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Clinical outcomes following reverse shoulder arthroplasty–allograft composite for revision of failed arthroplasty associated with proximal humeral bone deficiency: 2- to 15-year follow-up

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Background: Patients with pain and disability due to a prior failed shoulder arthroplasty with associated proximal humeral bone loss have limited reconstruction options. Our purpose was to report the results of a large cohort of patients treated with a reverse shoulder allograft–prosthetic composite (APC).
Methods: Between 2002 and 2012, a total of 73 patients were treated with a reverse shoulder APC and had adequate follow-up. Clinical outcome scores, range of motion, and radiographic evidence of failure were assessed. The minimum follow-up period was 2 years, with an average of 67.9 months (range, 21-157 months). Of the patients, 43 had more than 5 years' follow-up and 12 had more than 10 years' follow-up.
Results: The total American Shoulder and Elbow Surgeons score improved from 33.8 to 51.4 ($P < .0001$), and the Simple Shoulder Test score improved from 1.3 to 3.5 ($P < .0001$). Good to excellent results were reported in 42 of 60 patients (70%), 10 patients (17%) reported satisfactory results, and 8 patients (13%) were unsatisfied. Range of motion improved in forward flexion (49° to 75°, $P < .001$) and abduction (45° to 72°, $P < .001$). Revision was required in 14 patients (19%) for periprosthetic fracture (n = 6), instability (n = 2), glenosphere dissociation (n = 2), humeral loosening (n = 2), and infection (n = 2) at a mean of 38 months postoperatively. The reoperation-free survival rate of all reconstructions was 88% (30 of 34) at 5 years, 78% (21 of 27) at 10 years, and 67% (8 of 12) beyond 10 years. Ten patients had radiographic evidence of humeral loosening at final follow-up, and 2 required revision.
Conclusions: The use of a reverse total shoulder APC provides reliable pain relief and improved range of motion, with an acceptable rate of complications. Although ultimate function achieved is limited, patient satisfaction remains high.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Reverse total shoulder arthroplasty; RSA; allograft; revision; APC; proximal humeral bone loss

This study was determined to be exempt from review by the Western Institutional Review Board.

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Proximal humeral bone loss in revision shoulder arthroplasty represents a significant challenge for the reconstructive shoulder surgeon. Multiple previous studies have shown the difficulty associated with treating these failed arthroplasties.[3,5-8,10,11] This difficulty is a result of multiple factors, including a loss of structural support to provide adequate component fixation, the absence of soft-tissue attachment sites for the remaining rotator cuff musculature, and loss of humeral length resulting in the clinical manifestations of component micromotion and humeral loosening,[3] functional deficits, and instability.

Our institution previously reported on a cohort of patients with significant humeral bone loss with a minimum of 2 years' follow-up who were treated with a reverse shoulder prosthesis and a bulk proximal humeral allograft.[3] The early to midterm follow-up results in this patient group were encouraging, as a majority of the study population reported good to excellent functional scores, improvement in range of motion, satisfactory radiographic incorporation of the allograft, and few complications. The current study aims to further investigate this group of patients with extended follow-up to determine the long-term survival of these complex prosthetic-allograft composites.

Materials and methods

This study represents a retrospective consecutive case series of prospectively collected data that examined 99 patients who were treated with a proximal humeral allograft and reverse total shoulder arthroplasty (RSA) composite at our private institution between 2002 and 2012. Of these 99 patients, 73 had a minimum of 2 years' clinical and radiographic follow-up for analysis. We excluded 23 for lack of sufficient follow-up and 3 for lack of required radiographs for review. There were 55 female and 18 male patients. The patients were followed up on an annual basis after the first year. The average patient age at the time of reconstructive surgery was 67 years (standard deviation, 10 years). Of the 73 patients, 72 had undergone some form of arthroplasty before the APC procedure, with 1 patient presenting with a failed open reduction–internal fixation and significant bone loss. Patients underwent an average of 2 prior surgical procedures (range, 1-6 procedures). One patient died of unrelated health complications during the study period 10 years after revision surgery.

