J Shoulder Elbow Surg (2021) 30, 258–264

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

Neuroapraxia and early complications after reverse shoulder arthroplasty with glenoid bone grafting

Eric R. Wagner, MD[a,*], Andres R. Muniz, MD[b], Michelle J. Chang, BS[c], Tyler Hunt, BS[d], Kathryn M. Welp, MS[e], Jarret M. Woodmass, MD, FRCSC[f], Laurence Higgins, MD, MBA[g], Neal Chen, MD[b]

[a]*Department of Orthopedic Surgery, Emory University, Atlanta, GA, USA*
[b]*Department of Orthopedic Surgery, Massachusetts General Hospital, Boston, MA, USA*
[c]*Kansas City University of Medicine and Biosciences, Kansas City, MO, USA*
[d]*Lake Erie College of Osteopathic Medicine, Erie, PA, USA*
[e]*Tufts University School of Medicine, Boston, MA, USA*
[f]*PanAm Clinic, University of Manitoba, Winnipeg, MB, Canada*
[g]*King Edward Memorial Hospital, Hamilton, Bermuda*

Background: Bone grafting during primary reverse shoulder arthroplasty (RSA) is a technique used to restore poor glenoid bone, increase lateralization, and restore abnormal inclination or version. The purpose of this article is to analyze early outcomes of bone grafting during RSA, assessing the influence of technical and patient considerations.
Methods: In a 4.5-year time period, 137 RSAs with glenoid bone grafting were performed with a minimum 3 months' follow-up. The mean follow-up was 17 months (range, 3-38). The mean age was 71 years (range, 45-89), and body mass index was 28 (range, 19-44). The source of the autografts were humeral head (n = 113) and iliac crest autograft (ICBG; n = 24). The humeral components included 84 onlay and 53 inlay designs.
Results: Overall, there were 16 complications (12%), of which 6 were major (5%) (3 graft nonunions and 3 infections) and 10 minor (8%) (1 carpal tunnel syndrome and 9 transient axillary neuropraxias). Of the 9 axillary neuropraxias, 8 resolved by the most recent follow-up, whereas 1 patient was lost to follow-up. There were 4 reoperations (3%): 2 for glenoid baseplate loosening, 1 for severe notching associated with severe glenoid bone loss, and 1 for deep periprosthetic infection. One additional patient had a baseplate failure and is undergoing further treatment. There was no difference in the occurrence of graft nonunions, revision surgery, or glenoid component loosening when comparing type of graft or humeral component used. There was an association of revision surgery ($P = .02$) with ICBG and older age at the time of surgery ($P = .02$) and an association of transient neuroapraxia with onlay humeral components ($P = .01$) and workers' compensation cases ($P = .04$).
Conclusions: There is a high union rate and low complication rate after bone grafting of the glenoid performed with RSA. Transient neuropraxias are the most frequent complication, but the majority resolve within the first postoperative year. These early findings can serve as the basis for future long-term, comprehensive analysis of complications and outcomes after bone grafting during RSA.

Institutional review board approval was received from Partners Human Research Committee (protocol # 2015P002052/MGH).

*Reprint requests: Eric R. Wagner, MD, MS, Division of Upper Extremity Surgery, Department of Orthopaedic Surgery Emory University, Adjunct Faculty Morehouse School of Medicine, 59 Executive Park S, Suite 1000, Atlanta, GA 30329, USA.

E-mail address: Eric.r.wagner@emory.edu (E.R. Wagner).

https://doi.org/10.1016/j.jse.2020.05.004

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

Keywords: Reverse shoulder arthroplasty; BIO-RSA; bony increased offset; lateralization; glenoid bone graft; lateralized glenoid

Reverse shoulder arthroplasty is a surgical option for a variety of complex pathologies, including rotator cuff arthropathy,[6,16,30,42] massive irreparable rotator cuff tears,[6,37,51] inflammatory arthritis,[20,22] instability,[28] glenoid bone loss,[14,32,44] acute fractures,[1,12,15,41] post-traumatic reconstruction,[41,48] and humeral bone loss.[9,26,40] When there is substantial glenoid bone deficiency, autogenous glenoid bone grafting can be used to improve bone stock. This can involve increasing the lateralization, through a technique known as BIO-RSA (bony increased offset reverse shoulder arthroplasty),[4] or to correct pathologic version or inclination via wedge grafting (Fig. 1).

