Distal clavicle autograft for large glenoid defects during revision reverse total shoulder arthroplasty

Jordan A. Bauer, MD, Bradley Hawayek, MD, Gabrielle Hartman, BS, Lin Feng, MA, Thomas R. Duquin, MD*

Department of Orthopedics and Sports Medicine, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, SUNY, Buffalo, NY, USA

The number of patients receiving primary reverse total shoulder arthroplasty (rTSA) is increasing due to expanding indications and improving clinical outcomes.[9] Ultimately, this will lead to an increased incidence of revision rTSA cases, which introduces unique obstacles such as large glenoid defects.[40] Addressing severe glenoid bone loss can be a difficult challenge during primary or revision rTSA. Different glenoid morphologies significantly affect surgical factors and require thorough preoperative planning for rTSA.[14,25] These different factors affected by glenoid defects have been described by the Frankle classification and a newer classification by Kocsis et al which help predict the type and extent of glenoid reconstruction necessary based on glenoid bone loss and joint medialization.[14,25] There are multiple different techniques that have been described to manage glenoid defects in patients undergoing rTSA. These different options include bone grafting, augmented baseplates, patient-specific implants, bony-increased offset-reverse shoulder arthroplasty, and off-axis glenoid reaming.[3,5,8,15,18,23,26,32,35,37,38]

Although previous studies report that in primary rTSA there are fewer complications with augmented baseplates and off-axis reaming compared to bone grafts and eccentric reaming, structural bone grafts provide a unique advantage in the setting of patients with substantial glenoid bone loss.[15,18,21,23,26,32,38] In these cases, the use of standard baseplates alone is unable to achieve adequate glenoid fixation, resulting in baseplate instability and scapular notching.[6,12,16,17,19,20,22,24,31,33,39,42] Similarly, patients undergoing revision rTSA are likely to have complex and severe bone loss that is unable to be addressed with only an augmented baseplate.[33,36] Additionally, the use of bony-increased offset-reverse shoulder arthroplasty or humeral head autograft is not available in revision setting. Thus, a readily available bone graft with reliable and reproducible results is necessary during surgery.

Multiple structural and nonstructural bone grafting options exist to address severe glenoid bone loss during revision rTSA. Nonstructural grafts include options such as allograft bone chips, demineralized bone matrix, and proprietary grafting to address contained glenoid defects involving less than 50% of the vault.[4,27,39,41] Although nonstructural bone grafting has no donor site morbidity, in cases with large glenoid defects, a major disadvantage is a high rate of glenoid implant loosening secondary to poor fixation to the morselized graft used.[4,39] Thus, nonstructural grafts are thought to be more effective and are mainly reserved for smaller contained glenoid defects.[10] Conversely, structural autograft options include from the iliac crest[28-30] and distal clavicle,[36] or alternatively, structural allografts from the femoral head and neck.[2,7,24,34] The source of autologous iliac bone grafts is beneficial since it is native to the patient's cellular biology; however, a major disadvantage of harvesting this graft is donor site morbidity.[13] The distal clavicle is an advantageous source for a structural autograft during revision rTSA. Distal clavicle autografting is a new technique in the setting of revision rTSA to address severe glenoid bone loss involving over two-thirds of the existing glenoid surface area that is more cost-effective and has lower morbidity due to its close proximity during surgery.[1,36]

At this current time, there are very limited data on distal clavicle autografting in patients with severe glenoid bone loss undergoing revision rTSA. The goal of this study is to describe the surgical technique of revision rTSA with a distal clavicle autograft for severe glenoid bone loss and retrospectively examine the short-term clinical, patient-reported, and radiographic outcomes. We hypothesize that there will be a statistically significant improvement in clinical, patient-reported, and radiographic outcomes.

Methods

Patient population

This retrospective non-randomized study was reviewed and approved by the University at Buffalo Institutional Review Board. Electronic medical records were queried and 9 patients who underwent revision rTSA and received a distal clavicle autograft from January 2013 through January 2022 were identified and included in this study. All participants underwent the procedure at a single site and the operation was performed by a single surgeon. Inclusion criteria were as follows: (1) age between 18 and 100 years old; (2) underwent revision surgery in the specified time frame; and (3) had at a minimum of 12 months of follow-up.

Surgical technique

Procedure

All revision reverse shoulder replacements in this study were performed by a single fellowship-trained surgeon. Preoperative planning was performed using plain radiographs and computed tomography (CT) imaging in all cases (Fig. 1). Three-dimensional planning software (Zimmer-Biomet, Warsaw, IN) was used to create reconstructions of each patient's scapula to identify osseous defects and optimize implant position and orientation. The patient is placed in the beach chair with the head elevated 60 degrees. The previous surgical incision is utilized if in an acceptable location, and prior scar is excised. The deltopectoral interval is developed and careful mobilization of the deltoid is performed, releasing scar tissue in the subdeltoid and subacromial spaces while protecting the axillary nerve. The rotator cuff is preserved if still present and any sutures or hardware from prior subscapularis tendon repair are removed. The subscapularis is released using a peel if still intact. Next, the soft tissues are released from the medial calcar of the humerus, the humeral component is dislocated, and the humeral bearing surface is disengaged from the stem with a taper tuning fork. The humeral component is inspected at this point for any evidence of damage or loosening. If the component is convertible to rTSA, and it is well positioned without evidence of loosening, the humeral stem is retained.

The glenoid is then exposed by the release of soft tissue and capsular attachment starting anteriorly and carried around the inferior margin of the glenoid medially to the lateral pillar of the scapula. Careful dissection is performed to avoid injury to the axillary nerve, especially at the anterior-inferior aspect of the glenoid. Posterior capsular release is performed in a similar fashion until a 360-degree release of the capsule around the glenoid is complete. The glenoid implant is removed and a thorough débridement of all nonviable tissue and foreign material is performed (Fig. 2, A and B). After extensive débridement, the joint is irrigated with pulsatile lavage using saline and an antiseptic irrigation fluid.

