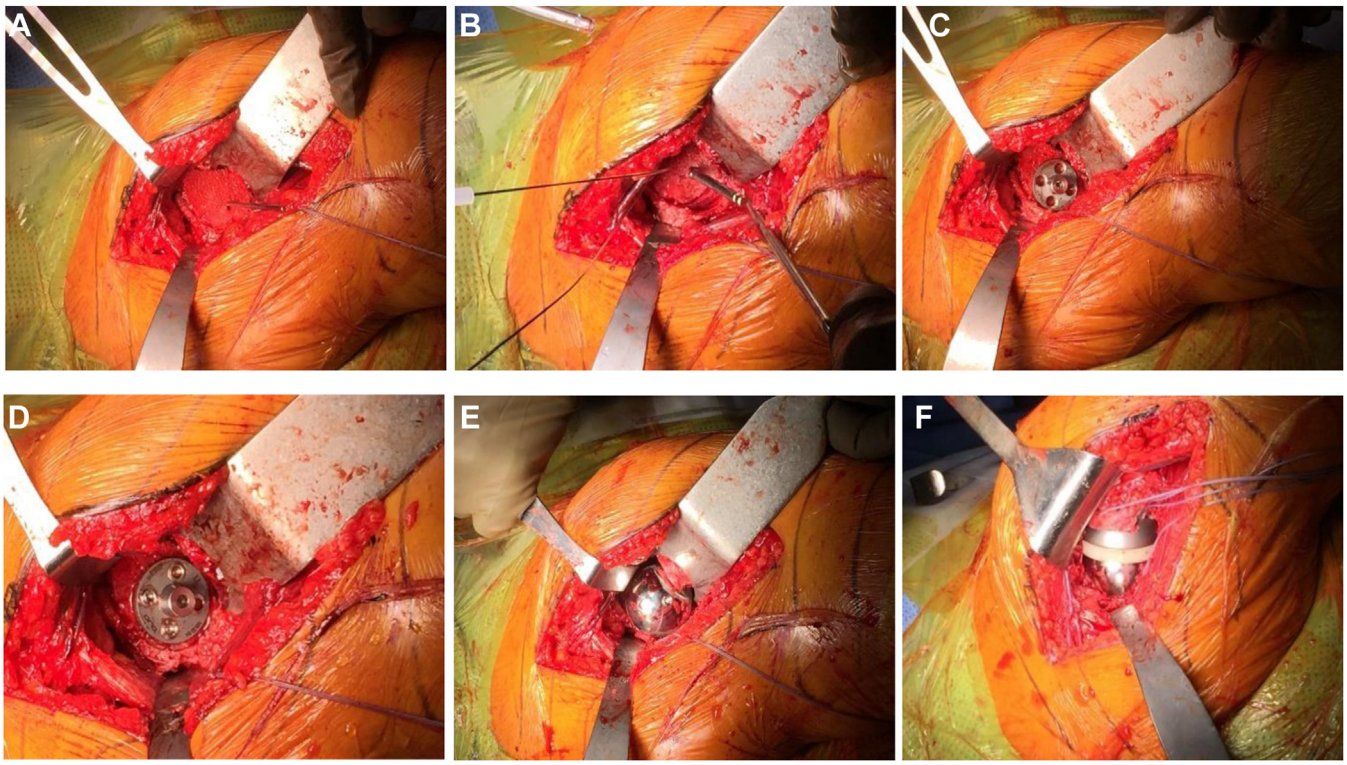

Figure 4 A: Graft inset over glenoid face with Kirshner wires for stability. B: Graft reamed during graft shaping. C: DJO/Encore baseplate screwed into position, compressing graft onto glenoid face. D: DJO/Encore locking screws placed in baseplate. E: Glenosphere implanted onto baseplate. F: Final prosthetic implant following passive intraoperative range-of-motion testing.