Lateralization via BIO-RSA is designed to enhance stability, as well as decrease bony impingement, which can improve the rates of scapular notching and shoulder motion.[3,18] The correction of version via a wedge grafting theoretically also has a similar function but to a lesser degree. Nonetheless, lateralization also has the capacity to increase the tension within the shoulder, potentially increasing the risk of acromial stress fracture, nonunions of the bone graft, and nerve injury.[4,5]

Currently, most of the series assessing structural bone grafting of the glenoid during primary RSA is limited to case series,[3-5,14,18] without any analysis of patient- or technique-specific factors that might impact outcomes, such as type of humeral component or type of bone graft used. Therefore, the purpose of this article is to analyze early outcomes of bone grafting during RSA, assessing the influence of technical and patient considerations that impact these complications.

Methods

After institutional review board approval, we performed a multicenter retrospective review of all patients who underwent bone grafting during reverse shoulder arthroplasty over a 4.5-year period from July 1, 2013, to December 31, 2017. All surgeries were performed by one of 2 high-volume, fellowship-trained shoulder surgeons at 2 level 1 academic medical centers. Inclusion criteria included glenoid bone grafting at the time of primary arthroplasty or revision arthroplasty with the purpose of either lateralization or correction of pathologic version/inclination, or both. Patients were excluded if they were <18 years of age (n = 0), pregnant (n = 0), or had <3 months' follow-up (n = 6).

Outcomes

The primary outcome measure used in this study was the occurrence of complications, including graft nonunion, glenoid baseplate or humeral component loosening, infection, transient or permanent nerve injuries, postoperative acromial or humerus fractures, donor site morbidity, revision surgeries, and reoperations. Nerve injury was based on clinical documentation, with electromyograph (EMG) documentation when available (n = 4). All patients underwent postoperative computed tomography (CT) scans to evaluate union. Nonunion was defined as no trabecular bridging bone from the native glenoid to the bone graft.

Patient characteristics

In the 137 RSAs performed with autogenous structural bone grafts, including 27 in the revision and 110 in the primary setting, the mean follow-up was 17 months (range, 3-38). The mean age was 71 years (range, 45-89) and body mass index was 28 (range, 19-44). The dominant extremity was involved in 81 cases; there were 78 female patients, 6 current smokers, 52 former smokers (>1 year ago), 5 workers' compensation cases, 16 with diabetes mellitus, 12 with fibromyalgia or polymyalgia rheumatica, and 5 with preoperative opioid dependence. The source of the autografts were humeral head (n = 113) and iliac crest autograft (n = 24). Grafting with iliac crest was performed usually in a revision or complex primary setting when the humeral head was not available. The humeral components included 84 onlay and 53 inlay designs. Tables I and II summarize the demographic comparisons between inlay vs. onlay (Table I) and humeral head vs. iliac crest bone grafts (Table II).

Surgical techinique

The surgical technique used in the cases, commonly referred to as "BIO-RSA," was described by Boileau et al.[4] All operations were performed by 2 shoulder fellowship–trained surgeons. The

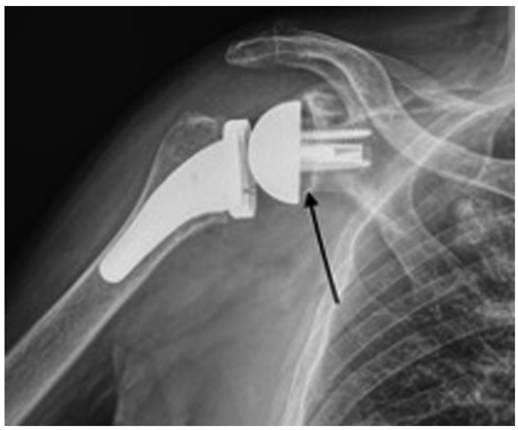

Figure 1 Bony increased offset reverse shoulder arthroplasty (BIO-RSA) follow-up radiograph at 3 months. The *black arrow* demonstrates the structural bone graft placed behind the glenoid baseplate.