Attention is then directed to glenoid reimplantation. The glenoid defect is assessed to determine the type and extent of bone loss.[1] Distal clavicle bone grafting is utilized in cases of severe cavitary bone loss without loss of containment and in cases of cavitary bone loss with minimal loss of containment. If the defect involves the glenoid vault and over one-third of the glenoid rim (moderate to severe combined glenoid defect per Antuna et al), the bone loss was determined to be greater than what can be treated with a distal clavicle autograft and an iliac crest autograft, metal augment, or patient-specific implant is then utilized.[1] In appropriate cases for distal clavicle bone graft, the deltopectoral incision is extended superiorly over the distal clavicle (Fig. 2, C). The interval between trapezius and deltoid is identified and subperiosteal dissection is performed reflecting the trapezius posterior and the deltoid anterior exposing the distal clavicle and acromioclavicular joint. The depth of the glenoid defect is assessed to determine the amount of distal clavicle needed. The coracoclavicular ligaments need to be preserved which allows for a graft up to 15 mm in most cases. The graft is harvested from the distal clavicle using a microsagittal saw with care to preserve the coracoclavicular ligaments and acromioclavicular joint capsule. The graft is set aside and the remaining acromioclavicular space is irrigated and hemostasis is obtained. The capsule and deltotrapezial fascia are repaired with #2 vicryl suture.

Glenoid preparation for the baseplate is performed using cannulated instrumentation over a guide pin placed in bicortical fashion down the center of the glenoid vault (Fig. 2, D). The preferred target for reverse baseplate position is low on the glenoid with neutral version and 5-10° of inferior tilt. The glenoid is initially reamed to allow contact of the baseplate with native glenoid bone. Ideally, at least 50% surface contact with native glenoid is obtained. The remaining glenoid defect is then sized, and the distal clavicle bone graft is fashioned to match the associated glenoid defect (Fig. 2, E and F). The appropriate orientation of the graft for each patient included rotating it 90 degrees so the anterior to posterior dimension of the distal clavicle fills the superior to inferior glenoid defect and the superior to inferior dimension of the distal clavicle fills the anterior to posterior glenoid defect. The graft is stripped of all soft tissue, partially decorticated with a burr, slightly oversized to obtain a secure press fit, and then impacted into place (Fig. 2, G). Fixation of the graft can be obtained with screws through the reverse baseplate or with additional screws depending on the size of the bone graft. The screw position and number of screws are dependent on the pattern of bone loss and the size of the bone graft. After stable fixation of the graft is achieved, the glenoid reaming is performed to prepare the bone graft to accept the appropriate implant. Trial implants are available to determine if a standard or augmented component is needed to address any additional bone deficiency. The use of augments can be helpful in cases of bone defects that involve the cortical rim of the glenoid. For patients who received an augmented baseplate, the implant used in this study is a half wedge with three different sizes: small (10°), medium (20°), and large (30°). There are many options for baseplate fixation in rTSA. Our preference in cases with distal clavicle bone graft is to use an implant that has a central boss to resist shear forces and a central compression screw for fixation of the baseplate and compression of the bone graft. (Fig. 2, H). The appropriate glenosphere size, lateral and inferior offset are selected by the surgeon to optimize range of motion (ROM) and prevent implant impingement. Lateralization of the glenosphere is typically avoided to reduce the biomechanical torque and shear forces on the baseplate and bone graft.

After baseplate implantation, humeral trialing is performed to obtain appropriate tensioning. The humeral preparation and implants are the same for all patients, utilizing a proximally porous-coated press fit stem and an onlay humeral component [Zimmer Biomet Comprehensive Mini humeral stem; Warsaw, IN, USA]. The final humeral implants are inserted, and repair of the subscapularis is performed when possible. A drain is placed deep to the deltoid and the deltopectoral interval is closed with absorbable sutures.
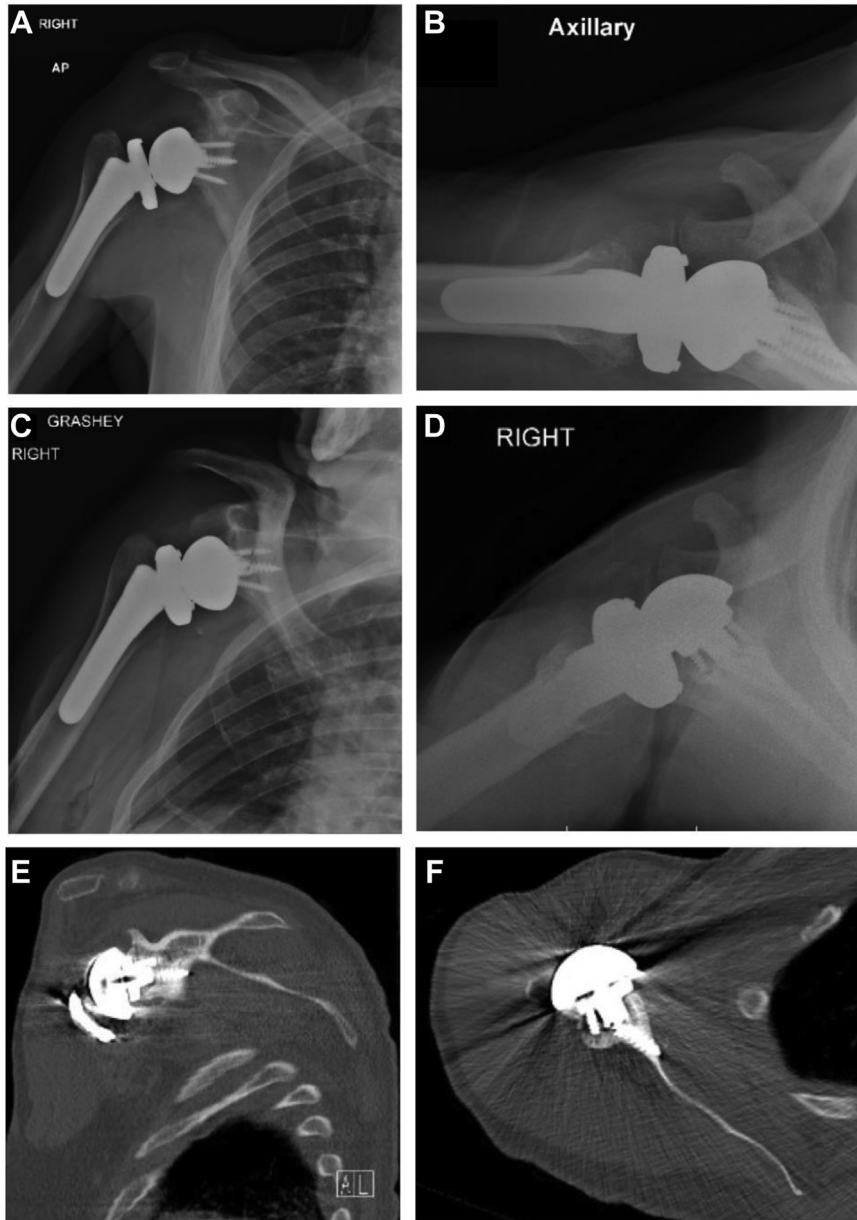
Figure 1 The patient in Fig. 1 initially underwent primary rTSA for right shoulder osteoarthritis with advanced posterior glenoid wear and calcification with partial tearing of the rotator cuff tendons. Primary implantation included 8 mm humeral head autograft for excessive posterior glenoid wear, 14 × 83 mm humeral stem, standard humeral tray with +3 retentive polyethylene insert, 25 mm glenosphere baseplate with 6.5 × 30 mm central non-locking screw and 4 peripheral locking screws (15, 20, 30, 35 mm), and a 41 mm standard offset glenosphere with Versa-Dial adapter set to C. Postoperatively at 6 months, anteroposterior (**A**) and axillary (**B**) radiographs showed intact glenoid and humeral implants. The patient had excellent ROM and strength. 4 years after primary rTSA, the patient presented with right shoulder pain after falling directly onto their shoulder 1 month prior to evaluation. (**C**) X-ray in the Grashey view of the right shoulder. (**D**) X-ray in the axillary view of the right shoulder. (**E**) Coronal CT of glenohumeral joint. (**F**) Axillary CT of glenohumeral joint. Imaging demonstrated failed right rTSA and right anterior glenoid fracture with failure of the glenoid baseplate. *rTSA*, reverse total shoulder arthroplasty; *ROM*, range of motion; *CT*, computed tomography.

