



Pitfalls of revision reverse replacement part II: dealing with humeral bone loss and periprosthetic fractures

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Abstract: Reverse total shoulder arthroplasty (RSA) has a complication rate of ~15% when used in the primary setting and can be higher in the revision setting. Complications related to the humerus include intraoperative or postoperative periprosthetic fractures and proximal humeral bone loss can also result in humeral bone loss. Non-operative treatment of fractures may be used for patients with stable implants and well-aligned fractures or those unsuitable for surgery. Operative techniques include implant revision, usually with a longer stem, and/or open reduction and internal fixation (ORIF) with some combination of plates, screws, cortical graft strut, and wires/cables. For patients with significant humeral bone loss, options include revision RSA without allograft, allograft prosthesis composite (APC), and endoprosthetic replacement. Each has their advantages and disadvantages without an agreed upon accepted standard of care. Unfortunately, treatment of periprosthetic fractures and proximal humerus bone loss both have high complications rates.

Keywords: Revision reverse total shoulder arthroplasty (revision RSA); periprosthetic fracture; humeral bone loss

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Introduction

Over the past decade, the utilization of reverse total shoulder arthroplasty (RSA) has increased in the United States (1). RSA was originally designed for patients with rotator cuff-deficient shoulders by inverting the ball-and-socket anatomy of the glenohumeral joint. The indications have grown to include glenohumeral arthritis (i.e., rheumatoid, osteoarthritis), acute and delayed treatment of complex proximal humerus fractures, failed shoulder arthroplasty, and tumors of the proximal humerus (1-4). Complications include instability, infection, scapular notching, acromion/scapular spine fractures, and periprosthetic fractures. Stability of the ball-and-socket is most dependent on proper tensioning of the soft tissues. Loss of proximal humerus bone stock can lead to insufficient lateral tensioning of the deltoid (5). In addition, it can be

challenging to reattach the anterior and posterior deltoid, further contributing to instability. Furthermore, fixation of the humeral stem into only the diaphysis can be inadequate in patients with metaphyseal bone loss increasing the risk of loosening and periprosthetic fracture.

As the indications for RSA have expanded, complications related to the humerus, including significant humeral bone loss and periprosthetic fracture, have become more common. Proximal humeral bone loss can result from prior surgery, infection, or complex proximal humerus fractures in which the surgical neck or tuberosities progress to malunion, nonunion, or resorption. Additionally, after resection of an anatomic or reverse total shoulder, it is not uncommon for the proximal humerus, most commonly the greater tuberosity, to fracture and fail to subsequently heal. Periprosthetic RSA fractures occur in roughly 1% to 3% of cases, which can arise intra-operatively or postoperatively,

Table 1 Classification of periprosthetic humerus fractures according to Wright and Cofield [reprint with permission from Wutzler *et al.* (10)]

Type	Location	Management
A	Proximal to tip of prosthesis	Revision to longer stem
B	At tip of prosthesis	Conservative vs. ORIF
C	Distal to tip of prosthesis	Conservative vs. ORIF

ORIF, open reduction and internal fixation.

which makes up close to 20% of all RSA complications (6-9). Risk factors include osteopenia, contracted soft tissues, and technical errors (7). Periprosthetic fractures can also result in deficiency of available humeral bone stock.

Classification of periprosthetic fractures

Wright and Cofield (6) in 1995 presented a classification system for humeral fractures after shoulder arthroplasty (Table 1). Type A fractures are located at the tip of the prosthesis and extend proximally, type B fractures lie at the tip of the prosthesis without proximal extension, and type C fractures are distal to the tip of the prosthesis. The authors recommended that type A fractures with a loose stem be treated with longer stem revision arthroplasty, and type A fractures with a well-fixed stem be treated with open reduction and internal fixation (ORIF). Type B and C fractures, which are long oblique or spiral, can be treated non-operatively if alignment is satisfactory and stable, whereas short oblique and transverse fracture should be treated with ORIF. These principles are largely still used today. There is a higher nonunion rate with type B fractures, so patients should be advised that a trial of non-operative management with these fractures may be unsuccessful (11). Andersen *et al.* (12) retrospectively reviewed a consecutive series of thirty-six patients with periprosthetic humerus fractures, 17 of which were around a reverse-geometry implant, and found low interobserver reliability (mean kappa, 0.37; range, 0.24 to 0.50) and a high intraobserver reliability (mean kappa, 0.69; range, 0.52 to 0.89) for the Wright and Cofield classification system. This makes it a useful but somewhat limited tool when evaluating patients.