Table I Humeral component: demographic and surgical comparison

	Onlay (n = 84)	Inlay (n = 53)
Age, yr*	70 ± 1	73 ± 1
Female sex	48 (57)	30 (57)
Workers' compensation	5 (6)	0 (0)
BMI*	29 ± 1	27 ± 1
Smokers	5 (6)	1 (2)
Diabetes mellitus	14 (17)	2 (4)
Psychiatric diagnosis	27 (32)	13 (25)
Opioid dependence	3 (4)	2 (4)
Graft type		
Humeral head	62 (74)	51 (96)
ICBG	22 (26)	2 (4)

BMI, body mass index; *ICBG*, iliac crest autograft.
Unless otherwise noted, values are n (%).
* Mean ± standard error.

procedures were carried out under general anesthesia with an interscalene block in the beach chair position. A deltopectoral approach was used. If the long head of biceps tendon remained, tenodesis to pectoralis major was performed. Any remaining subscapularis tendon was tagged with suture and was peeled off the lesser tuberosity. Humeral head grafting was performed using a guide placed at the summit of the humeral head and set parallel to the forearm axis (0°-30° according to the transepicondylar axis) and a 2.5-mm Kirschner wire was inserted. A 29-mm reamer, guided along the guidewire, was used to flatten the humeral head until subchondral bone is encountered. Then, the humeral cut was made, securing the graft previously harvested. The humeral head graft was prepared in the back-table using a high-speed burr to be able to be inserted into the glenoid baseplate peg and also contoured to correct the version as determined preoperatively. The graft is placed in a moist gauze. For those who underwent iliac crest bone graft, the iliac crest of ipsilateral side was draped in a usual sterile manner and the iliac crest was harvested. The glenoid is exposed and reamed to where it is necessary as determined preoperatively. The glenoid baseplate with the harvested disc of the bone graft was then impacted into the central hole and fixation was obtained with 4 screws in the glenoid baseplate. The glenosphere was then inserted. Humeral step was done as described for implantation of Aequalis reverse prosthesis stem (Wright Medical, Minneapolis, MN, USA) or Arthrex Universe reverse shoulder prosthesis stem (Arthrex Inc, Naples, FL, USA). The subscapularis was repaired every time it was possible to do so by making humeral holes and securing it with suture. The patient was placed in a sling and was allowed to immediately perform pendulum exercises. Patients were admitted for 1-2 days and discharged. Postoperative physical therapy was directed by surgeon in the first postoperative visit.

Statistical analysis

Descriptive statistics were used to present categoric and continuous variables. Univariate analysis was performed to assess the associations between various outcomes and patient or surgical variables, including the Fisher exact test for categorical variables and Student t test assuming unequal variances for continuous variables. Statistical significance was a P value of .05 or less. Multivariable analysis was unable to be performed given the low number of complications found within this study. A post hoc power analysis for a difference in nerve injuries from 20%-5%, with a power of 0.8, alpha of 0.05, and allocation ratio of 1, demonstrated a target sample size of 82 patients per group. A post hoc power analysis for nonunion rate reduction from 5%-1%, with a power of 0.8, alpha of 0.05, and allocation ratio of 1, demonstrated a target sample size of 302 patients per group.

Results

Complications

Of the 137 primary RSAs with structural bone grafting, there were 17 complications (12%). Among those 17 complications, 7 (41%) required either revision surgery, planned revision surgery, or medical intervention, like intravenous antibiotics or arthroscopic biopsies. These included 3 graft-bone nonunions (2%), 3 infections (2%), and 1 severe posterior scapular notching and associated bone loss (1%). All 3 of the graft nonunions were followed by baseplate loosening. The first patient had a prior rotator cuff repair that was complicated by infection. After being treated for the infection, RSA was performed, but the graft did not unite and the baseplate failed. Revision surgery was recommended, but the patient was lost to follow-up. The second patient underwent a removal of a failed baseplate and reconstruction with iliac bone graft, whereas the third patient underwent a resection arthroplasty. There were 3 infections (2%), including one that was treated with a superficial débridement followed by eventual resection arthroplasty because of persistent infection that did not respond to antibiotics. The other 2 patients underwent 2-stage revision for a prior infected primary arthroplasty, had infections recur postoperatively and were managed with long-term suppression. There were no postoperative periprosthetic humeral fractures, dislocations, or cases of humeral component loosening.