Postoperative plan

Postoperatively, patients were non-weight-bearing. One day after the procedure, patients begin a therapy program with pendulum exercises, passive ROM exercises of the shoulder, and active elbow, wrist, and hand exercises. The patient is given an immobilizer to wear during the first 6 weeks after surgery; the immobilizer can be removed for hygiene activities and light below-shoulder-level activity as pain allows. After 6 weeks, the immobilizer is discontinued, and patients are allowed to use the arm for light daily activity. Full-weight-bearing activity is permitted at 3 months after surgery.

Postoperative outcomes

Patient records and radiographs were reviewed. Radiographic measurements were independently performed by three reviewers including the primary orthopedic surgeon involved in the study and two orthopedic surgery residents. Any discrepancies were reviewed again by the primary surgeon for final assessment. Patients were scheduled for 2-week, 6-week, 3-month, 6-month, 1-year, and 2-year clinical and radiographic follow-up. Clinical and radiographic survivorship of components was evaluated through chart review and examination of postoperative radiographs (Fig. 3) for any evidence of lucent lines or component failure. Functional outcomes
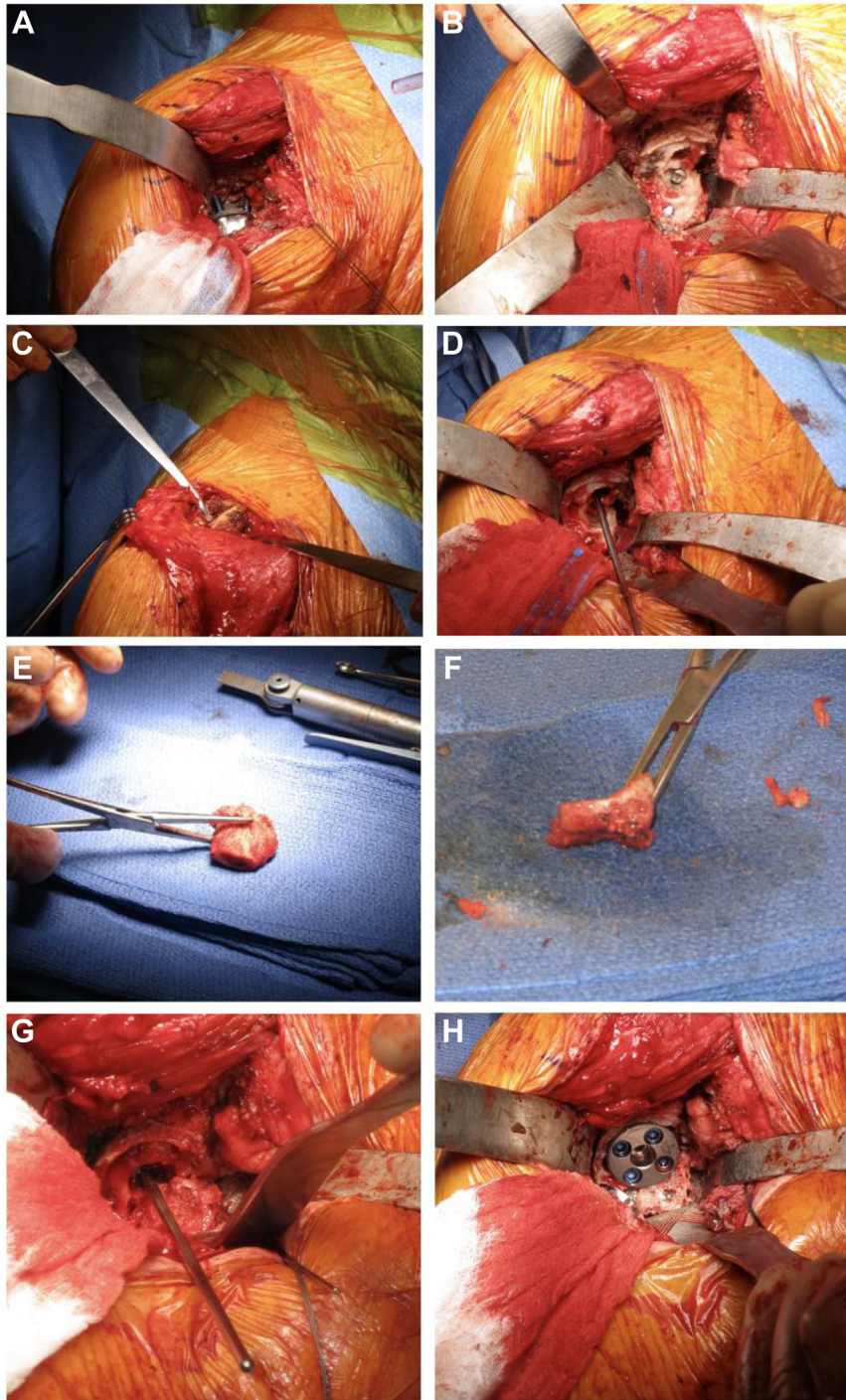
Figure 2 82-year-old patient undergoing revision reverse total shoulder arthroplasty (rTSA) with distal clavicle autografting for a large anterior glenoid defect. Revision surgery was indicated for failed right rTSA and right anterior glenoid fracture with failure of the glenoid baseplate. All patients received a deltopectoral approach. (**A**) Identification of glenoid components. (**B**) Visualization of broken screws fixed into the glenoid. (**C**) Superior extension of deltopectoral incision with exposure of distal clavicle. (**D**) Glenoid surface preparation with cannulated instrumentation using a central guide pin. (**E-F**) Resected distal clavicle autograft contoured to match anterior glenoid defect. (**G**) Placement and impaction of distal clavicle autograft, later fixed to the glenoid with a 3.0 mm screw. (**H**) Glenoid baseplate fixed with central 6.5mm central non-locking screw and 4 peripheral locking screws.