Periprosthetic fractures can also be isolated to the greater or lesser tuberosity. In these cases, consideration should be given to fixation of the fractured tuberosity. Ohl *et al.* (13) demonstrated superior objective and subjective outcomes in

RSA patients with greater tuberosity union when compared with patients with nonunion or excision. Autograft bone may be added to the tuberosity fixation and may improve union rates.

Measurement of humeral bone loss

Currently, there is no classification of humeral bone loss in the setting of shoulder arthroplasty, including RSA. However, preoperatively radiographs of the contralateral humerus can be obtained to compare to the operative side. Poltaretskyi *et al.* (14) proposed a novel, computerized model to calculate pre-morbid proximal humerus anatomy using 57 humeral CT scans with 3D humeral reconstructions in order calculate the 3D geometric parameters required to restore normal anatomy for patients undergoing shoulder arthroplasty. When including the metaphyseal region and mimicking osteoarthritis, the authors were able to prediction retroversion, inclination, height, radius of curvature and posterior and medial offset of the head of the humerus with errors of $2.9^{\circ} \pm 2.3^{\circ}$, $4.0^{\circ} \pm 3.3^{\circ}$, 1.0 ± 0.8 mm, 0.8 ± 0.6 mm, 0.7 ± 0.5 mm and 1.0 ± 0.7 mm, respectively. Future research is needed to determine the clinical application of the computer models and how they can help surgeons improve the function and outcomes of shoulder arthroplasty patients, especially those with RSA and humeral bone loss.

Postoperatively, humeral bone loss is measured on a standard anteroposterior radiograph. The measurement is the distance from the lateral aspect of the proximal end humeral prosthesis to the most proximal aspect of the remaining humeral bone (15). However, the actual magnitude of bone loss has been reported to be up to 1.5 cm greater than this measurement (15). A cut-off point that dictates management (no allograft *vs.* allograft *vs.* endoprosthesis) has not been determined.

Mechanism/prevention

Intraoperative iatrogenic fractures can occur most commonly during reaming of the humeral canal when there is excessive torque of the arm without allowing the arm to rotate or if resistance is met during reduction/dislocation maneuvers when longitudinal traction is not used; however, the usual lack of a rotator cuff makes iatrogenic fracture less common when compared with anatomic total shoulder arthroplasty. In osteopenic patients, a number of measures

can be used to prevent intraoperative fracture. These include complete anterior and inferior capsular releases, use of a bone hook to deliver the humerus from the glenoid fossa and using a stem with a diameter smaller than the endosteal diameter of the diaphysis.

Management: periprosthetic fractures

Conservative

Intraoperative periprosthetic fractures are usually managed with immediate conversion to a longer stem or ORIF. It is generally advised to bypass the fracture by two cortical diameters (16). The management of postoperative fractures is more complicated; the treating surgeon must weigh a variety of factors to determine the need for surgical intervention. Non-operative management is indicated for patients unfit for surgery, certain non-displaced fractures with well-fixed stems (type B and C fractures), or patients refusing surgery. Activity modification, pain control, and frequent radiographic monitoring are the mainstays of treatment. Fracture braces may be beneficial depending on the nature and location of the fracture. The patient should be counseled that healing can take weeks to months, and there is a risk of non-union. Stiffness is also a common complication due to the prolonged immobilization for healing. A bone stimulator may be used for patients without evidence of union at three months. Wright and Cofield initially treated a patient after failed non-operative management with cerclage wire fixation, followed by bone grafting and electrical stimulation, which united at 33 months (6).