A total of 54 failed hemiarthroplasties (HAs) were included, of which 53 were performed for fracture and 1 was performed for cuff tear arthropathy. The indications for the APC procedure in the HA patients included glenoid erosion and instability (43), tuberosity nonunion (3), periprosthetic fracture (2), humeral stem loosening (1), and infection (5 total, 3 with resections performed elsewhere). A total of 17 RSAs were initially performed for indications including fracture (8), cuff tear arthropathy (6), failed HA (1), failed total shoulder arthroplasty (1), and Charcot arthropathy (1). These RSAs were revised to APCs owing to baseplate failure (4), periprosthetic fracture (4), humeral stem loosening (3), instability (2), infection (2, with 1 resected elsewhere), glenosphere dissociation (1), and chronic pain with grade IV notching (1). Finally, 1 anatomic total shoulder arthroplasty was performed for primary glenohumeral arthritis that underwent revision to APC secondary to mechanical failure of a metal-backed glenoid component.

All patients underwent preoperative radiographs and computed tomography scans. The final decision to use an allograft was made intraoperatively. This was determined by the stability of the humeral reconstruction (if the trial humeral component was rotationally unstable) or if soft-tissue tension was such that glenohumeral stability during passive motion was compromised. In addition, if the humeral implant had greater than 5 cm of implant exposed, this was considered an indication to proceed with an APC. All patients in this population were treated with either a Reverse Shoulder Prosthesis (RSP; DJO Surgical, Austin, TX, USA) or RSP Monoblock (DJO Surgical) combined with a proximal humeral allograft by a single surgeon (M.A.F.).

Surgical technique

The revision surgical procedure was performed through the standard deltopectoral approach in all patients, with division of the subscapularis during dissection. After removal of the humeral head component, management of the humeral stem was dictated by the implant in place. Press-fit stems were removed using a combination of burrs and osteotomes to separate the bone-implant interface, followed by impaction devices and mallets to remove the stem in an atraumatic fashion. For cemented stems, if the previous cement mantle was stable and there was no concern for infection, the cement was left intact and a cement-within-cement technique was performed (Fig. 1). On removal of the stem, serial broaches were used for successive trialing until stability was achieved. The quantity of bone loss was assessed at this stage by measuring the gap from the remaining native humeral bone distally along the medial cortex and the inferomedial portion of the polyethylene trial in the humeral component. If the bone loss was deemed sufficient to compromise the stability of the revision prosthetic stem, then an allograft–prosthetic composite (APC) was chosen to provide enhanced stability of the construct. The fresh-frozen bulk allograft was shaped using an oscillating saw and a step-cut technique (Fig. 2). The prepared allograft was then cabled to the host bone using multiple 1.7-mm cables, and the definitive humeral component was cemented into the final construct. The remnant of the allograft subscapularis insertion was used to achieve repair to the remaining native subscapularis with multiple nonabsorbable sutures.

Postoperative care

All patients were placed in a sling for 2 weeks until the first clinical follow-up. The sutures were removed at that time if the wound was healed, and the patient was allowed to discontinue sling use. Pendulum exercises were performed until 6 weeks postoperatively, at which point activity was gradually progressed with passive range-of-motion exercises in formal physical therapy. Patients progressed to full activity at 3 months postoperatively.

Infectious consideration

Preoperatively, all patients underwent laboratory analysis to monitor for elevated levels of inflammatory markers including a complete blood count, the erythrocyte sedimentation rate, and the C-reactive