were evaluated at follow-up clinical evaluations (Table I) and complications were recorded. All patients were followed for a minimum of two years postoperatively.

Results

From January 2013 to January 2022, a total of 9 revision rTSA surgeries with distal clavicle autografts were performed. All patients had clinical and radiographic follow-up at the two-year mark. Thus, 9 surgeries are included for review. Groupwise demographics are presented for the patients included in Table II. Preoperative and surgical characteristics are presented in Table III. There were no intraoperative complications.

Of the 9 patients who underwent revision rTSA with a distal clavicle autograft, 8 patients (88.9%) were found to have survivorship of the implants free from loosening or revision at two years.
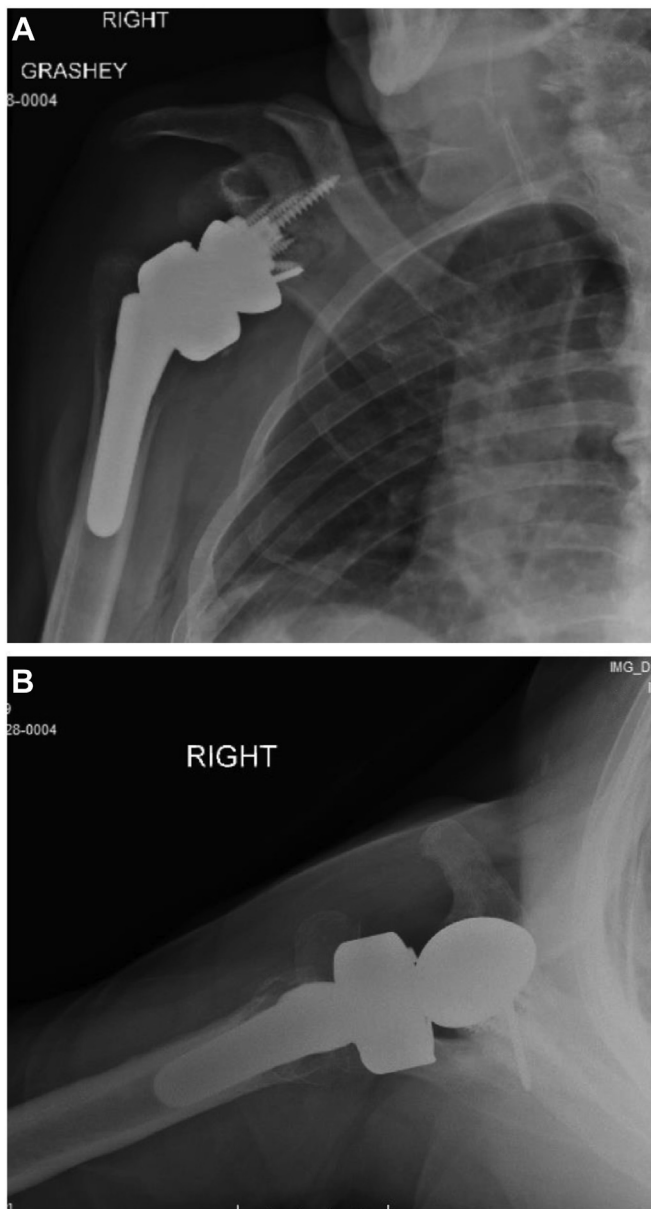
Figure 3 Postoperative Grashey (**A**) and axillary (**B**) radiographs of the same patient in Figs. 1 and 2. Revision rTSA implantation included distal clavicle autograft fixed with a 3.0 mm screw, +10 humeral tray, +3 retentive E1 polyethylene liner, 25 mm glenosphere baseplate with 6.5 × 40 mm central non-locking screw and 4 peripheral locking screws (15, 20, 20, 30 mm), and a 41 mm standard offset glenosphere with Versa-Dial adapter set to E. The humeral stem in the primary surgery was not removed and only the humeral tray and liner were replaced. Glenoid and humeral components remained well fixed at follow-up. *rTSA*, reverse total shoulder arthroplasty.

Radiographs for these 8 patients demonstrated adequate graft incorporation and well-fixed components with no evidence of loosening and no scapular notching. One patient did develop hardware failure of his glenosphere and glenoid baseplate at two years postoperatively following a fall that required revision surgery. He was also noted to have graft osteolysis and resorption at that time.

Retrospectively, the anterior to posterior dimensions of each patient's distal clavicle and glenoid rim were measured using axial cut CT scans, and the superior to inferior dimensions were measured using coronal cut CT scans and compared (Fig. 4, Table IV). The superior to inferior dimension of the distal clavicle was similar to the anterior to posterior dimension of the glenoid vault (12.4 ± 0.7 vs. 16.6 ± 0.5), and the anterior to posterior dimension of the distal clavicle was just slightly smaller than the superior to inferior dimension of the glenoid (23.1mm ± 1.1 mm vs. 24.2mm ± 1.6mm).