Revision

Surgical management of postoperative fractures is broadly divided into implant revision, where the humeral stem is removed and replaced, and implant sparing, where the stem is retained and a fracture is treated with extramedullary fixation. Implant revision is generally indicated for a loose prosthesis, whereas implant sparing techniques are generally used for well-fixed prostheses. When revising the implant, a stem that bypasses the fracture by at least two cortical diameters is recommended. Most reverse systems have a variety of humeral stem lengths in order to facilitate this. Longer revised stems provide a biomechanically superior construct to extramedullary fixation and are at lower risk for loosening; however, care should be taken to

avoid intraoperative fractures, distal cortical perforation, and cement extrusion (17). In addition, removing the stem can be difficult and may worsen the fracture and/or comminution. The modularity of some shoulder arthroplasty systems can prevent this complication if portions are well-fixed. Sommacal *et al.* (18) reported a good outcome with a partial revision of a SMR reverse system with retention of the glenoid and humeral body and just conversion to a longer humeral stem.

Anderson *et al.* (12) presents a case series of reverse and anatomic periprosthetic humerus fractures divided by treatment group (ORIF *vs.* revision). Nine RSA patients were treated with revision arthroplasty; 7 of which had severe osteopenia. Time to union was 7.4 months (range 4 to 13.5). Three patients experienced complications including Morse taper dissociation, periprosthetic fracture initially treated non-operatively but became infected and required resection, and stem loosening treated conservatively.

Revision to a custom long-stem total shoulder replacement (TSR) is also an option for patients with humeral bone loss and/or component loosening. Sewell *et al.* (19) had satisfactory results in 4 patients with RSA periprosthetic fractures that were treated with custom TSR. Two fractures were type A, one was type B, and one was type C, and all four patients had severe osteopenia. No complications were noted.

ORIF

A variety of extramedullary fixation techniques may be employed when deciding to retain the implant. In the most basic sense, the stem can be ignored, and the fracture can be treated with a compression or locking plate (*Figure 1*). This can be difficult since the screws cannot be placed through the stem. In some instances, a cable can be used to augment the fixation of the plate. Another option is cortical strut allograft secured with cables. The strut allograft increases load dispersion of the cable and may incorporate into the humerus. Care should be taken when placing cables as not to incarcerate the radial nerve. Lastly, cables alone may be used in rare instances with non-displaced, long oblique fractures, but there is a high risk of cutting through the bone of the humerus. Overall, the main advantage of implant sparing is the decreased risk of damage with removing the prosthesis and worsening the fracture; however, biomechanically extramedullary fixation is usually

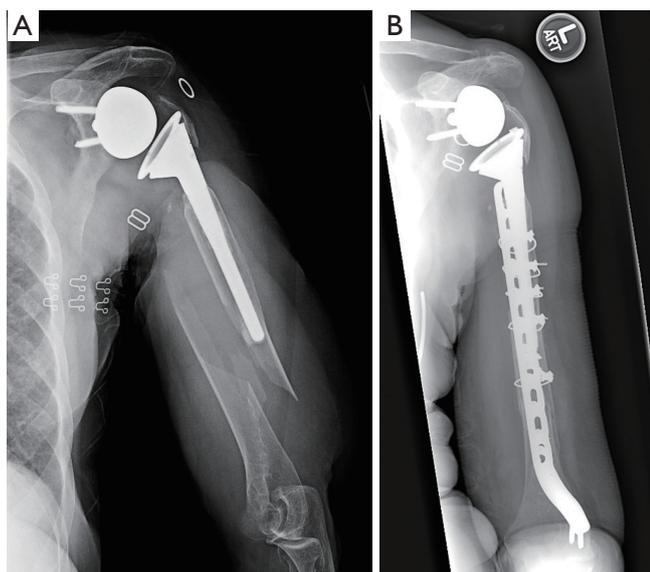


Figure 1 Patient of Dr. Paxton, original images, never published before. Anteroposterior radiographs of an 82-year-old female (A) with a periprosthetic RSA fracture of the left humerus and (B) post-operative after treatment with open reduction and internal fixation. RSA, reverse total shoulder arthroplasty.

weaker.

