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A retrospective review of revision proximal humeral allograft-prosthetic composite procedures: an analysis of proximal humeral bone stock restoration

Taylor Reif, MD[a], Bradley Schoch, MD[b], Andre Spiguel, MD[a], Bassem Elhassan, MD[c], Thomas Wright, MD[a], Joaquin Sanchez-Sotelo, MD, PhD[c], Benjamin K. Wilke, MD[b,*]

[a]*Department Orthopaedic Surgery and Rehabilitation, University of Florida, Gainesville, FL, USA*
[b]*Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA*
[c]*Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, FL, USA*

Background: Allograft-prosthetic composite (APC) reconstruction of the proximal humerus is a technique for reconstruction of large bone deficits, provides improvement in pain and function, and is thought to restore bone if revision surgery is needed. The purpose of this study was to evaluate the ability of proximal humeral APCs to restore usable bone at the time of revision surgery.
Methods: Two institutional electronic medical records were reviewed to evaluate proximal humeral APC procedures performed between 1970 and 2018. We identified 115 cases, of which 14 underwent revision for aseptic causes. The indications for revision included nonunion (n = 7), glenohumeral instability (n = 5), and allograft fracture (n = 2). Three categories were used to classify the amount of usable allograft retained at revision surgery: type A, complete allograft retention; type B, partial retention; and type C, no retention.
Results: A total of 14 patients (6 male and 8 female patients) underwent revision of the APC reconstruction at a mean of 22.8 months. At revision, allograft retention was classified as type A in 6 shoulders, type B in 3, and type C in 5. Type A cases were associated with nonunion with a well-fixed stem, type B cases were associated with instability and were converted from a hemiarthroplasty to a reverse total shoulder arthroplasty, and type C cases were associated with an allograft fracture or nonunion with a loose humeral component.
Conclusion: A substantial number of revisions of proximal humeral APC reconstructions maintain a portion of the allograft bone (64.3%). This study supports the ongoing use of the APC reconstruction technique for large bone deficits.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Shoulder arthroplasty; APC; allograft; allograft-prosthetic composite; revision; reconstruction

Large proximal humeral bone deficits represent a challenging reconstructive problem most commonly encountered at the time of tumor resection, surgical management of infection, or failed arthroplasty.[14,17,22] Options for reconstruction of these defects historically have included

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*Reprint requests: Benjamin K. Wilke, MD, Department of Orthopedic Surgery, Mayo Clinic, 4500 San Pablo Rd, Jacksonville, FL 32224, USA.
E-mail address: wilke.benjamin@mayo.edu (B.K. Wilke).

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osteoarticular allografts, allograft-prosthetic composites (APCs), or mega-prostheses.[2] Osteoarticular allografts are an attractive biological option, but collapse of the cartilaginous surface leading to instability as well as articular degeneration limits their longevity and practical use.[20] Mega-prostheses have continued to improve with more modular options for length and joint stability, but they provide limited opportunity for attachment of the soft tissues to the metal surfaces to restore function to the shoulder girdle musculature.[24] In addition, certain designs fail to restore proximal humeral bulk, leading to the inability to restore the deltoid tension, which may affect component stability.[23] Biomechanical studies also suggest that these modular prostheses are at a higher risk of torsional failure over time.[9] APC reconstruction combines the benefits of a prosthetic joint and the potential biological healing of the shoulder tendons to the allograft, which has the potential to improve function.[3,22]

An additional purported benefit of APCs is the restoration of bone stock for future revision procedures.[16] This has been studied in other anatomic regions, but to our knowledge, this benefit has never been examined in the shoulder.[27] This study evaluates whether APC reconstruction restores usable bone stock at the time of revision surgery when performed in the proximal humerus. On the basis of previous retrieval studies that demonstrated that most of the allograft remains acellular even after several years, we hypothesized that the humeral allograft bone would be completely replaced by a new allograft at the time of revision surgery in the majority of cases, similarly to what is reported for other anatomic sites.[11-13]