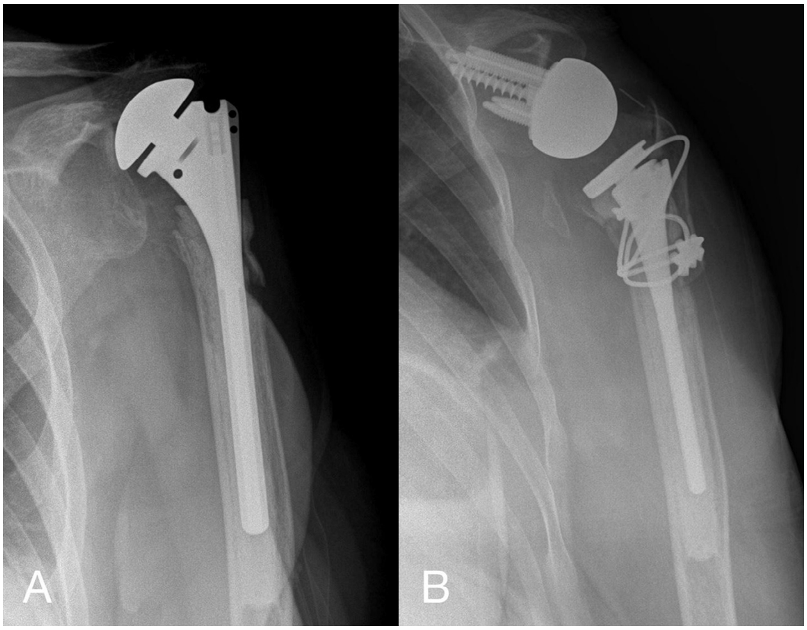

Figure 1 **(A)** Radiograph showing the left shoulder in a female patient with pain, superior migration, and functional deficit. **(B)** Radiograph showing immediate postoperative results of allograft–prosthetic composite with cement-within-cement technique.

Figure 2 Diagram depicting allograft–prosthetic composite with securing of cerclage cables anchoring allograft to native host bone.

protein level. Multiple tissue samples were obtained intraoperatively at the time of reconstruction to assess for infection, with frozen-section analysis and culture in all patients. All patients in whom frozen-section microscopy revealed greater than 5 polymorphonuclear cells per high-power field, with prior infection, or with positive culture results postoperatively were managed with an intravenous antibiotic regimen by an infectious disease specialist postoperatively and underwent the reconstruction with an APC as planned in a 1-stage manner. All other patients were treated with a 2-week course of postoperative antibiotics until the cultures were re-evaluated and, if found to be negative, antibiotics were discontinued.

Clinical analysis

All patients underwent preoperative and postoperative clinical evaluations beginning at the first postoperative visit and continuing until last follow-up. Clinical assessments included the American Shoulder and Elbow Surgeons (ASES) assessment for pain and function,[12] the Simple Shoulder Test,[1] and a rating scale for overall satisfaction with the outcome of surgery (unsatisfied, satisfied, good, or excellent). These assessments were completed by all patients and available for review. Clinical evaluations of all patients also included videographic analysis at the preoperative visit and at all subsequent follow-up visits. Patients were asked to perform a range-of-motion demonstration in direct forward flexion, internal and external rotation, and abduction, and these values were recorded after the videographic records were reviewed and a digital goniometer was used to make measurements.

Radiographic analysis

Postoperative radiographs were assessed by 2 orthopedic fellowship-trained shoulder surgeons. These included internal and external rotation anteroposterior, axillary lateral, and scapular-Y lateral radiographs. The final quantity of bone loss was based on a measurement made from the proximal tip of the allograft construct to the most proximal aspect of the host humerus remaining distally (Fig. 3).

Radiographs obtained at most recent follow-up were analyzed for evidence of humeral or glenoid component loosening, allograft incorporation and survival, hardware failure, inferior glenoid notching, and instability. Humeral component loosening was determined by inspecting for radiolucencies around the implant as previously

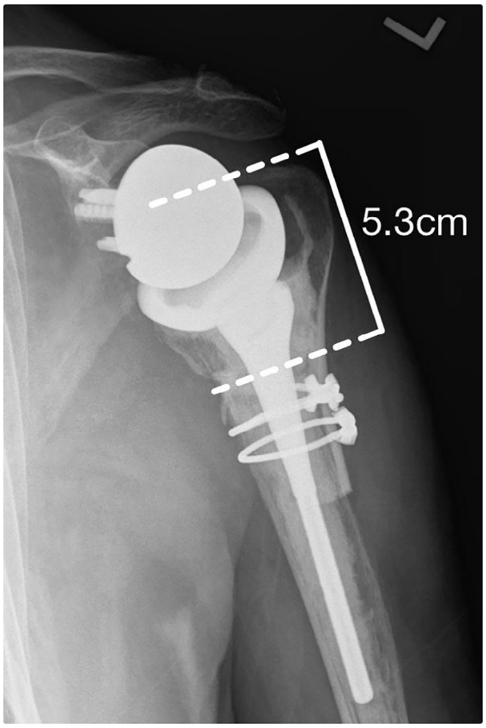

Figure 3 Technique illustration of measuring amount of bone loss on first postoperative anteroposterior radiograph. A parallel line was measured from the tip of the allograft greater tuberosity to the level of host bone remaining most proximally.

described by Sperling et al.[14] The allograft was determined to have incorporated with the host bone if there was a complete absence of junctional lines and clear evidence of bridging bone visible on 2 orthogonal views[16] (Fig. 4). The allograft was considered to have resorbed if more than 25% of the area of the graft was absent on final follow-up radiographs.