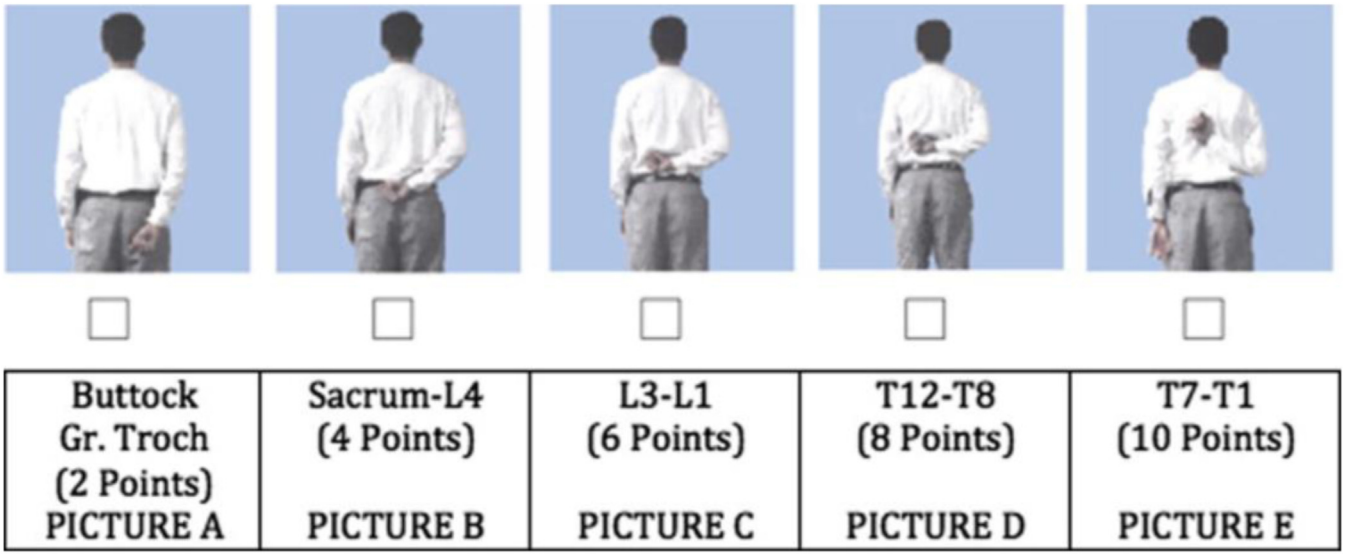

Figure 5 Internal rotation 10-point scale. Created by Levy et al, 2014,[16] adapted from Triplet et al, 2015.[23]

position. Once there was the beginning of compression seen on the graft, the two Kirshner wires were carefully removed, and the graft was fully compressed into position (Fig. 4*C*). As a general rule, when the scapula began to rotate through the screwdriver handle as the baseplate was being inserted thus compressing the graft underneath, the baseplate installation was complete. Because the graft was wedge shaped, it did not rotate upon applying further compression after the Kirshner wires were removed. The 4 peripheral 5.0 mm locking screws were placed through the baseplate further securing the autograft using the fixed angle guides available in the standard instrument set (Fig. 4*D*). The baseplate was then over-reamed and excess graft was removed when there was a risk of humeral impingement. If anterior dislocation of the humerus was difficult following implantation of a thick graft and/or lateralizing glenosphere, additional anterior releases, release of an intact superior rotator cuff when present, use of a more medialized glenosphere, and/or partial release of the pectoralis major and/or latissimus dorsi was performed as not to compromise the greater

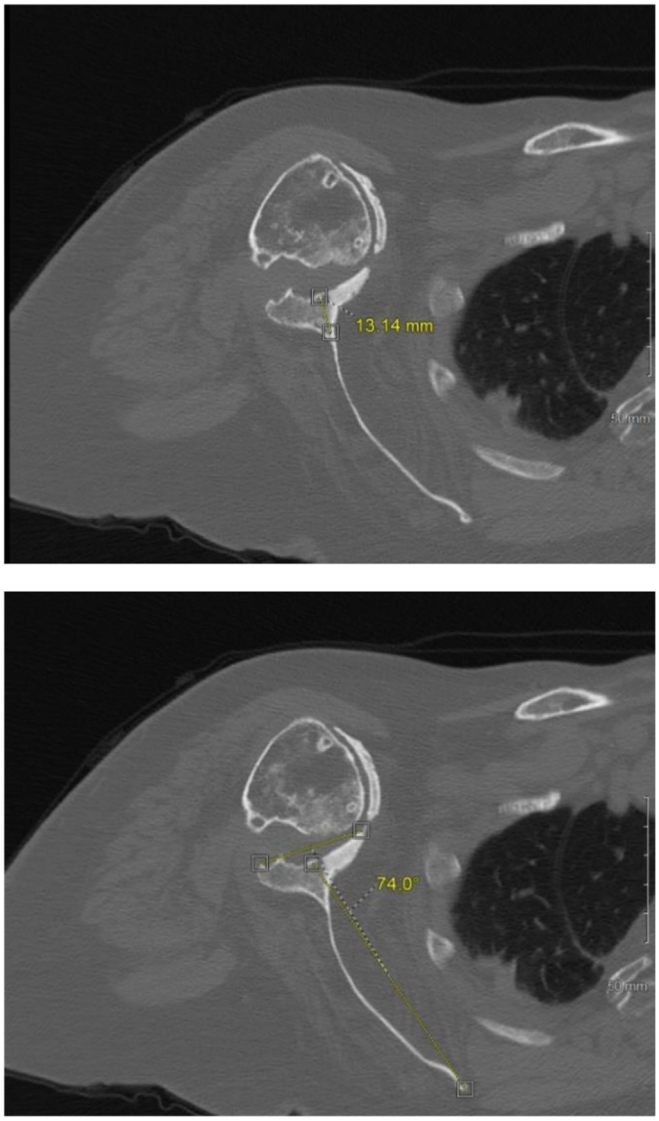

Figure 6 Preoperative glenoid vault depth and retroversion measurement via CT imaging (Horizon Rad Station, McKesson Co., Irving, TX, USA). Note the coracoid insufficiency fracture at the base.