Clinical outcomes are presented in Table I. At an average follow-up of 22.3 ± 5.0 months, active forward flexion and abduction were significantly improved ($P < .05$), and there was no significant change in external rotation. Patient-reported measures revealed improvements at 26.9 ± 10.2 months postoperatively, with significantly improved scores ($P < .05$) for Quick Disabilities of Arm, Shoulder and Hand (QuickDASH). There were nonsignificant improvements in visual analog scale (VAS) function, single assessment numeric evaluation (SANE) score, and American Shoulder and Elbow Surgeons (ASES) score, with no improvement in VAS pain.

Discussion

Revision rTSA can be a technically cumbersome surgery due to soft tissue scaring, implant removal, and significant bone loss. Historically, in cases where severe glenoid bone deficiency requires grafting, there are limited options during revision surgery such as iliac crest autografts and other allograft options.[2,7,24,28-30,34] However, these choices have disadvantages related to patient morbidity, longer time to union, and infection.[11,13,36] In this report, we describe a technique to harvest the distal clavicle autograft and incorporate it into the glenoid to fill large defects during revision rTSA. We feel that this graft is best suited for cases of severe cavitary glenoid defects without loss of containment and cavitary glenoid defects with minimal loss of containment.[14,25] Our experience demonstrates that a distal clavicle autograft is a safe and reproducible procedure with low morbidity that adequately addresses severe glenoid defects in revision rTSA.

Eight of 9 patients included in this study demonstrated excellent clinical and radiographic outcomes observed at follow-up. Among these 8 patients, each humeral stem and glenoid baseplate were well fixed without lucent lines, and the graft appeared to have incorporated appropriately. No patients were overserved to have radiographic or clinical signs of iatrogenic clavicular elevation secondary to coracoclavicular diastasis, which was reported in one patient of a prior study.[36]

One patient did experience hardware failure of his glenosphere and glenoid baseplate following a fall at approximately two years postoperatively. Prior to this patient's injury, he was progressing well at his 6-month postoperative evaluation. Radiographically, the glenoid baseplate and humeral stem were stable and well aligned without evidence of implant loosening or surrounding lucency. The graft remained in the appropriate position without signs of significant osteolysis or resorption. Furthermore, the patient reported a VAS pain score of 0, VAS function of 8, QuickDASH of 9.09, SANE of 100, and ASES of 96 at 6-month follow-up with a forward flexion of 150 degrees, abduction of 150 degrees, external rotation of 45 degrees, and 5/5 strength in deltoids, biceps, and triceps and 4/5 strength in his subscapularis. Subsequently, the patient was not present for his 1-year follow-up evaluation and sustained an acute periprosthetic proximal humerus fracture near the time of his 2-year follow-up. Osteolysis and resorption of the graft were also noted at that time, likely indicating incomplete graft incorporation and healing. This patient ultimately underwent revision surgery and was treated with conversion to hemiarthroplasty. Of note, this patient was found to have a small defect of the posterior wall of the glenoid in addition to the central cavitary defect at the time of the primary revision surgery. This may put patients at increased risk of graft nonunion secondary to loss of containment and lower stability of the graft fixation on the native glenoid.

Table I
Clinical outcomes.

Assessment	Patient-reported scores (mean ± SD)		P value	Power
	Preoperative	Postoperative*		
Shoulder pain (VAS range 0-10)	5.0 ± 0.8	4.8 ± 2.3*	.377	0.08
Shoulder function (VAS range 0-10)	4.3 ± 1.7	5.4 ± 2.3*	.500	0.25
QuickDASH	52.3 ± 1.9	38.2 ± 14.6*	**.027**	0.77
SANE	35.6 ± 4.5	39.6 ± 15.1*	.092	0.16
ASES shoulder (surgery side)	41.60 ± 21.6	61.00 ± 8.0*	.250	0.68
Active ROM				
Forward flexion	85 ± 25	150 ± 25[†]	**.026**	0.99
Abduction	80 ± 20	140 ± 30[†]	**.026**	0.99
External rotation @ 0°	50 ± 20	40 ± 25[†]	.190	0.19
Muscle strength				
Deltoid	5 ± 0.5	5 ± 0.3[†]	.211	0.05
Subscapularis	3 ± 0.5	5 ± 0.5[†]	**.001**	1.00
Biceps	5 ± 0.0	5 ± 0.0[†]	>.999	-
Triceps	5 ± 0.0	5 ± 0.0[†]	>.999	-

SD, standard deviation; VAS, visual analog scale; QuickDASH, Quick Disabilities of Arm, Shoulder and Hand; SANE, single assessment numeric evaluation; ASES, American Shoulder and Elbow Surgeons; ROM, range of motion.
Bold values were considered significant if P < .05.
  *Time since surgery (mean ± SD) was 26.9 ± 10.2 months.
  [†]Time since surgery (mean ± SD) was 22.3 ± 5.0 months.

Table II
Groupwise demographics (n = 9).

Characteristic	Value
Age (y) (mean ± SD)	77.9 ± 9.9
Sex (%)	
Male	10%
Female	90%
BMI (in kgm^{-2}) (mean ± SD)	29.9 ± 5.4
Tobacco use (n)	
Active smokers	0
Past smokers	2
No smoking history	7
Alcohol use (n)	
No use	3
Rare/Social	6
Regular	0
Medical history (%)	
Cardiovascular disease	56%
Gastrointestinal	44%
Endocrine	43%
Genitourinary/Renal	11%
Respiratory	11%
Autoimmune	11%

SD, standard deviation; BMI, body mass index.

Table III
Preoperative and surgical characteristics.

Characteristic	Value
Operative side (n)	
Right	6
Left	3
Primary surgery (n)	
Anatomic TSA	4
Reverse TSA	5
Indication for primary surgery (n)	
Primary osteoarthritis	5
Rotator cuff arthropathy	4
Revision surgery (n)	
Reverse TSA + distal clavicle autograft	9
Indication for revision surgery (n)	
Instability arthroplasty	5*
Acute fracture	2
Rotator cuff tear	2
Nonunion of previous fracture	1*
Baseplate size (n)	
Mini (25 mm) - non-augment	2
Small augment	4
Medium augment	2
Large augment	1
Augment location (n)	
Superior	4
Superoposterior	2
Inferior	1
Intraoperative complications (n)	0

TSA, total shoulder arthroplasty.
  *One patient had a nonunion of a previous fracture with instability arthroplasty.