Subgroup analysis and classification of bone loss

Patients were classified based on different factors related to either the size or pattern of bone loss (or both). The size of allograft used in the APC construct was categorized based on the bone loss classification method originally described by McLendon et al.[9] This classification system, originally created to identify which preoperative factors predict the use of a larger diaphyseal allograft that may comprise the deltoid insertion, was modified to encompass all forms of bone loss that the revision surgeon will encounter (Fig. 5). In this modified version, type I consists of cases in which there is less than 5 cm of bone loss circumferentially, often with loss of the tuberosities, in which allografts are typically not necessary. Type IB is a subgroup of type I in which there is asymmetrical bone loss, typically less than 5 cm medially but greater than 5 cm laterally, and the remaining bone is typically unable to accommodate a revision stem without the additional proximal support supplied by an allograft (Fig. 6). Type IC represents another subgroup in which there is a cemented stem with an intact cement mantle that the surgeon wishes to revise with a cement-within-cement technique, but the working length within the existing cement mantle is not sufficient to provide rotational stability without the addition of allograft (Fig. 7). Type II includes cases of greater than 5 cm but less than 10 cm of effective bone loss, in which the majority of the deltoid insertion is intact, and shorter allografts are typically recommended. Type III includes cases in which there is greater than 10 cm of effective bone loss with significant compromise of the deltoid insertion, necessitating additional techniques to preserve deltoid function. Humeral stem diameter and the use of the cement-within-cement technique were also evaluated in relation to failure rates.

Statistical analysis

Basic descriptive statistics have been reported for continuous (average, standard deviation) and categorical (proportion) variables. Pain scores, clinical outcome scores, and range-of-motion values were compared using a paired *t* test and categorical data were evaluated using

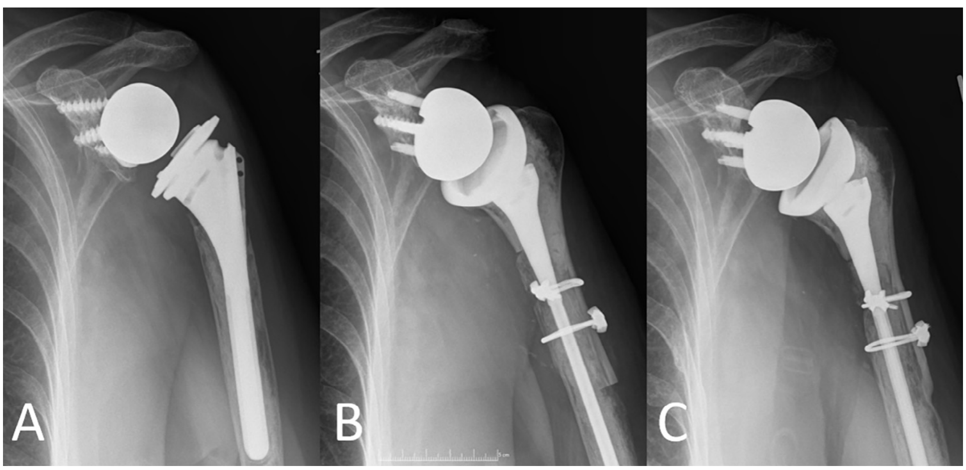

Figure 4 **(A)** Preoperative radiograph in a patient with a history of proximal humeral fracture treated with hemiarthroplasty with subsequent pain, followed by revision to reverse total shoulder arthroplasty, complicated by dissociation of her glenosphere. **(B)** Immediate postoperative radiograph of allograft–prosthetic composite. **(C)** Most recent follow-up radiograph (7 years' follow-up) showing incorporation of allograft.