tuberosity or lever against the coracoid. A trial glenosphere was placed and the humeral reconstruction was performed using standard methods. The glenosphere ultimately chosen was based upon standard principles of reverse total shoulder arthroplasty, making sure there was adequate overhead and external rotation motion, proper tension on the conjoint tendon and posterior capsule, and no posterior instability (Fig. 4 *E* and *F*). Adequate tension of the posterior capsule was assessed through range of motion and stability testing. Desired stability was defined as less than 25 percent posterior translation or shuck between the glenoid and humeral components when reduced in neutral rotation and zero degrees of abduction all the way through the spectrum up to maximum internal and external rotation with associated degrees of increasing abduction. After implantation of all final components, the anterior capsule and subscapularis were repaired if feasible using 2 #5 FiberWire sutures (FiberWire; Arthrex, Naples, FL, USA). Two drains were placed for 24-48 hours within the dead space, and a standard closure was performed. Grashey and axillary views were performed postoperatively with the patient under anesthesia. All patients were placed into a sling with a waist strap and admitted for 24 hours of IV antibiotics.

Patients were allowed to move their arms with up to 1 pound of additional weight to approximately 120 degrees of forward elevation and 30 degrees of external rotation with the arm at the side beginning postop day one. Patients were not permitted to weight bear on the arm. At 6 weeks postop, AP, Grashey, and axillary radiographs were performed and if no loosening, implant shift, stress fractures, or other concerns were seen, patients were allowed to move the arm ad lib with up to 10lbs lifting in the postoperative arm. By 6 months postsurgery, if there was no change in the glenoid component on plain radiographs, weight bearing on the upper extremity was allowed when needed for ambulatory assistance. Formal physical therapy was initiated only at the patient's request but was not routinely ordered. A standard postoperative follow-up examination was performed by the surgeon with additional documentation provided using patient-reported outcome measures, any therapy notes, resident notes, radiology reports at 3-month intervals for the first year, and then yearly thereafter until the patient either relocated out of state and was no longer willing to travel or died. The data recorded prospectively preoperatively and postoperatively included active range of motion (forward elevation, abduction, internal and external rotation) and pain score (VAS) reported on a scale of 0-10. External rotation was performed at 0 degrees abduction. Internal rotation was reported using a 10-point scale based on 5 anatomical range segments adapted from Levy et al (2014) (Fig. 5).[16,23] A goniometer was used for range of motion measurements. The Simple Shoulder Test (SST)[17] and Disabilities of the Arm, Shoulder, and Hand (DASH)[12] scores were collected preoperatively and then postoperatively at 6 months, one year, and beyond with each subsequent visit.

Additional data collected included age, gender, Walch classification, Favard classification, and all medical comorbidities including: osteoporosis, obesity, smoking status (current or former), alcohol use, diabetes, hypertension, heart disease, liver disease, autoimmune disease (including inflammatory arthritis), malignancy (former or current), psychiatric disease (anxiety, depression, mania), or other systemic diseases. Medical comorbidities were identified by searching our institution's electronic medical record. Supporting consultation notes and active medical treatment for a given medical problem were required in order to be included in our analysis. Patients who sustained postoperative complications were identified. We defined successful graft incorporation as radiographic evidence of healing, without any shift of implants in position over time, no screw fracture, no progressive osteopenia/osteolysis around the screws or behind the baseplate. If there was concern for eminent failure, a computed tomography (CT) scan was obtained. Medical comorbidities were evaluated as risk factors for complications.

Preoperative CT imaging, as well as pre- and postoperative plain films were analyzed via Horizon Rad Station (McKesson Co., Irving, TX, USA) to determine Walch and Favard glenoid morphology classifications, preoperative glenoid vault depth, and pre- and postoperative glenohumeral version and inclination angles (Figs. 6–8).

Preoperative glenohumeral version was measured on axial CT scan using the Friedman method in which a line is drawn down the long axis of the scapula, from the tip of the medial border of the scapula to the center of the glenoid. The line of neutral glenoid version is then drawn perpendicular to the first line. Lastly, the glenoid fossa line is drawn between the anterior and posterior margins of the glenoid. The angle between the glenoid fossa line and the neutral glenoid version line is the version angle.

Postoperative glenohumeral version was measured on axial plain films. A line was first drawn through the scapular spine or