Retrospectively it was felt that the dimensions of the distal clavicle typically matched the glenoid defect when rotating the distal clavicle 90 degrees so that the anterior to posterior dimension of the distal clavicle filled the superior to inferior glenoid defect and the superior to inferior dimension of the distal clavicle filled the anterior to posterior glenoid defect. Each patient's distal clavicle and glenoid vault defect dimensions were measured using preoperative CT scans (Fig. 4). Our results show the areas of the distal clavicle and glenoid surface match relatively well. When comparing the anterior to posterior dimension of the distal clavicle and the superior to inferior dimension of the glenoid vault defect, we measured about a 1:1 ratio (0.96 ± 0.1), and the superior to inferior dimension of the distal clavicle and anterior to posterior dimension of the glenoid vault defect had about a 3:4 relationship (0.76 ± 0.1) (Table III). Practically speaking, when the distal clavicle graft is rotated 90 degrees, the dimensions of the graft match the glenoid defect very well. Further research is needed to evaluate how closely the dimensions of the distal clavicle match the glenoid. This information may be helpful when planning for revision rTSA.

Postoperatively, active ROM significantly improved from 85 to 150 degrees of forward flexion and from 80 to 140 degrees of abduction. However, there was no significant change in external rotation at the final follow-up. Overall, these results compare favorably to the reported outcomes of recent literature. One study examining 16 patients with severe glenoid defects undergoing revision rTSA who received a distal clavicle autograft demonstrated significant improvement in forward flexion from 77 degrees to 123 degrees without significant improvement in external rotation over 1 year after surgery.[36]

Patient-reported outcome scores also improved from preoperative values in this study, except for VAS pain score, which remained to be scored around 5 out of 10 at follow-up. VAS
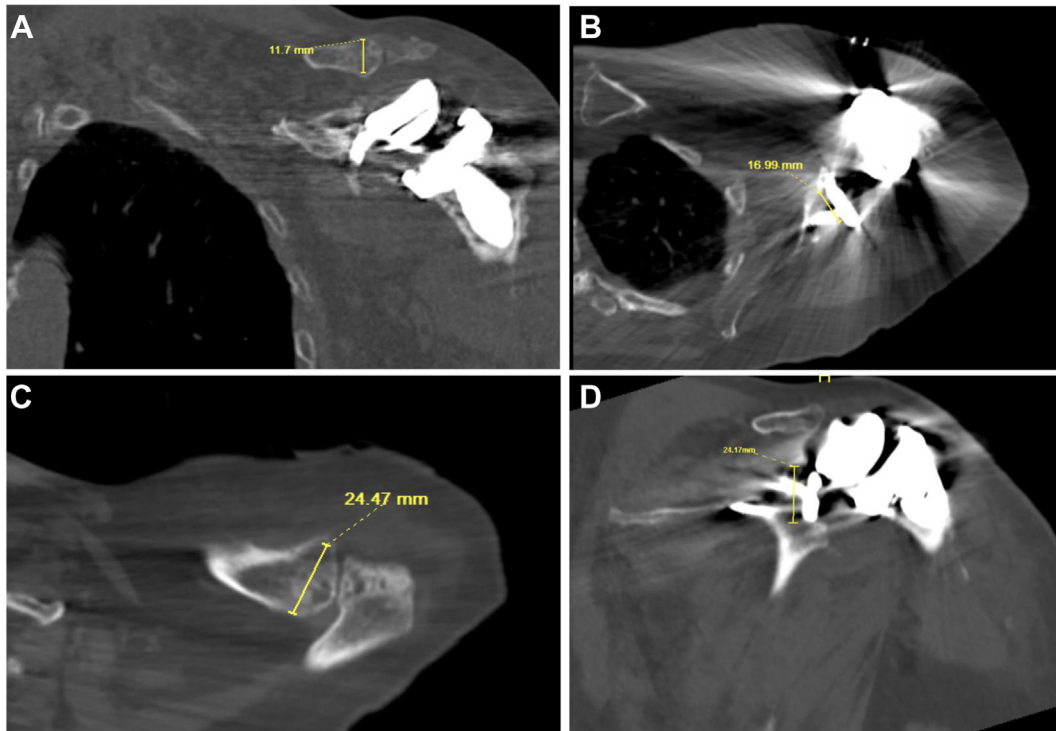
Figure 4 (**A**) Superior to inferior measurement of the distal clavicle taken in the coronal plane in the cut of largest height. (**B**) Anterior to posterior measurements of the glenoid vault defect measured in the axial plane. (**C**) Anterior to posterior measurements of the clavicle measured in the axial plane. (**D**) Superior to inferior measurement of the glenoid vault defect measured in the coronal plane. Rotating the distal clavicle graft 90 degrees allows the superior to inferior dimension of the distal clavicle to fill the anterior to posterior dimension of the glenoid vault defect (**A** and **B**) and the anterior to posterior dimension of the distal clavicle to fill the superior to inferior dimension of the glenoid vault defect (**C** and **D**).

function, SANE, and ASES scores were each observed to have a nonsignificant improvement at follow-up, and QuickDASH improved significantly. These results are similar to prior literature examining a similar population of patients that showed a significant improvement in ASES score from 35.8 to 67.8[36]. However, the VAS pain score was observed to have a nonsignificant improvement from 5.9 to 2.0 at a mean follow-up of 25 months.[36] Due to the small cohorts and low powers of the previous study referenced and our own study, it is difficult to confidently compare patient reported and clinical outcomes.

Despite successful results, there are limitations to this study, including a small patient population, lack of a control group, and short-term follow-up. Thus, future studies are required to obtain more data from larger cohorts with longer-term follow-up to confirm the benefit and reproducibility of this new autograft technique in the setting of revision rTSA with large glenoid defects. An additional direction for future research is the comparison of outcomes among patients who have undergone revision rTSA with distal clavicle autograft with other procedures to address glenoid bone loss in a revision setting.