Martinez *et al.* (20) reported on 6 patients with type C periprosthetic fractures treated with broad 4.5 mm locking compression plate applied laterally through anterolateral approach. Bicortical screws were used for distal fixation, and cable wires for proximal and distal fixation. Strut allograft was applied medially and fixed with wires and distal bicortical screws. They achieved union of all fractures, and pre-fracture shoulder range of motion and satisfaction attained in all but one patient at 12–17 months follow-up (20). Mineo *et al.* (8) described two cases of RSA patients with postoperative type C periprosthetic fractures, which were treated with locking plates with screws and cable wiring. Both fractures united by 5 months without complications. Andersen *et al.* (12) treated eight RSA patients with periprosthetic fractures with ORIF. Six of the eight had some degree of osteopenia. Time to union was on average 6.25 months (range, 4 to 12). Complications included baseplate and humeral socket fracture and distal fracture extension; both required revision surgery.

While choosing an implant revising versus an implant sparing management can be fairly straightforward based on the fracture characteristics, the implementation of the techniques is very much individualized and nuanced.

Both strategies have proven to have satisfactory outcomes; however, patients should be advised that complications are not uncommon, and revision surgery may be indicated.

Management: humeral bone loss

The loss of humeral bone stock can affect component fixation as well as disruption of the insertion of the rotator cuff muscle (21). RSA is effective in treating failed shoulder arthroplasty because of its increased constraint and diminished reliance on the intact rotator cuff. Nevertheless, this implant relies on the humeral bone stock for implant fixation, rotational stability, and soft tissue attachment to improve function and stability. The loss of proximal humeral bone plays an important role in patient outcome; therefore, several options have been described to manage humeral bone loss during RSA, including the revision without allograft, allograft prosthesis composite (APC), and endoprosthetic replacement (Table 2).

Long stem component without graft

One option for treatment is revision of the humeral bone defect without the use of an allograft. Some surgeons recommend this technique due to significant concerns regarding the prosthetic allograft, including cost, increased risk of infection, donor to host reaction, increased operative time and complexity, graft resorption, and/or failure of graft incorporation. Surgeons favoring this technique report rotational and length stability of the prosthesis can be achieved with the use of long stem component, negating the need for allograft support. Also, that the semi-constrained nature of the reverse prosthesis and the ability to adjust the soft tissue tension with spacers results in a low rate of instability. Budge *et al.* (15) studied 15 patients with significant humeral bone loss (38.4 mm) who underwent RSA without allograft. Result showed an 87% satisfaction rate, a mean forward flexion of 103.2° and external rotation of 11.9°. Complications were notching in 3 patients, one anterior instability that required revision, and a periprosthetic fracture of one modular humeral stem. No subsidence or loosening was reported.

Shukla *et al.* (5) used a proximal humerus replacement system [Segmental Revision System (SRS); Zimmer-Biomet, Warsaw, IN, USA] to perform RSA on 34 patients. Indications included failed shoulder arthroplasty, tumor resection, malunion/nonunion, prior resection arthroplasty,

Table 2 Comparison of humeral bone loss management options (original table, never published before)