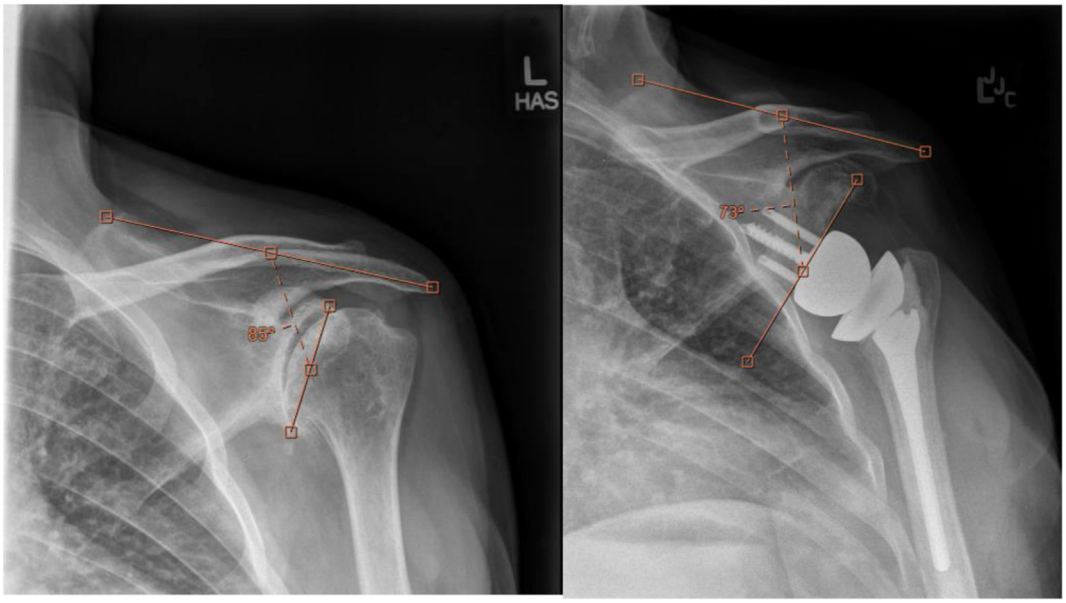

Figure 7 Preoperative and postoperative glenohumeral inclination angle measurements (Horizon Rad Station, McKesson Co., Irving, TX, USA).

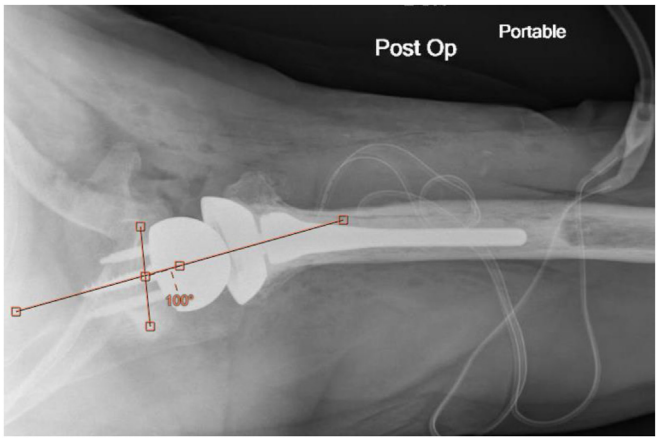

Figure 8 Postoperative glenohumeral retroversion angle measurement (Horizon Rad Station, McKesson Co., Irving, TX, USA).

the central locking screw. Next, the glenoid fossa line is drawn as previously described. The angle between these two lines represents the amount of correction from the preoperative version angle.

Preoperative and postoperative glenohumeral inclination angles were measured on coronal plain films. A line is first drawn from the tip of the acromion to the superior angle of the scapula. The glenoid fossa line (preoperatively) or a line parallel to the glenosphere baseplate (postoperatively) was then drawn. The angle between the scapular line and the glenoid fossa or baseplate line is the inclination angle.

Statistically significant differences in categorical variables representing graft failure to incorporate postoperatively and other complications between cases were tested for using contingency tables by Fisher's Exact Test, due to small cell sample sizes. Statistically significant differences in categorical variables representing comorbidities between cases were also tested for using Fisher's Exact Test. For continuous outcome variables representing numeric measures, such as shoulder ROM, VAS, DASH, SST, the Wilcoxon Rank Sum test, and Kruskal-Wallis test, were used in order to test for statistically significant differences between levels of independent variables. These tests were also used due to the non-normal distribution of the outcome variables. Statistical analyses were performed using SAS statistical analysis software (SAS Institute, Inc., Cary, NC, USA). Statistical significance level alpha was set a priori at 0.05.

Results

Thirty procedures met inclusion criteria and 10 belonged to patients found to be deceased at the time of data analysis. Seventeen shoulders had rotator cuff tear arthropathy, seven shoulders had osteoarthritis with posterior glenoid bone loss along with posterior instability and tears to the superior subscapularis with fatty atrophy of the muscle belly, four shoulders had rheumatoid arthritis with erosive bone loss and rotator cuff insufficiency, and 2 shoulders had postcapsulorraphy arthropathy with subscapularis insufficiency secondary to prior Putti-Platt procedure. The 3D printed glenoid model and targeting guide for glenoid central screw placement was utilized intraoperatively for 16 shoulders. Patient-reported outcomes and functional range-of-motion testing were collected at an average of 4.3 years (range: 2.0-7.6 years, SD: 1.5 years) for the alive cohort, and 3.1 years (range: 0.2-8.5 years, SD: 2.7 years) for the deceased cohort. In the deceased cohort, the mean time between most recent follow-up and date of death was 1.9 years (range: 0.05-5.86 years, SD: 1.62 years).

The mean age of patients included in this study at the time of surgery was 73.5 years (range: 63-89 years, SD: 6.8 years), and the mean body mass index (BMI) at the time of surgery was 31.0 kg/m^2 (range: 17.0-47.5 kg/m^2, SD: 8.2 kg/m^2). Additional patient demographic information can be found in Table I.