The other 10 complications included 9 transient axillary neuropraxias (7%), and 1 median neuropathy. Of the 10 neuropraxias, 5 were identified by EMG studies. And of the 9 axillary neuropraxias, 8 resolved within 14 months postoperatively. One patient had a mildly weak deltoid and decreased axillary nerve sensation and was lost to follow-up at 4 months postoperatively before an EMG could be obtained. The patient with median nerve neuropathy was treated with carpal tunnel release and median nerve neurolysis. Of the 10 neuropraxias, 3 (30%) were in the setting of revision surgery.

There were 6 cases (4%) of scapular notching, one of which underwent revision surgery due to baseplate loosening. All other cases had good to excellent outcomes.

Table II Bone graft source: demographic and surgical comparison

	Humerus (n = 113)	Iliac crest (n = 24)
Age, yr*	72 ± 1	73 ± 2
Female sex	67 (59)	11 (46)
Workers' compensation	3 (3)	2 (8)
BMI*	28 ± 0	27 ± 1
Smokers	5 (4)	1 (4)
Diabetes mellitus	16 (14)	0 (0)
Psychiatric diagnosis	34 (30)	6 (25)
Opioid dependence	5 (4)	0 (0)

BMI, body mass index.
Unless otherwise noted, values are n (%).
* Mean ± standard error.

There were 4 reoperations (3%), all involving revision surgery for glenoid baseplate loosening (n = 2), severe posterior scapular notching associated with marked bone loss (n = 1), and deep periprosthetic infection (n = 1). Additionally, the other patient with glenoid baseplate failure and graft nonunion was recommended to undergo revision surgery, but was eventually lost to follow-up. Of the 17 patients who presented with complications, 7 (41%) were revision surgeries from either failed arthroplasty or prior periprosthetic joint infection.

Technical and patient considerations

There was no difference in the occurrence of major complications, including graft nonunion, revision surgery, glenoid component loosening, or infection when comparing type of humeral component utilized (Table III). There was a higher rate of revision surgery ($P = .02$), failure (revision or planned revision), and a trend toward a higher nonunion rate ($P = .08$) when using iliac crest autograft compared with humeral head autograft (Table IV). When analyzing minor complications, there was an association of transient axillary neuropraxia with onlay humeral component ($P = .01$), but no association with graft source.

When analyzing patient considerations, there was an association between graft nonunion and older age ($P = .02$). Furthermore, patients involved in workers' compensation cases had higher rates of transient axillary nerve injuries ($P = .04$).

Discussion

Pathologic glenoid deformity, including excessive inclination, version, or medialization, may contribute to higher rates of complications and inferior function after shoulder arthroplasty.[11,13,17,21,25,35,39,43] An effective strategy to address glenoid bone loss, as well as decrease impingement and potentially improve motion, has been structural autogenous glenoid bone grafting.[3-5,14,18,24,27,35,45] Bony lateralization via structural grafting, commonly known as BIO-RSA, can correct various types of glenoid pathology.[4,5,18] Glenoid structural wedge grafts function similarly but lateralize to a lesser degree and instead are designed at correcting pathologic version or inclination.

Lateralization of the glenoid has the potential to increase tension and subsequent force transmitted through the shoulder, possibly increasing the rates of certain complications, such as graft nonunions, acromial stress fractures, or nerve injuries. Given the paucity of information investigating the different patient and technical considerations in structural glenoid bone grafting, we performed an analysis of the early complications associated with this procedure, as well as assessing various patient and technical considerations.

In this series of 137 patients who underwent structural autogenous glenoid bone grafting during RSA, there was a low rate of early complications. Only 2% of patients developed a native bone-graft nonunion, but these were accompanied by baseplate failure. Higher age was associated with nonunion. Transient axillary neuropraxia was observed in 7% of cases, but all either resolved, except 1 that was clinically diagnosed, or was lost to follow-up at 4 months postoperatively. Patients with a workers' compensation claim were more likely to report neuropraxia. There were no postoperative fractures, dislocations, or cases of humeral component loosening. There was also a higher rate of complications in those who were undergoing revision surgery from either a prior failed arthroplasty.

The findings of this study should be considered in the setting of its limitations. We focused on early complications and are not able to comment on the long-term durability of this procedure. Furthermore, this is a retrospective study that is dependent on medical records, including complication (eg, nerve injury) diagnosis by the treating surgeons. For example, for nerve injuries, EMG was only used to confirm the diagnosis in half of the cases, and half of the diagnoses were based on the patient's report of abnormal sensation. Additionally, we were unable to perform multivariable analysis given the low number of outcomes.