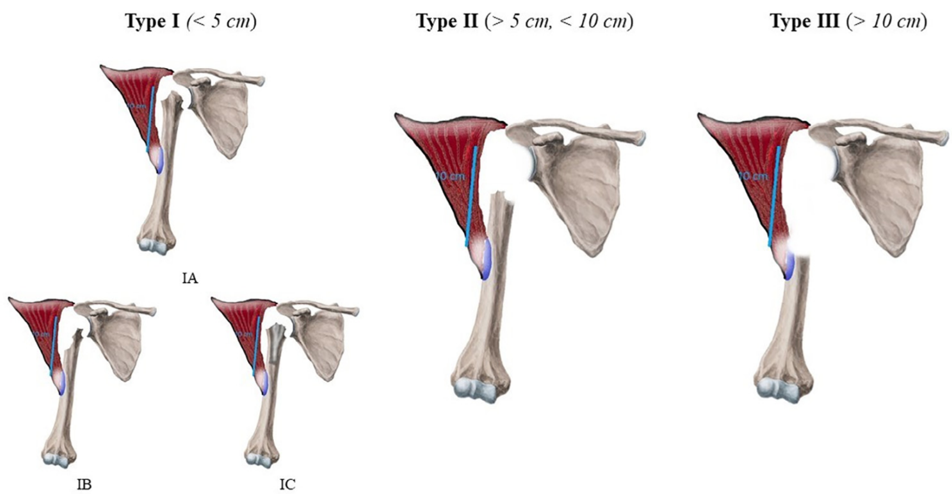

Figure 5 Modified classification of proximal humeral bone loss as originally described by McLendon et al.[9] Type I consists of cases of less than 5 cm of bone loss, often with loss of the tuberosities, and its associated subtypes. Type II includes cases of greater than 5 cm but less than 10 cm of bone loss, in which the majority of the deltoid insertion is intact. Type III includes cases in which there is greater than 10 cm of bone loss with significant compromise of the deltoid insertion.

Figure 6 Example of type IB bone loss in which there is less than 5 cm of bone loss medially but significantly more bone loss laterally. This patient was treated with an allograft–prosthetic composite.

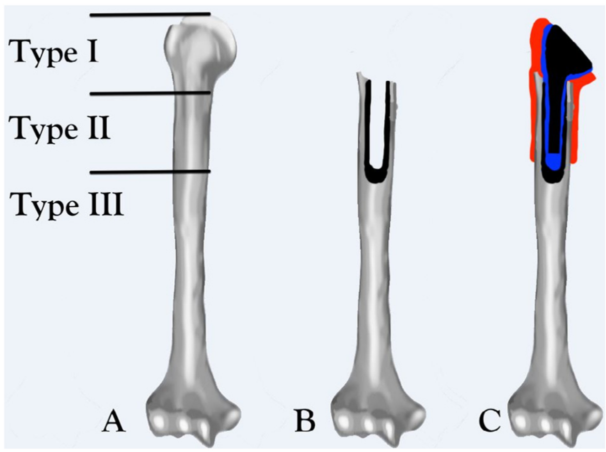

Figure 7 Type IC bone loss. **(A)** Three main bone loss categories of McLendon classification.[9] **(B)** Example of type IC, in which there is a well-fixed cement mantle and less than 5 cm of bone loss but the length of the mantle available to provide rotational stability is relatively short. **(C)** Example of cement-within-cement technique combined with allograft (in which *black* shows the remaining cement mantle; *blue*, new cement; and *red*, allograft).

the χ^2 test by an independent statistician. The level of significance was set at $P < .05$ for this study.

Results

Clinical outcome measures

The clinical outcomes are summarized in Table I. The average total ASES score improved from 33.7 to 51.1 (change of 17.4, $P < .0001$). The average ASES pain score improved from 23.8 preoperatively to 32.1 postoperatively (change of 8.3, $P < .0001$). The average ASES function score improved from 9.8 preoperatively to 19.4 postoperatively (change of 9.6, $P < .0001$). The average Simple Shoulder Test score improved from 1.3 preoperatively to 3.5 postoperatively (change of 2.2, $P < .0001$). Patient-perceived satisfaction at final follow-up was rated as good to excellent in 70% of patients, satisfied in 17%, and unsatisfied in 13%. Regardless of satisfaction, 83% of patients stated that they would undergo the APC procedure again if needed, and 3 of the 8 unsatisfied patients stated that they would still undergo the surgical procedure again if

Table I Clinical results

	Preoperative	Postoperative	Improvement	*P* value
ASES function score	9.8	19.4	9.6	<.001
ASES pain score	23.8	32.1	8.3	<.001
ASES total score	33.7	51.1	17.4	<.001
FF, °	49	75	27	<.001
AB, °	45	72	27	<.001
IR*	2	3	0	.3
ER, °	15	16	1	.8
SST score	1.3	3.5	2.2	<.001
Patient satisfaction				
Good to excellent		70%		
Satisfactory		17%		
Unsatisfied		13%		