The anatomy of each shoulder was characterized utilizing both the Favard and Walch classification systems. The Walch B3 (n = 10) and the Favard E3 (n = 9) and E4 (n = 9) classifications were the most prevalent (Table II). When combining both classifications to describe the 3D morphology of each shoulder, we found 16 unique combinations. No one combination was described for more than three shoulders; however, the Walch B3 was associated with Favard E2 or E3 in 6 cases (Table III).

Table I
Summary of patient demographics.

Variable	n = 30 (%)
Sex	
Male, n (%)	12 (40)
Female, n (%)	18 (60)
Implant Laterality	
Dominant Side, n (%)	16 (53)
Non-Dominant Side, n (%)	14 (47)
Smoking Status	
Never Smoked, n (%)	17 (57)
Former Smoker, n (%)	12 (40)
Current Smoker, n (%)	1 (3)
Diabetes, n (%)	3 (10)
Inflammatory Arthritis, n (%)	4 (13)

Table II
Walch and Favard classification of shoulders.

Favard	n = 30	Walch	n = 30
E0	3	A2	6
E1	1	B1	1
E2	8	B2	5
E3	9	B3	10
E4	9	D	8

Table III
Unique shoulder morphologies using combined Walch and Favard classifications.

Morphology	n = 30
E0-B2	2
E0-D	1
E1-B3	1
E2-A2	2
E2-B2	1
E2-B3	3
E2-D	2
E3-A2	2
E3-B2	1
E3-B3	3
E3-D	3
E4-A2	2
E4-B1	1
E4-B2	1
E4-B3	3
E4-D	2

Preoperatively, patients were found to have an average glenoid vault depth of 20.0 mm (range: 11.0-30.0 mm, SD: 4.3 mm), with an average retroversion angle of 10.6 degrees (range: −32.0 to 40.0 degrees, SD: 17.6 degrees), and a superior inclination angle of 4.3 degrees (range: −12.0 to 25.0 degrees, SD: 10.0 degrees). Postoperatively, the average retroversion angle was found to be 6.8 degrees (range: 0.0-16.0 degrees, SD: 4.3 degrees), and the inclination angle was −8.4 degrees (range: −23.0 to 9.0 degrees, SD: 7.7 degrees). Mean correction of retroversion angle was found to be −3.7 degrees (range: −30.0 to 42.0 degrees, SD: 17.8 degrees), and mean correction of glenohumeral inclination was −12.8 degrees (range: −30.0 to 3.0 degrees, SD: 8.3 degrees). Anatomical details are listed in Table IV.

Patient-reported outcome measures improved during the study period with VAS improving from 4.9 to 0.03 (range: 0-1, SD: 0.2, *P* value <.0001), SST improving from 2.6 to 8.7 (range: 1-12, SD: 3.4, *P* value <.0001) and DASH improving from 53.6 to 24.5 (range: 0-67, SD: 23.9, *P* value <.0001). In addition, forward flexion improved from 76.4 degrees to 148.7 degrees (range: 80-170 degrees, SD: 22.2 degrees, *P* value <.0001), abduction increased from 64.3 degrees to 137.9 degrees (range: 60-170 degrees, SD: 28.7 degrees, *P* value <.0001), internal rotation improved from 2.1 to 4.3 (range: 2-8, SD: 1.6, *P* value <.0001), and external rotation increased from 20.8 degrees to 54.7 degrees (range: 30-70 degrees, SD: 12.8 degrees, *P* value <.0001), (Table V).

Table IV
Anatomical and intraoperative details.

Variable	n = 30 (%)
Walch Classification	
A2	6 (20)
B1	1 (3.3)
B2	5 (16.7)
B3	10 (33.3)
D	8 (26.7)
Favard Classification	
E0	3 (10.0)
E1	1 (3.3)
E2	8 (26.7)
E3	9 (30.0)
E4	9 (30.0)
Variable	**Mean (Range)**
Preop Glenoid Vault Depth (mm)	20.0 (11.0-30.0)
Retroversion Angle (°)	
Preop	10.6 (−32.0 to 40.0)
Postop	6.8 (0.0-16.0)
Correction	−3.7 (−30.0 to 42.0)
Superior Inclination Angle (°)	
Preop	4.3 (−12.0 to 25.0)
Postop	−8.4 (−23.0 to 9.0)
Correction	−12.8 (−30.0 to 3.0)

All numbers are absolute values.

No revision procedures were performed on any patient during the follow-up period, and all patients were satisfied with their shoulder postoperatively. Bone grafts were found to incorporate into 100% of shoulders with greater than 6 months of follow-up, with no prostheses displaying signs of loosening or other structural concerns. Two patients (6%) were noted to have developed scapular notching on follow-up. One patient sustained a scapular body fracture as the result of a fall that healed without surgery.