Glenoid baseplate loosening as the result of either poor glenoid fixation or graft nonunion is an important consideration in patients with glenoid bone loss. Compromised glenoid bone stock leading to poor baseplate fixation can lead to catastrophic baseplate loosening and associated implant failure.[16,24,45] Bone grafting at the time of RSA has in general been associated with low rates of baseplate loosening and high rates of graft incorporation.[4,5,14,18,27,35] Using the BIO-RSA technique, Boileau et al[5] reported 51 of 54 bone humeral autografts demonstrated complete incorporation. Our study demonstrated similarly encouraging rates of graft incorporation

Table III Humeral component: complications

	Onlay, n (%) (n = 84)	Inlay, n (%) (n = 53)
Revision surgery	2 (2)	1 (2)
Major complications		
Baseplate failure	3 (4)	0 (0)
Nonunion	3 (4)	0 (0)
Infection	2 (2)	1 (2)
Minor complications		
Transient axillary neuropraxia	9 (11)	0 (0)
Median neuropathy	1 (1)	0 (0)

Table IV Bone graft source: complications

	Humerus, n (%) (n = 113)	Iliac crest, n (%) (n = 24)
Revision surgery	1 (1)	3 (13)
Major complications		
Baseplate failure	1 (1)	2 (8)
Nonunion	1 (1)	2 (8)
Infection	0 (0)	3 (13)
Minor complications		
Transient axillary neuropraxia	6 (5)	3 (13)
Median neuropathy	1 (1)	0 (0)

documented by CT scan, with only 2% experiencing a nonunion. This high union rate is likely due in part to the use of autogenous structural graft and compressive forces from the RSA construct.

Two percent (n = 3) of patients developed an infection, including 2 that had a prior history of periprosthetic infection. Although infection after primary RSA is low, in the revision setting for infection it is much more common. After 2-stage revision arthroplasty for infection, up to 21% of patients have persistent sepsis.[2,8]

We observed 9 transient neuroapraxias. The axillary nerve is at risk for stretch injuries during total shoulder arthroplasty, both in anatomic and reverse procedures. Nerve alerts are common in nerve monitoring studies.[34,36] Furthermore, lateralization and lengthening of the arm both have the potential to increase the stresses through the axillary and brachial plexus nerves leading to stretch injuries. Ladermann et al[29] found 9 subclinical transient neuropraxias in 19 patients postoperatively after RSA, compared with 1 neuropraxia among 24 anatomic total shoulder arthroplasties. This potentially was in part associated with the fact that the RSAs lengthened the arm by 2.7 cm compared to the contralateral unaffected side. Boileau et al[4] noted 1 transient neuropraxia in 42 patients undergoing BIO-RSA. Reasons for our higher rate of transient neuroapraxia may be related to (1) mechanical lengthening after grafting with RSA and (2) thoroughness of postoperative clinical assessment and early identification of neuroapraxic symptoms. It is notable that 1 surgeon performed the majority of the onlay RSAs, which can cause a more global lateralization and distalization of the shoulder. Alternatively, that surgeon may have a lower threshold to diagnose axillary neuroapraxia, which could explain our findings.

Workers' compensation status was also independently associated with nerve injury. We did not have a specific explanation for this finding; however, it is possible that workers' compensation patients tend to report mild symptoms more readily when compared to others. In general, workers' compensation patients generally have inferior outcomes compared with other patient groups after anatomic and reverse arthroplasty.[23,33]

Although there are many technical factors that potentially either improve or increase the risk of complications, the 2 we analyzed in this study included the source of autograft and humeral component design. In one study of 41 shoulders that underwent glenoid bone grafting during revision RSA, there were 4 revision surgeries because of glenoid loosening, potentially because of the high number of corticocancellous grafts used (n = 35) that did not provide adequate baseplate support for ingrowth.[45] It also should be noted that lateralized implants increased the risk for glenoid loosening in that same study. Glenoid loosening and variable rates of graft incorporation has also been seen in the use of structural allografts.[24,31] In the analysis by Jones et al of 44 who underwent structural autograft (n = 30) or allograft (n = 14), there was an 81% rate of incomplete or complete graft incorporation, whereas 6 baseplates (14%) were considered loose.[24] In another review of 23 cases of allograft (n = 13) or autograft (n = 10) for glenoid defects, there was a 95% rate of graft incorporation, whereas there was only 1 case (4%) of baseplate loosening.[31] In our study, all patients underwent structural autografts, either from the iliac crest or proximal humerus.