ASES, American Shoulder and Elbow Surgeons; *FF*, forward flexion; *AB*, abduction; *IR*, internal rotation*; *ER*, external rotation; *SST*, Simple Shoulder Test.
* Measured in vertebral levels as follows: 0, ipsilateral hip; 1, ipsilateral back pocket; 2, contralateral back pocket; 3, S1/L5; 4, T11-L1; 5, T7-T10; 6, T4-T6; 7, T2-T3; 8, C8-T1.

needed. Only 1 of 8 unsatisfied patients experienced a complication; this patient had a periprosthetic infection 6 months postoperatively, ultimately requiring resection and placement of an antibiotic cement spacer. The patient elected not to undergo further reconstruction. The remaining 7 patients were unsatisfied regarding their functional deficits, and 3 had chronic pain.

Range of motion improved significantly in forward flexion and abduction compared with preoperative values. Average forward flexion improved from 49° preoperatively to 75° postoperatively (change of 26°, $P < .001$). Average abduction improved from 45° preoperatively to 72° postoperatively (change of 27°, $P < .001$). Average internal rotation improved from 2.2 to 2.6 vertebral levels ($P = .327$). Average external rotation increased from 15° preoperatively to 16° postoperatively (change of 1°, $P = .753$).

Radiographic analysis

Average bone loss measured on immediate postoperative radiographs was 55.0 mm (range, 20-211 mm). Radiographic incorporation was observed at the metaphysis in 39 of 73 patients (53%) and at the diaphysis in 61 of 73 patients (84%) at final follow-up. Ten patients had humeral stems suggestive of loosening, with either a 2-mm line in 3 or more zones or a change in component position.

Complications and survivorship analysis

Complications occurred in 19 patients (26%). There were 8 periprosthetic fractures, 4 dislocations, 3 patients with humeral loosening, 2 glenosphere dissociations, and 2 infections. In total, 14 patients (19%) required revision. Of the revisions, 6 were for periprosthetic fracture; 2, instability with dislocation; 2, glenosphere dissociation; 2, humeral loosening; and 2, infection. Of the periprosthetic fractures, 3 occurred at the junction of the allograft and host bone and 3 occurred at the level of the distal tip of the humeral stem. Two of the distal fractures presented with radial nerve palsy after the fracture but before revision, and neither recovered at the time of most recent clinical follow-up. Two of the proximal fractures were treated with revision to a long-stem prosthesis using a new allograft–prosthetic component, whereas one was addressed with open reduction–internal fixation using a plate-and-screw construct. Two of the distal fractures were addressed with plate-and-screw constructs, and one was revised with a repeated allograft–prosthetic component and a long-stem prosthesis.

The overall reoperation-free survival rate was 88% (30 of 34) at 5 years, 78% (21 of 27) at 10 years, and 67% (8 of 12) beyond 10 years in our patient population. When we excluded infection, instability, or glenoid-sided failures, the humeral-sided revision-free survival rate was 94% (32 of 34) at 5 years, 89% (24 of 27) at 10 years, and 75% (9 of 12) beyond 10 years.

Subgroup analysis

There were 25 shoulders with type I bone loss (1 type IA, 11 type IB, and 13 type IC), 34 with type II bone loss, and 14 with type III bone loss. Revision was performed in 2 shoulders (8%) with type I bone loss versus 7 shoulders (21%) with type II and 5 shoulders (36%) with type III bone loss ($P = .104$). Subgroup analysis between these types of bone loss was underpowered to detect differences in additional variables such as failure types, patient satisfaction, and functional outcomes. Moreover, no significant difference was detected when we compared patients presenting with failed HA versus RSA and undergoing APC reconstruction.

Regarding stem size, 46 patients had a 6-mm stem (11 revisions, 24%) and 20 had an 8-mm stem (3 revisions, 15%), whereas 6 had a 10-mm stem and 1 had a 12-mm stem (no revisions). The difference in the revision rate between 6- and 8-mm stems was not significant ($P = .4156$). Two cases of stem breakage occurred, both in the middle portion of 6-mm stems. The operation was performed with the cement-within-cement technique in 27 patients, 6 (22%) of whom underwent revision. This was not statistically significant in comparison with the remainder of the population (P = .6128).