Discussion

To achieve anatomical reconstruction of glenoid anatomy in patients with bone defects options include metal augments, allograft, autograft from a distant site, and autograft from the local surgical field.[10,14,24] In this study, we have shown that the native humeral head will match the observed defect in the glenoid. This relationship can be leveraged to the surgeon and patients' advantage, as the humeral head which is normally resected as part of a total shoulder arthroplasty can serve as structural bone graft. Its thickness and diameter are wide enough to fill the defect and to provide stability to the glenoid baseplate. In this particular arthroplasty system, the baseplate central screw can be used to fixate the bone graft with compression. As the glenoid-facing side of the graft is shaped like a wedge, graft rotation during final screw compression was not observed. The peripheral locking screws further stabilize the graft. This improves mechanical stability of the construct, and likely engenders incorporation. With glenoid anatomy restored to 0-10 degrees of retroversion, -10-0 degrees of inferior tilt, and lateral offset of the glenoid neck restored to the paleo-glenoid, the likelihood of postoperative instability is greatly reduced, and superior shear forces on the glenosphere are also reduced. This should therefore result in improved range of motion and longevity of the implant, compared to a medialized glenoid with a superiorly angled glenosphere.

In a study of 54 patients undergoing reverse total shoulder arthroplasty using an autograft from humeral head to purely

Table V
Patient-reported outcomes and active range-of-motion comparisons.

Variable	Preop mean (range, SD)	Postop mean (range, SD)	*P* value
Forward Flexion (°)	76.4 (0-135, 27.9)	148.7 (80-170, 22.2)	<.0001
Abduction (°)	64.3 (0-100, 23.6)	137.9 (60-170, 28.7)	<.0001
External Rotation (°)	20.8 (0-60, 18.0)	54.7 (30-70, 12.8)	<.0001
Internal Rotation*	2.1 (0-4, 1.1)	4.3 (2-8, 1.6)	<.0001
VAS (0-10)	4.9 (0-10, 2.7)	0.03 (0-1, 0.2)	<.0001
DASH	53.6 (18-91, 19.9)	24.5 (0-67, 23.9)	<.0001
Simple Shoulder Test	2.6 (0-9, 2.2)	8.7 (1-12, 3.4)	<.0001

VAS, visual analog scale; *DASH*, disabilities of the arm shoulder and hand; *SD*, standard deviation.
*Internal Rotation was reported using a 10-point scale based on 5 anatomical range segments adapted from Levy et al, 2014.[16] See Fig. 5.

lateralize the glenoid component, Boileau et al reported a failure rate of 6%.[3] The technique they called "BIO-RSA" used a keyhole saw to remove a circular bone graft from the humeral head shaped like a donut. This graft was placed onto the metaglene component and was impacted on the face of the glenoid adding lateral offset. It was secured using 2 locking and 2 compression screws. The mechanical theory of the technique was to add lateral offset to a reverse total shoulder implant system that was not designed with any significant lateral offset. The hope was to improve range of motion and reduce scapular notching.[3] This technique is substantially different from the described technique as it is not designed to reconstruct a defect in the native glenoid. The use of bone graft in our technique allowed for correction of glenoid bone loss and retroversion, as well as lateralization of the construct back to the native paleo-glenoid alignment.

A similar surgical technique has been described in 2 recent retrospective case series. Tashjian et al. studied 17 patients undergoing primary RTSA with concomitant structural humeral head autografting with a mean follow-up of 2.6 years. Fifty percent of patients had been diagnosed with rotator cuff tear arthropathy preoperatively. Glenohumeral inclination angle was corrected a mean of 19 degrees, however maximum correction was performed to 35 degrees. Radiographic evaluation demonstrated 100% graft incorporation. Active forward elevation as well as patient outcome measures including visual analog pain scale, Simple Shoulder Test, and the American Shoulder and Elbow Surgeons score were all significantly improved postoperatively.[22]

In an additional study, Harmsen et al. reviewed 29 shoulders from 26 patients undergoing RTSA with a "shaped" humeral head autograft. All patients had primary glenohumeral osteoarthritis with significant posterior glenoid bone loss and an intact rotator cuff. Mean follow-up time was 2.9 years. Mean preoperative glenohumeral retroversion angle was 32.3 degrees (range: 17-52 degrees). All autografts were found to incorporate without radiographic evidence of loosening. Patient-reported outcome measures, range of motion, and strength were all significantly improved postoperatively.[11]

These studies used long-post metaglene components, similar to the BIO-RSA technique. In contrast, our construct was designed using a central compression screw. Additionally, both studies cited used Grammont humeral components with a 155 degree neck shaft angle. As previously described, this valgus neck shaft angle has been associated with scapular notching. Thus, the rate of scapular notching in our construct (6%) was considerably less than Harmsen (28%) and Tashjian (64%).[11,22]