There are multiple patient considerations that have the potential to affect the rate of early complications after bone grafting with RSA. For example, age,[19,47] body mass index,[46] depression/anxiety,[7,10,49,50] diabetes mellitus,[38] male gender,[50] revision surgery, and workers' compensation[23,33] have all been shown to impact the outcomes after anatomic and reverse shoulder arthroplasty. In our study, higher age was associated with an increased risk of graft nonunion. This is likely due to the quality of the native glenoid bone and possibly associated with age-related changes in bone density, although we were not able to specifically analyze osteoporosis as a risk factor.

Conclusions

In this study of 137 structural glenoid autografts performed during RSA, there was a low early complication rate, with a high rate of bone graft healing. Most transient neuropraxias resolved within the first year postoperatively. Factors that were associated with complications included an increased risk of neuropraxia in onlay prostheses and workers' compensation cases and an increased nonunion rate in older patients. These promising early findings can serve as the basis for future long-term, comprehensive analysis of complications and outcomes after bone grafting during RSA.

Disclaimer

Laurence Higgins receives salary and royalties from Arthrex. All the other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Anakwenze OA, Zoller S, Ahmad CS, Levine WN. Reverse shoulder arthroplasty for acute proximal humerus fractures: a systematic review. J Shoulder Elbow Surg 2014;23:e73-80. https://doi.org/10.1016/j.jse.2013.09.012
2. Assenmacher AT, Alentorn-Geli E, Dennison T, Baghdadi YMK, Cofield RH, Sanchez-Sotelo J, et al. Two-stage reimplantation for the treatment of deep infection after shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1978-83. https://doi.org/10.1016/j.jse.2017.05.005
3. Athwal GS, MacDermid JC, Reddy KM, Marsh JP, Faber KJ, Drosdowech D. Does bony increased-offset reverse shoulder arthroplasty decrease scapular notching? J Shoulder Elbow Surg 2015;24:468-73. https://doi.org/10.1016/j.jse.2014.08.015
4. Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clin Orthop Relat Res 2011;469:2558-67. https://doi.org/10.1007/s11999-011-1775-4
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 glenoid bone loss and erosion. J Shoulder Elbow Surg 2017;26:2133-42. https://doi.org/10.1016/j.jse.2017.05.024
6. Boileau P, Watkinson D, Hatzidakis AM, Hovorka I. Neer Award 2005: the Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. J Shoulder Elbow Surg 2006;15:527-40. https://doi.org/10.1016/j.jse.2006.01.003
7. Bot AG, Menendez ME, Neuhaus V, Ring D. The influence of psychiatric comorbidity on perioperative outcomes after shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:519-27. https://doi.org/10.1016/j.jse.2013.12.006
8. Buchalter DB, Mahure SA, Mollon B, Yu S, Kwon YW, Zuckerman JD. Two-stage revision for infected shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:939-47. https://doi.org/10.1016/j.jse.2016.09.056
9. Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of a reverse shoulder prosthesis-allograft composite. J Bone Joint Surg Am 2009;91:119-27. https://doi.org/10.2106/JBJS.H.00094