Conclusion

The use of an ipsilateral distal clavicle autograft to address severe glenoid bone loss in revision rTSA results in good clinical and radiographic outcomes at two-year follow-up when used in patients who have severe cavitary glenoid defects without loss of containment or cavitary glenoid defects with minimal loss of containment. This new autograft technique is beneficial during revision rTSA because it is conveniently close, only requires a small extension of a deltopectoral incision superiorly, has low donor site

Table IV
Comparison of glenoid defect and distal clavicle dimensions on CT imaging.*

Description	Value
Glenoid defect and distal clavicle dimensions (mean ± SD)	
Distal clavicle AP dimension (mm)	23.1 ± 1.1
Glenoid SI dimension (mm)	24.2 ± 1.6
Clavicle (AP)/Glenoid (SI) ratio	0.96 ± 0.1
Distal clavicle SI dimension (mm)	12.4 ± 0.7
Glenoid AP dimension (mm)	16.6 ± 0.5
Clavicle (SI)/Glenoid (AP) ratio	0.76 ± 0.1

CT, computed tomography; *AP*, anterior to posterior; *SI*, superior to inferior; *SD*, standard deviation.
*Dimensions based on axial and coronal CT imaging prior to primary surgery.

morbidity compared to other autograft harvests, has the biologic advantage as opposed to allograft, is cost-effective, and the dimensions of the distal clavicle match the dimensions of contained glenoid vault defects and glenoid defects with minimal loss of containment very well.

Disclaimers:

References

1. Antuna SA, Sperling JW, Cofield RH, Rowland CM. Glenoid revision surgery after total shoulder arthroplasty. J Shoulder Elbow Surg 2001;10:217-24.
2. Bateman E, Donald SM. Reconstruction of massive uncontained glenoid defects using a combined autograft-allograft construct with reverse shoulder arthroplasty: preliminary results. J Shoulder Elbow Surg 2012;21:925-34. https://doi.org/10.1016/j.jse.2011.07.009.
3. Bauer JA, Slowinski JJ, Feng L, Sperling JW, Duquin TR. Optimizing glenoid bone preservation in reverse total shoulder arthroplasty using augmented baseplates. JSES Rev Rep Tech 2022;3:77-82. https://doi.org/10.1016/j.xrrt.2022.10.008.
4. Bitzer A, Rojas J, Patten IS, Joseph J, McFarland EG. Incidence and risk factors for aseptic baseplate loosening of reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:2145-52. https://doi.org/10.1016/j.jse.2018.05.034.
5. 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.
6. Chalmers PN, Boileau P, Romeo AA, Tashjian RZ. Revision reverse shoulder arthroplasty. J Am Acad Orthop Surg 2019;27:426-36. https://doi.org/10.5435/JAAOS-D-17-00535.
7. De Biase CF, Ziveri G, De Caro F, Roberts N, Delcogliano M. Reverse shoulder arthroplasty using a "L" shaped allograft for glenoid reconstruction in a patient with massive glenoid bone loss: case report. Eur Rev Med Pharmacol Sci 2014;18(1 Suppl):44-9.
8. Debeer P, Berghs B, Pouliart N, Van den Bogaert G, Verhaegen F, Nijs S. Treatment of severe glenoid deficiencies in reverse shoulder arthroplasty: the glenius glenoid reconstruction system experience. J Shoulder Elbow Surg 2019;28:1601-8. https://doi.org/10.1016/j.jse.2018.11.061.
9. Familiari F, Rojas J, Nedim Doral M, Huri G, McFarland EG. Reverse total shoulder arthroplasty. EFORT Open Rev 2018;3:58-69. https://doi.org/10.1302/2058-5241.3.17004.
10. Fliegel BE, DeBernardis D, Ford E, Favorito P, McMillan S. Biologic graft augmentation for glenoid bone loss in conversion of failed anatomic to reverse shoulder arthroplasty: a systematic review. JSES Rev Rep Tech 2022;3:44-8. https://doi.org/10.1016/j.xrrt.2022.10.005.
11. Flierl MA, Smith WR, Mauffrey C, Irgit K, Williams AE, Ross E, et al. Outcomes and complication rates of different bone grafting modalities in long bone fracture nonunions: a retrospective cohort study in 182 patients. J Orthop Surg Res 2013;8:33. https://doi.org/10.1186/1749-799X-8-33.
12. Formaini NT, Everding NG, Levy JC, Santoni BG, Nayak AN, Wilson C, et al. The effect of glenoid bone loss on reverse shoulder arthroplasty baseplate fixation. J Shoulder Elbow Surg 2015;24:e312-9. https://doi.org/10.1016/j.jse.2015.05.045.
13. Fowler BL, Dall BE, Rowe DE. Complications associated with harvesting autogenous iliac bone graft. Am J Orthoped 1995;24:895-903.
14. Frankle MA, Teramoto A, Luo ZP, Levy JC, Pupello D. Glenoid morphology in reverse shoulder arthroplasty: classification and surgical implications. J Shoulder Elbow Surg 2009;18:874-85. https://doi.org/10.1016/j.jse.2009.02.013.
15. Friedman R, Stroud N, Glattke K, Flurin PH, Wright TW, Zuckerman JD, et al. The Impact of posterior wear on reverse shoulder glenoid fixation. Bull Hosp Jt Dis 2015;73(1 Suppl):S15-20.
16. Glenday J, Kontaxis A, Roche S, Sivarasu S. Effect of humeral tray placement on impingement-free range of motion and muscle moment arms in reverse shoulder arthroplasty. Clin Biomech 2019;62:136-43. https://doi.org/10.1016/j.clinbiomech.2019.02.002.
17. Gohlke F, Werner B, Wiese I. Glenoidrekonstruktion bei Wechseloperationen an der Schulter [Glenoid reconstruction in revision shoulder arthroplasty]. Operat Orthop Traumatol 2019;31:98-114. https://doi.org/10.1007/s00064-019-0594-8.
18. Gulotta LV, Grey SG, Flurin P-H, Wright TW, Zuckerman JD, Roche CP. Clinical Outcomes of Augmented rTSA glenoid baseplates. J Shoulder Elbow Surg 2020;29:e168-9. https://doi.org/10.1016/j.jse.2020.01.055.
19. Hasan SS, Levy JC, Leitze ZR, Kumar AG, Harter GD, Krupp RJ. Reverse shoulder prosthesis with a lateralized glenosphere: early results of a prospective multicenter study stratified by diagnosis. JSES 2019;3. https://doi.org/10.1177/2471549219844040.
20. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Jt Surg Am 2001;83:877-83.
21. Ho JC, Thakar O, Chan WW, Nicholson T, Williams GR, Namdari S. Early radiographic failure of reverse total shoulder arthroplasty with structural bone graft for glenoid bone loss. J Shoulder Elbow Surg 2020;29:550-60. https://doi.org/10.1016/j.jse.2019.07.03.
22. Hoffelner T, Moroder P, Auffarth A, Tauber M, Resch H. Outcomes after shoulder arthroplasty revision with glenoid reconstruction and bone grafting. Int Orthop 2014;38:775-82. https://doi.org/10.1007/s00264-013-2191-z.
23. Jones RB, Wright TW, Roche CP. Bone grafting the glenoid versus use of augmented glenoid baseplates with reverse shoulder arthroplasty. Bull Hosp Jt Dis 2015;73(Suppl 1):S129-35.
24. Klein SM, Dunning P, Mulieri P, Pupello D, Downes K, Frankle MA. Effects of acquired glenoid bone defects on surgical technique and clinical outcomes in reverse shoulder arthroplasty. J Bone Jt Surg Am 2010;92:1144-54. https://doi.org/10.2106/JBJS.I.00778.
25. Kocsis G, Thyagarajan DS, Fairbairn KJ, Wallace WA. A new classification of glenoid bone loss to help plan the implantation of a glenoid component before revision arthroplasty of the shoulder. Bone Joint J 2016;98-B:374-80. https://doi.org/10.1302/0301-620X.98B3.36664.
26. Lopiz Y, García-Fernández C, Arriaza A, Rizo B, Marcelo H, Marco F. Midterm outcomes of bone grafting in glenoid defects treated with reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1581-8. https://doi.org/10.1016/j.jse.2017.01.017.
27. Mahylis JM, Puzzitiello RN, Ho JC, Amini MH, Iannotti JP, Ricchetti ET. Comparison of radiographic and clinical outcomes of revision reverse total shoulder arthroplasty with structural versus nonstructural bone graft. J Shoulder Elbow Surg 2019;28:e1-9. https://doi.org/10.1016/j.jse.2018.06.026.
28. Melis B, Bonnevialle N, Neyton L, Lévigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Shoulder Elbow Surg 2012;21:342-9. https://doi.org/10.1016/j.jse.2011.05.021.
29. Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. J Bone Jt Surg Am 2013;95:1297-304. https://doi.org/10.2106/JBJS.L.00820.
30. Neyton L, Boileau P, Nové-Josserand L, Edwards TB, Walch G. Glenoid bone grafting with a reverse design prosthesis. J Shoulder Elbow Surg 2007;16(3 Suppl):S71-8. https://doi.org/10.1016/j.jse.2006.02.002.
31. Neyton L, Walch G, Nové-Josserand L, Edwards TB. Glenoid corticocancellous bone grafting after glenoid component removal in the treatment of glenoid loosening. J Shoulder Elbow Surg 2006;15:173-9. https://doi.org/10.1016/j.jse.2005.07.010.
32. Roche C, Flurin PH, Grey S, Wright T, Zucherman J, Jones R. Clinical outcome comparison of augmented glenoid components vs glenoid bone grafting with reverse total shoulder arthroplasty. Orthopaedic Proceedings 2016;98-B(SUPP_10):9. https://doi.org/10.1302/1358-992x.98bsupp_10.lsta2015-009.
33. Scalise JJ, Iannotti JP. Bone grafting severe glenoid defects in revision shoulder arthroplasty. Clin Orthop Relat Res 2008;466:139-45. https://doi.org/10.1007/s11999-007-0065-7.
34. Seidl AJ, Williams GR, Boileau P. Challenges in reverse shoulder arthroplasty: addressing glenoid bone loss. Orthopedics 2016;39:14-23. https://doi.org/10.3928/01477447-20160111-01.
35. Slowinski JJ, Bauer JA, Feng L, Schoch N, Sperling JW, Duquin TR. CT-based 3D modeling of glenoid bone preservation with augmented baseplates. Semin Arthroplasty: JSES 2022;33:162-8. https://doi.org/10.1053/j.sart.2022.09.005.
36. Taylor JR, Schrumpf MA, Shea KE, Kelly JD 2nd. Distal clavicle autograft augmentation for glenoid bone loss in revision shoulder arthroplasty: results and technique. J Shoulder Elbow Surg 2020;29:e386-93. https://doi.org/10.1016/j.jse.2020.05.009.
37. Villatte G, Muller AS, Pereira B, Mulliez A, Reilly P, Emery R. Use of Patient-Specific Instrumentation (PSI) for glenoid component positioning in shoulder arthroplasty. A systematic review and meta-analysis. PLoS One 2018;13: e0201759. https://doi.org/10.1371/journal.pone.0201759.
38. Virk M, Yip M, Liuzza L, Abdelshahed M, Paoli A, Grey S, et al. Clinical and radiographic outcomes with a posteriorly augmented glenoid for Walch B2, B3, and C glenoids in reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2020;29:e196-204. https://doi.org/10.1016/j.jse.2019.09.031.
39. Wagner E, Houdek MT, Griffith T, Elhassan BT, Sanchez-Sotelo J, Sperling JW, et al. Glenoid bone-grafting in revision to a reverse total shoulder arthroplasty. J Bone Jt Surg Am 2015;97:1653-60. https://doi.org/10.2106/JBJS.N.00732.
40. Wagner ER, Houdek MT, Schleck CD, Harmsen WS, Sánchez-Sotelo J, Cofield R, et al. The role age plays in the outcomes and complications of shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1573-80. https://doi.org/10.1016/j.jse.2017.01.020.
41. Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:514-22. https://doi.org/10.1016/j.jse.2011.03.006.
42. Werner BS, Böhm D, Abdelkawi A, Gohlke F. Glenoid bone grafting in reverse shoulder arthroplasty for long-standing anterior shoulder dislocation. J Shoulder Elbow Surg 2014;23:1655-61. https://doi.org/10.1016/j.jse.2014.02.017.