Study	Patients	Type of graft/ implant use	Postoperative function	Postoperative (mean unless specified)	Radiographic union	Complications
Budge <i>et al.</i> 2013 (15)	15: 12 failed HA for fracture, 3 previously infected HA	2 press-fit, 13 cemented	FF: 103.2° ER: 11.9°	ASES: 68.3	n/a	7 (47%), 2 (13%) reoperations. 1 dislocation requiring revision, 1 painful cerclage wire requiring removal of hardware, 1 intraoperative periprosthetic fracture, 1 deep vein thrombosis, 3 transient nerve palsies
Shukla <i>et al.</i> 2018 (5)	34: 15 failed shoulder arthroplasty, 9 tumor resection, 1 humeral malunion/nonunion, 2 prior resection arthroplasty, 1 intraoperative fracture	13 press-fit, 21 cemented. Segmental revision system (SRS); Zimmer-Biomet, Warsaw, IN, USA	FF: 109°, ER: 37°	81% satisfaction rate 91% felt they improved as result of surgery	n/a	9 (26%), 8 (24%) reoperations. 2 humeral loosening, 3 periprosthetic fractures (2 requiring reoperation), 2 infections, 1 dislocation
Sanchez- Sotelo <i>et al.</i> 2017 (22)	26: 8 primary (5 proximal humerus malunion or nonunion with bone loss, 3 resection of tumor), 18 revision (11 HAs, 4 TSAs, 3 RSAs)	APC	FF: 98°±9°, ER: 31°±4°	ASES: 66.1 (48 to 82); SST: 4.4 (1 to 10); Neer (7 excellent, 10 satisfactory); 9 unsatisfactory); 25 patients (96%) answered yes to if shoulder was improved	Time to union 7 months (3 to 13): primary 6, revision 8	6 (23%): 1 postoperative hematoma requiring I&D complicated by deep infection treated with plate removal and chronic suppression, dislocation, 1 delayed union requiring bone-grafting, 1 delayed wound healing, 1 allograft fracture, 1 type C periprosthetic fracture
Chacon <i>et al.</i> 2009 (23)	25: 24 failed HA used to treat a fracture, 1 failed bipolar HA	APC	FF: 82.4° (2° to 142°), ER: 17.6° (-10° to 65°)	ASES: 69.4 (25 to 93.3), SST: 4.5 (0 to 11)	Incorporation of allograft in the metaphyseal region of 21 patients (84%) and in the diaphyseal region of 19 patients (76%)	4 (16%): 1 fracture/dislocation requiring multiple revisions, 1 recurrent instability, 1 allograft fracture, 1 acromion fracture
Martinez <i>et al.</i> 2011 (20)	6 proximal humerus nonunions with extension bone loss	APC	FF: 90°, ER: 30°	Constant 55%. SST 6, 2 of 6 (33%) would undergo same procedure again, 2 very satisfied/ satisfied, 2 unhappy	3 allografts (50%) integrated, 1 removed during I&D, 2 were resorbed	4: 2 dislocations revised to larger glensphere, 2 infections
Kumar <i>et al.</i> 2003 (11)	47 tumor resections	Endoprosthesis	FF: 55° (35° to 140°)	MSTS 23.7±3.38 out of 30, 16 excellent results, 11 good, 3 poor	n/a	5 infections, 5 radial nerve injuries (4 neurapraxia with complete recovery, 1 incomplete recovery), 6 aseptic loosening requiring revision, 2 dislocations requiring open reduction
Cannon <i>et al.</i> 2009 (24)	83 tumor resections	Endoprosthesis	FF: 42° (5° to 115°)	MSTS 63%±15% (40% to 83%)	n/a	2 deep infections. Proximal migration in 22 (29%) patients

HA, hemiarthroplasty; TSA, anatomic total shoulder arthroplasty; FF, forward flexion; ER, external rotation; ASES, American Shoulder and Elbow Assessment; SST, Simple Shoulder Test; Neer, Neer Rating; MSTS, Musculo-Skeletal Tumour Society rating system; I&D, irrigation and debridement.