10. Cho CH, Song KS, Hwang I, Coats-Thomas MS, Warner JJP. Changes in psychological status and health-related quality of life following total shoulder arthroplasty. J Bone Joint Surg Am 2017;99:1030-5. https://doi.org/10.2106/JBJS.16.00954
11. Cofield RH, Edgerton BC. Total shoulder arthroplasty: complications and revision surgery. Instr Course Lect 1990;39:449-62.
12. Dezfuli B, King JJ, Farmer KW, Struk AM, Wright TW. Outcomes of reverse total shoulder arthroplasty as primary versus revision procedure for proximal humerus fractures. J Shoulder Elbow Surg 2016;25:1133-7. https://doi.org/10.1016/j.jse.2015.12.002
13. Elhassan B, Ozbaydar M, Higgins LD, Warner JJ. Glenoid reconstruction in revision shoulder arthroplasty. Clin Orthop Relat Res 2008;466:599-607. https://doi.org/10.1007/s11999-007-0108-0
14. Ernstbrunner L, Werthel JD, Wagner E, Hatta T, Sperling JW, Cofield RH. Glenoid bone grafting in primary reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1441-7. https://doi.org/10.1016/j.jse.2017.01.011
15. Formaini NT, Everding NG, Levy JC, Rosas S. Tuberosity healing after reverse shoulder arthroplasty for acute proximal humerus fractures: the "black and tan" technique. J Shoulder Elbow Surg 2015;24:e299-306. https://doi.org/10.1016/j.jse.2015.04.014
16. Frankle M, Siegal S, Pupello D, Saleem A, Mighell M, Vasey M. The reverse shoulder prosthesis for glenohumeral arthritis associated with severe rotator cuff deficiency. A minimum two-year follow-up study of sixty patients. J Bone Joint Surg Am 2005;87:1697-705. https://doi.org/10.2106/JBJS.D.02813
17. Franta AK, Lenters TR, Mounce D, Neradilek B, Matsen FA 3rd. The complex characteristics of 282 unsatisfactory shoulder arthroplasties. J Shoulder Elbow Surg 2007;16:555-62. https://doi.org/10.1016/j.jse.2006.11.004
18. Greiner S, Schmidt C, Herrmann S, Pauly S, Perka C. Clinical performance of lateralized versus non-lateralized reverse shoulder arthroplasty: a prospective randomized study. J Shoulder Elbow Surg 2015;24:1397-404. https://doi.org/10.1016/j.jse.2015.05.041
19. Griffin JW, Hadeed MM, Novicoff WM, Browne JA, Brockmeier SF. Patient age is a factor in early outcomes after shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1867-71. https://doi.org/10.1016/j.jse.2014.04.004
20. Hattrup SJ, Sanchez-Sotelo J, Sperling JW, Cofield RH. Reverse shoulder replacement for patients with inflammatory arthritis. J Hand Surg Am 2012;37:1888-94. https://doi.org/10.1016/j.jhsa.2012.05.015
21. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Joint Surg Am 2001;83:877-83.
22. Holcomb JO, Hebert DJ, Mighell MA, Dunning PE, Pupello DR, Pliner MD, et al. Reverse shoulder arthroplasty in patients with rheumatoid arthritis. J Shoulder Elbow Surg 2010;19:1076-84. https://doi.org/10.1016/j.jse.2009.11.049
23. Jawa A, Dasti UR, Fasulo SM, Vaickus MH, Curtis AS, Miller SL. Anatomic total shoulder arthroplasty for patients receiving workers' compensation. J Shoulder Elbow Surg 2015;24:1694-7. https://doi.org/10.1016/j.jse.2015.04.017
24. 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
25. Keller J, Bak S, Bigliani LU, Levine WN. Glenoid replacement in total shoulder arthroplasty. Orthopedics 2006;29:221-6. https://doi.org/10.3928/01477447-20060301-05
26. King JJ, Nystrom LM, Reimer NB, Gibbs CP Jr, Scarborough MT, Wright TW. Allograft-prosthetic composite reverse total shoulder