RTSA has revolutionized the treatment of the rotator-cuff deficient shoulder, however the indications for the procedure have vastly increased. For patients with severe bone loss to the glenoid, with or without concomitant rotator cuff arthropathy, RTSA with autograft humeral head bone augmentation seems to be a viable surgical option. Even in cases with significant subluxation of the humeral head, correction of inclination angle >30 degrees and retroversion angle >40 degrees yields satisfactory outcomes without graft failure.[11,22] McFarland described the midterm results of rTSA without bone grafting for glenoid bone loss in 31 cases utilizing the same implant system in our study. Unlike our cohort, none of their cases were associated with rotator cuff deficiency. Rather, an anatomical glenoid component could not be utilized because of lack of fit or support by the native glenoid vault. They reported a 94% baseplate survival rate at 5 years, and a significantly higher rate of scapular notching than we observed in our sample (19% vs. 6%). Their methodology for normalization (lateralization) of the joint line relied on commercially available glenospheres after reaming the high side of the glenoid to restore glenoid version to a nonpathological state. We used autograft to restore the joint line and only added high lateral offset glenospheres if laxity or instability was encountered during trialing. Although both methods are proven viable at mid-term, we believe bone grafting should be considered as a first line of reconstruction when feasible, because removing native glenoid bone could lead to medialization of the joint line with subsequent inability to restore stability of the final construct using commercially available implants.[19]

A recent study investigated the utility of retroversion correction during rTSA on patient-reported outcomes and concluded that patients with postoperative retroversion >15 degrees had similar outcomes to those with <15 degrees of postoperative retroversion. The mean retroversion correction of both cohorts (1 degrees and 4 degrees) was similar to 3.7 degrees seen in our cohort. However, the range of correction we observed (−30 to 42 degrees) was significantly larger than the range reported by the authors (−8 to 10 degrees and −6 to 14 degrees). In addition, the range reported by the authors (−8 to 10 degrees and −6 to 14 degrees) was significantly less than the range we observed in our study (−30 to 42 degrees). While there may be utility in focusing on preservation of bone stock rather than aiming for a certain degree postoperative retroversion in patients with minimal to moderate alterations in preoperative version, we believe that patients with significant alterations in native alignment benefit from version corrective measures at the time of surgery.[5]

We observed considerable variation in preoperative glenoid morphology given the large range of retroversion (−32.0 to 40.0 degrees) and inclination (−12.0 to 25.0 degrees) angles. Thus, the mean preoperative retroversion and inclination of 10.6 degrees and 4.3 degrees respectively, represent averages of a wide distribution and likely are clinically insignificant. Additionally, we were surprised by the relatively large increase in external rotation postoperatively. There is a possibility that this could represent a post operative subscapularis tear in some patients allowing for increased external rotation, however performing a functional subscapularis repair was not a goal of this procedure and was not specifically assessed intraoperatively or postoperatively.

We studied whether medical comorbidities had any association with catastrophic failure or outcome. Compared against current or former smokers, nonsmokers were found to have a significant improvement in both forward flexion ($P = .04$) and external rotation ($P = .04$). It is possible that this relationship is related to

particular behaviors unique to patients and not reflective of the general population. We did not find any significant differences in functional or patient-reported outcomes when analyzing implant laterality in relation to a patient's dominant hand, diabetes status, history of a prior shoulder surgery, age, sex, or BMI.

While many of the patients included in this study were of advanced age, functional decline and deconditioning over the course of follow-up impacted our cumulative outcome measure analysis. Multiple patients became wheelchair bound or were placed in nursing homes in the years following their procedure. Other patients suffered from autoimmune arthritis of the hands and elbow. Additionally, one patient fell 6 years postoperatively leading to a scapular body fracture. The fracture healed, yet it caused her to lose a tremendous amount of function. Deconditioning has a negative impact on both objective range of motion measures, as well as DASH and SST scores, which assess activities of daily living (ADLs) to evaluate functional status. Additionally, 2 patients within the deceased cohort did not follow-up within 3 years of their date of death. Therefore, we cannot exclude the possibility of graft failure or re-operation at another institution. We believe this to be unlikely because we were able to review the electronic health records (EHRs) for these patients, as our health network uses a unified EHR, which did not indicate any post-operative shoulder problems or referral out of network for revision surgery.

A strength of our study was that it implemented strict inclusion criteria: patients must have had abnormal glenoid morphology as the majority of autograft studies draw conclusions from cohorts of patients with normal glenoid morphology and thus biomechanical considerations are different. Limitations of this study include its retrospective nature, small sample size, and variable follow-up after 2 years.

Conclusion

There is value in using the patient's humeral head as an autograft to restore glenoid bone stock and alignment in reverse total shoulder arthroplasty. It allows for a local graft source to be utilized thus avoiding potential comorbidity and complications associated with the use of alternative site autografts or allografts and has the advantage of nearly congruent fit within the defect. Even though this technique may add time, cost, and risk to the procedure, it appears to lead to excellent clinical outcomes and mid-term durability.