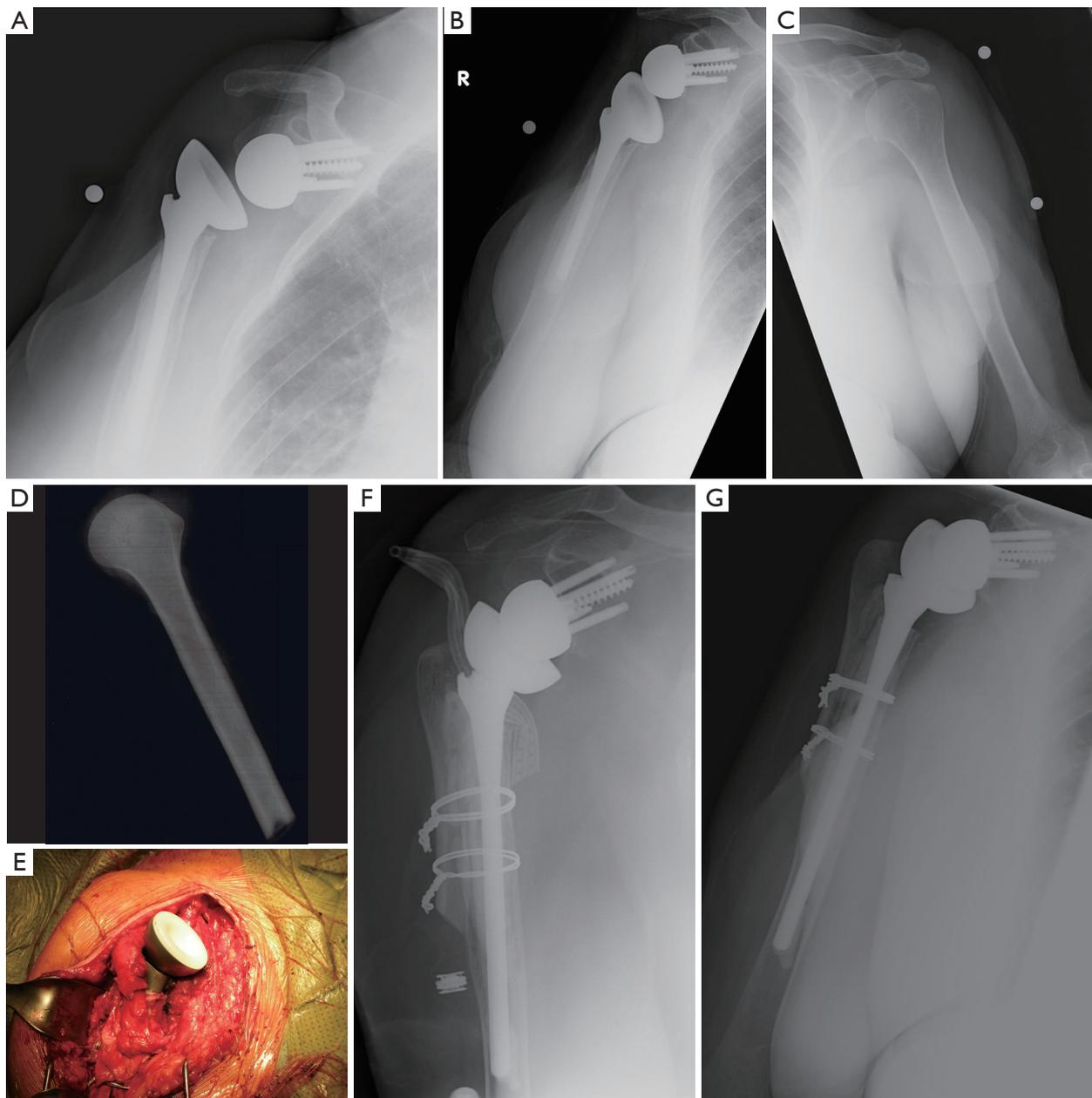


Figure 2 Patient of Dr. Green, original images, never published before): a 77-year-old right hand dominant female treated with a RSA for a right proximal humerus fracture nonunion, who suffered a periprosthetic fracture of the humerus as well as chronic dislocation: anteroposterior radiographs of (A) the right shoulder and (B) the right humerus showing a loose humeral stem and significant loss of proximal humerus bone stock; (C) contralateral radiographs were obtained to determine the amount of proximal humerus bone loss; (D) radiograph of the proximal humerus allograft used in the revision surgery; (E) intraoperative clinical photo demonstrating the allograft; post-operative anteroposterior radiographs of (F) the right shoulder and (G) the right humerus; RSA, reverse total shoulder arthroplasty.

and intraoperative fracture. Forward flexion improved from 31° to 109° ($P < 0.001$), postoperatively. There was an 81% satisfaction rate. Eight patients (24%) required reoperations.