arthroplasty for reconstruction of proximal humerus tumor resections. J Shoulder Elbow Surg 2016;25:45-54. https://doi.org/10.1016/j.jse.2015.06.021
27. 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 Joint Surg Am 2010;92:1144-54. https://doi.org/10.2106/JBJS.I.00778
28. Kurowicki J, Triplet JJ, Momoh E, Moor MA, Levy JC. Reverse shoulder prosthesis in the treatment of locked anterior shoulders: a comparison with classic reverse shoulder indications. J Shoulder Elbow Surg 2016;25:1954-60. https://doi.org/10.1016/j.jse.2016.04.019
29. Ladermann A, Lubbeke A, Melis B, Stern R, Christofilopoulos P, Bacle G, et al. Prevalence of neurologic lesions after total shoulder arthroplasty. J Bone Joint Surg Am 2011;93:1288-93. https://doi.org/10.2106/JBJS.J.00369
30. Levigne C, Boileau P, Favard L, Garaud P, Mole 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
31. Lopiz Y, Garcia-Fernandez 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
32. 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
33. Morris BJ, Haigler RE, Laughlin MS, Elkousy HA, Gartsman GM, Edwards TB. Workers' compensation claims and outcomes after reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:453-9. https://doi.org/10.1016/j.jse.2014.07.009
34. Nagda SH, Rogers KJ, Sestokas AK, Getz CL, Ramsey ML, Glaser DL, et al. Neer Award 2005: peripheral nerve function during shoulder arthroplasty using intraoperative nerve monitoring. J Shoulder Elbow Surg 2007;16:S2-8. https://doi.org/10.1016/j.jse.2006.01.016
35. Neyton L, Boileau P, Nove-Josserand L, Edwards TB, Walch G. Glenoid bone grafting with a reverse design prosthesis. J Shoulder Elbow Surg 2007;16:S71-8. https://doi.org/10.1016/j.jse.2006.02.002
36. Parisien RL, Yi PH, Hou L, Li X, Jawa A. The risk of nerve injury during anatomical and reverse total shoulder arthroplasty: an intraoperative neuromonitoring study. J Shoulder Elbow Surg 2016;25:1122-7. https://doi.org/10.1016/j.jse.2016.02.016
37. Petrillo S, Longo UG, Papalia R, Denaro V. Reverse shoulder arthroplasty for massive irreparable rotator cuff tears and cuff tear arthropathy: a systematic review. Musculoskelet Surg 2017;101:105-12. https://doi.org/10.1007/s12306-017-0474-z
38. Ponce BA, Menendez ME, Oladeji LO, Soldado F. Diabetes as a risk factor for poorer early postoperative outcomes after shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:671-8. https://doi.org/10.1016/j.jse.2014.01.046
39. Rice RS, Sperling JW, Miletti J, Schleck C, Cofield RH. Augmented glenoid component for bone deficiency in shoulder arthroplasty. Clin Orthop Relat Res 2008;466:579-83. https://doi.org/10.1007/s11999-007-0104-4
40. Sanchez-Sotelo J, Wagner ER, Sim FH, Houdek MT. Allograft-prosthetic composite reconstruction for massive proximal humeral bone loss in reverse shoulder arthroplasty. J Bone Joint Surg Am 2017;99:2069-76. https://doi.org/10.2106/JBJS.16.01495
41. Shannon SF, Wagner ER, Houdek MT, Cross WW 3rd, Sanchez-Sotelo J. Reverse shoulder arthroplasty for proximal humeral fractures: outcomes comparing primary reverse arthroplasty for fracture versus reverse arthroplasty after failed osteosynthesis. J Shoulder Elbow Surg 2016;25:1655-60. https://doi.org/10.1016/j.jse.2016.02.012
42. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole 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
43. Steinmann SP, Cofield RH. Bone grafting for glenoid deficiency in total shoulder replacement. J Shoulder Elbow Surg 2000;9:361-7.
44. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg Am 2015;97:251-9. https://doi.org/10.2106/JBJS.N.00566
45. 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 Joint Surg Am 2015;97:1653-60. https://doi.org/10.2106/JBJS.N.00732
46. Wagner ER, Houdek MT, Schleck C, Harmsen WS, Sanchez-Sotelo J, Cofield R, et al. Increasing body mass index is associated with worse outcomes after shoulder arthroplasty. J Bone Joint Surg Am 2017;99:929-37. https://doi.org/10.2106/JBJS.15.00255
47. Wagner ER, Houdek MT, Schleck CD, Harmsen WS, Sanchez-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
48. Wall B, Nove-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am 2007;89:1476-85. https://doi.org/10.2106/JBJS.F.00666
49. Werner BC, Wong AC, Chang B, Craig EV, Dines DM, Warren RF, et al. Depression and patient-reported outcomes following total shoulder arthroplasty. J Bone Joint Surg Am 2017;99:688-95. https://doi.org/10.2106/JBJS.16.00541
50. Werner BC, Wong AC, Mahony GT, Craig EV, Dines DM, Warren RF, et al. Causes of poor postoperative improvement after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2016;25:e217-22. https://doi.org/10.1016/j.jse.2016.01.002
51. Werner CM, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 2005;87:1476-86. https://doi.org/10.2106/JBJS.D.02342