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References

1. Ascione F, Schiavone Panni A, Braile A, Corona K, Toro G, Capuano N, et al. Problems, complications, and reinterventions in 4893 onlay humeral lateralized reverse shoulder arthroplasties: a systematic review (part I-complications). J Orthop Traumatol 2021;22:27. https://doi.org/10.1186/s10195-021-00592-w.
2. Berton A, Longo UG, Gulotta LV, De Salvatore S, Piergentili I, Calabrese G, et al. Humeral and glenoid version in reverse total shoulder arthroplasty: a systematic review. J Clin Med 2022;11:7416. https://doi.org/10.3390/jcm11247416.
3. Boileau P, Morin-Salvo N, Gauci MO, Seeto BL, Chalmers PN, Holzer N, et al. Angled BIO-RSA (bony-increased offset-reverse shoulder arthroplasty): a solution for the management of glenoid bone loss and erosion. J Shoulder Elbow Surg 2017;26:2133-42. https://doi.org/10.1016/j.jse.2017.05.024.
4. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14:147S-61S. https://doi.org/10.1016/j.jse.2004.10.006.
5. Elmallah R, Swanson D, Le K, Kirsch J, Jawa A. Baseplate retroversion does not affect postoperative outcomes after reverse shoulder arthroplasty. J Shoulder Elbow Surg 2022;31:2082-8. https://doi.org/10.1016/j.jse.2022.02.043.
6. Erickson BJ, Frank RM, Harris JD, Mall N, Romeo AA. The influence of humeral head inclination in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2015;24:988-93. https://doi.org/10.1016/j.jse.2015.01.001.
7. Favre P, Sussmann PS, Gerber C. The effect of component positioning on intrinsic stability of the reverse shoulder arthroplasty. J Shoulder Elbow Surg 2010;19:550-6. https://doi.org/10.1016/j.jse.2009.11.044.
8. Grogan BF, Jobin CM. Evaluation of humeral and glenoid bone deformity in glenohumeral arthritis. In: Tashjian R, editor. Complex and revision shoulder arthroplasty. Cham: Springer; 2019. p. 3-13. https://doi.org/10.1007/978-3-030-02756-8_1.
9. Gulotta LV, Choi D, Marinello P, Knutson Z, Lipman J, Wright T, et al. Humeral component retroversion in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:1121-7. https://doi.org/10.1016/j.jse.2011.07.027.
10. Gupta A, Thussbas C, Koch M, Seebauer L. Management of glenoid bone defects with reverse shoulder arthroplasty-surgical technique and clinical outcomes. J Shoulder Elbow Surg 2018;27:853-62. https://doi.org/10.1016/j.jse.2017.10.004.
11. Harmsen S, Casagrande D, Norris T. "Shaped" humeral head autograft reverse shoulder arthroplasty: treatment for primary glenohumeral osteoarthritis with significant posterior glenoid bone loss (B2, B3, and C type). Orthopä 2017;46:1045-54. https://doi.org/10.1007/s00132-017-3497-0.
12. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand). Am J Ind Med 1996;29:602-8. https://doi.org/10.1002/(SICI)1097-0274(199606)29:6<602::AID-AJIM4>3.0.CO;2-L.
13. Jawa A, Shields MV. The evolution of the Walch classification for primary glenohumeral arthritis. J Am Acad Orthop Surg 2021;29:e635-45. https://doi.org/10.5435/JAAOS-D-20-00880.
14. Jones RB, Wright TW, Zuckerman JD. Reverse total shoulder arthroplasty with structural bone grafting of large glenoid defects. J Shoulder Elbow Surg 2016;25:1425-32. https://doi.org/10.1016/j.jse.2016.01.016.
15. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, et al. Scapular notching in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2008;17:925-35. https://doi.org/10.1016/j.jse.2008.02.010.
16. Levy JC, Everding NG, Gil CC Jr, Stephens S, Giveans MR. Speed of recovery after shoulder arthroplasty: a comparison of reverse and anatomic total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1872-81. https://doi.org/10.1016/j.jse.2014.04.014.
17. Lippitt SB, Harryman DT, Matsen FA. A practical tool for evaluating function: the simple shoulder test. In: Matsen III FA, Fu FH, Hawkins RJ, editors. The shoulder: A balance of mobility and stability. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1993. p. 501-18.
18. Malhas A, Rashid A, Copas D, Bale S, Trail I. Glenoid bone loss in primary and revision shoulder arthroplasty. Shoulder Elbow 2016;8:229-40. https://doi.org/10.1177/1758573216648601.
19. McFarland EG, Huri G, Hyun YS, Petersen SA, Srikumaran U. Reverse total shoulder arthroplasty without bone-grafting for severe glenoid bone loss in patients with osteoarthritis and intact rotator cuff. J Bone Joint Surg Am 2016;98:1801-7. https://doi.org/10.2106/JBJS.15.01181.
20. Sheth U, Saltzman M. Reverse total shoulder arthroplasty: implant design considerations. Curr Rev Musculoskelet Med 2019;12:554-61. https://doi.org/10.1007/s12178-019-09585-z.
21. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388-95. https://doi.org/10.1302/0301-620x.86b3.14024.
22. Tashjian RZ, Granger E, Chalmers PN. Structural glenoid grafting during primary reverse total shoulder arthroplasty using humeral head autograft. J Shoulder Elbow Surg 2018;27:e1-8. https://doi.org/10.1016/j.jse.2017.07.010.
23. 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.
24. Wright TW, Roche CP, Wright L, Flurin PH, Crosby LA, Zuckerman JD. Reverse shoulder arthroplasty augments for glenoid wear. Comparison of posterior augments to superior augments. Bull Hosp Jt Dis 2015;73:124-8.