Discussion

Proximal humeral bone loss represents a complex problem with a heterogeneous presentation. The quantity of bone loss and the quality of the remaining bone are important considerations in the management of these patients. In cases with mild proximal humeral bone loss (typically <5 cm) with good bone quality, successful results can be achieved with a long monobloc humeral stem. Budge et al[2] reported excellent results using this technique in a small population of patients with an average of 38 mm of bone loss. In more advanced cases of bone loss, however, lack of proximal humeral bony support becomes more problematic. Biomechanical analysis has shown that increased bending and torsional forces are exerted on the humeral component when significant bone loss is present,[4] which can ultimately lead to mechanical failure. The increased stress on the humeral implant is often further exacerbated by use of larger glenospheres as a method to prevent instability. Increasing the contact area between the glenosphere and humeral socket adds further constraint to the articulation, and this increased constraint is then transmitted to the humeral stem. This rationale leads to the selection of the APC treatment strategy of this study as one such solution to provide additional support for a revision construct.

When revision of a cemented stem is being performed, one strategy that has become popular is the cement-within-cement technique. This technique, which preserves proximal humeral bone stock and avoids the morbidity associated with cement removal, has shown good medium-term survival rates in revision shoulder arthroplasty.[17] However, we suggest that caution be used when considering this technique in the setting of proximal humeral bone loss, as there is no current literature to guide the orthopedic surgeon as to what minimum length of remaining cement mantle is necessary to impart rotational stability to the construct. In this series, cases that were classified as type IC (13), in which there was less than 5 cm of bone loss but the remaining cement mantle was considered to be of inadequate length to provide rotational stability, were augmented with an allograft. These constructs showed excellent results, with only 1 revision due to periprosthetic fracture. Nevertheless, this is certainly an area that warrants further study, perhaps with biomechanical testing as well as additional clinical data.

Our previous data demonstrated excellent early clinical results with the use of a reverse shoulder APC to treat advanced bone loss, with significant, though modest, improvements in pain, range of motion, and function.[3] A recent study by Sanchez-Sotelo et al[13] reported similarly excellent clinical results and survivorship, with an allograft-specific survival rate of 96% and overall survival rate of 80% at 5 years. In the current study, we found an overall survival rate of 88% at 5 years, as well as a humeral-sided survival rate of 94% at 5 years, 89% at 10 years, and 75% beyond 10 years. Sanchez-Sotelo et al reported similar improvements in the range of motion and clinical scores of patients, with increased elevation of 41° to 98° and a mean ASES functional score at final follow-up of 66.1. These results parallel our increase in elevation from 49° to 75° and increase in the ASES score from 33.7 to 51.1 at final follow-up. The extended follow-up in this study showed that although additional complications and revisions did occur over time, patients continued to demonstrate significant improvements in clinical outcomes, with an acceptable rate of survivorship.

To our knowledge, this is the largest population of reverse shoulder APCs reported in the literature. Unfortunately, the study remains somewhat underpowered to detect differences between the subgroups. For instance, patients with more advanced type III bone loss and smaller-diameter stems showed higher rates of revision, although these were not found to be statistically significant. In addition, as a retrospective case series, this study does not address the comparison of APCs with alternative treatment strategies such as proximal humeral replacement, a mega-prosthesis, or osteoarticular allografts that have also been used to address significant proximal humeral bone loss. Teunis et al[15] performed a meta-analysis of available literature discussing the use of these differing techniques to address bone loss after complicated resection for tumors of the proximal humerus. Overall, reconstructions with APCs and prostheses had similar implant survival rates and functional scores, but caution is advised because, given the small sample sizes and substantial heterogeneity of the patient populations, it is difficult to demonstrate the clear superiority of any particular technique.

Conclusion

In our series of patients, the use of a reverse total shoulder allograft composite for the treatment of large proximal humeral bony defects has shown consistent, though modest, clinical improvement and acceptable construct survival at extended follow-up of up to 15 years. To date, no other treatment option has shown superior long-term clinical outcomes for this challenging problem. The results of this study provide a useful comparison by which to test emerging techniques and strategies and to counsel patients as to what can be reasonably expected when confronting challenging reconstructive scenarios of the proximal humerus.

Disclaimer

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