The complications included humeral loosening (3 shoulders), periprosthetic fracture (2 shoulders), infection (2 shoulders), and dislocation (1 shoulder). An additional

patient sustained a minimally displaced periprosthetic fracture successfully treated non-operatively.

APC

APC provides several theoretical benefits, including implants support, increase bone stock, restoration of humeral length, deltoid tensioning, an opportunity to repair the posterior aspect of the cuff to improve strength in external rotation and repair of the subscapularis to improved stability (Figure 2). It combines the durability of an endoprosthesis and the benefits of allograft (22,25).

Sanchez-Sotalo *et al.* (22) reviewed the results of 26 patients that received an APC, 8 primary and 18 revision. In this study, the fixation to hold the APC was performed with a compression plate. During a mean follow-up of 4 years, there were no significant differences in clinical outcomes between primary and revision case. No patients required revision surgery for nonunion at the host-allograft junction. The mean time to union was 7 months. The 2- to 5-year revision free survival rate was 96%.

Chacon *et al.* (23) evaluated the results of 25 patients with a reverse shoulder prosthesis allograft composite with a mean follow up was 30.2 months. The study shows improve score in the ASES and SST scores. The range of motion improved in flexion from 32.7° to 82.4° ($P<0.001$) and abduction from 40.4° to 81.4° ($P<0.0001$). And, 76% of patients reported a good or excellent result. Radiographic evaluation show incorporation of the allograft in the metadiaphysis in 84% of the patients and incorporation of the allograft in the diaphyseal region in 76% of the patients (23).

Martinez *et al.* (26) reported on 6 patients, who received a RSA and an APC for proximal humerus nonunion and extensive proximal bone loss. Two of the patients had postoperative infections, which required one or more surgeries and long-term antibiotics to treat. Two others had recurrent postoperative dislocations, which required revision surgery to a larger glenosphere. No further dislocations occurred thereafter. The remaining two patients who did not experience a complication were satisfied or very satisfied and would undergo the procedure again. APC is a viable option for humeral bone loss in the setting of RSA, but there is a high complication rate.

Endoprosthetic replacement

Endoprosthetic replacement was originally designed for

reconstruction after limb salvage surgery. Almost no study has reviewed the results of these procedures for humeral bone loss management in a revision RSA. Nevertheless, it is an option for the management of humeral bone loss. Kumar *et al.* (11) performed a study in 47 patients that had a tumor reconstruction with endoprosthesis after limb salvage surgery, with a mean follow-up of 9 years. The mean length of the replaced humerus was 17 cm. The study showed survival of the prostheses of 86.5% at 20 years, and that the functional outcome was influenced by the size of the bone left after the resection. Cannon *et al.* (24) performed a study in 83 patients who underwent proximal humeral endoprosthetic reconstruction following intra-articular deltoid muscle and axial nerve sparing resection. Mean follow up was 30 months. Results showed active abduction of 41°, mean active forward elevation of 42°. Complications included 2 deep infections. No prosthesis was loosened.

Management of humeral bone defect can be challenging. Further studies reviewing the results of the multiple options in revision RSA will give us a better understanding of their role in this condition. Management for humeral bone defect will be dictated in great part by the amount of bone loss. Prosthetic revision without allograft showed good results for small to medium size defects. Allograft prosthetic composites may be the better option for medium to large defects of the humerus, based on the ability to reconstitute the bone stock, reattach the subscapularis tendon insertion, lateralizing the pull of the deltoid, and improved the contour of the shoulder. Various reconstruction techniques for the proximal humerus lead to relatively similar functional results. Surgical choice should be tailored to anatomic defect and functional requirements.

Conclusions

Fortunately, periprosthetic fractures are a rare, but potentially devastating complication of RSA. Non-operative management is possible for certain fractures with good alignment and a stable implant. Operative management whether implant revising or implant sparing is very much individualized for the type of RSA implant and nature and location of the fracture. Either operative strategy has a relatively high complication rate, and non-operative management frequently leads to non- or malunion. In addition, humeral bone loss in the setting of RSA is a complex problem with several potential treatment options that also have high complication rates.

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