Methods

We conducted a retrospective chart review of patients who underwent a proximal humeral APC reconstruction at Mayo Clinic and the University of Florida between 1970 and 2018. A total of 115 proximal humeral APC procedures were performed over the study period. We identified 14 patients (12%) who had undergone a revision procedure for an aseptic cause and reviewed their medical records. Patient demographics were obtained. Allograft retention was determined from the operative reports of the revision procedure and categorized as previously described: type A, complete allograft retention (100%); type B, partial retention (1%-99%); and type C, no allograft retention (0%).[27]

Outcomes were analyzed using appropriate summary statistics with 95% confidence intervals. All statistical tests were 2-sided with a P value set to .05. Analyses were performed using SPSS software (version 25; IBM, Armonk, NY, USA).

Results

Of the 14 patients included in the study, 6 were male patients (43%) and 8 were female patients (57%); the average age was 35 years (range, 8-70 years). The average follow-up period was 6.7 years (range, 1.8-21.6 years). The average time from APC placement to revision surgery was 22.8 months (range, 1.7-237.2 months). Patient demographics are listed in Table I.

The indication for the initial APC reconstruction was tumor resection in 11 shoulders (79%). Other indications included failed arthroplasty in 2 shoulders (14%) and periprosthetic fracture in 1 (7%). Most patients underwent placement of a hemiarthroplasty during the initial APC procedure (11 of 14, 79%), with 3 patients (21%) undergoing reverse total shoulder arthroplasty during the initial APC procedure. The APCs were fixed by a variety of techniques, with transverse osteotomy with compression plating and cementation of a humeral stem as the most frequent form of fixation (6 of 14 [43%]). Other forms of fixation included transverse osteotomy with cement fixation only (3 of 14 [21%]), step-cut osteotomy with allograft and strut cables (2 of 14 [14%]), step-cut osteotomy with a cemented stem (1 of 14 [7%]), transverse osteotomy with vascularized fibula and a cemented stem (1 of 14 [7%]), and intussusception of the allograft into the native humerus (1 of 14 [7%]). The indications for revision surgery of the failed APC construct included aseptic nonunion in 7 patients (50%), glenohumeral instability in 5 (36%), and allograft fracture in 2 (14%) (Table II).

In the nonunion group, 4 patients (57%) presented with a stable prosthetic component and nonunion at the allograft-host junction. These patients underwent revision surgery in an effort to promote healing at the allograft-host junction, including compression plating and bone grafting at the junction site. All 4 patients had complete retention of the allograft (type A resection).

The remaining 3 patients with a diagnosis of nonunion presented with evidence of prosthetic loosening. Of these 3 patients, 2 underwent revision to a mega-prosthesis whereas the remaining patient underwent placement of a

Table I Patient demographics

Characteristic	Data
Average age at initial surgery (range), yr	35 (8-70)
Average time to revision surgery (range), mo	22.8 (1.7-237.2)
Average follow-up (range), yr	6.7 (1.8-21.6)
Sex, n	6 male/8 female
Reason for index APC procedure, n	
Oncologic	11
Non-oncologic	3
Reason for revision surgery, n	
Nonunion at host junction	7
Glenohumeral instability	5
Allograft fracture	2

APC, allograft-prosthetic composite.

Table II Individual patient results

Sex/ Age, yr	Date from initial surgery to revision, mo	Time from surgery to last follow-up, yr	Date of revision surgery	Reason for APC procedure	Initial fixation	Reason for revision	Amount of allograft preserved at revision
M/16	121	10	2017	Osteosarcoma	Transverse osteotomy with plate and cemented stem	Nonunion	C: APC removed and revised to mega-prosthesis
M/50	7	4	2015	Chondrosarcoma	Transverse osteotomy with plate and cemented stem	Instability	A: rTSA revised to thicker polyethylene
M/40	6	6	2013	Chondrosarcoma	Transverse osteotomy with plate and cemented stem	Nonunion	A
F/22	17	11	2008	Osteosarcoma	Transverse osteotomy with plate and cemented stem	Nonunion	A
F/25	9	10	2003	Osteosarcoma	Transverse osteotomy with cemented stem	Nonunion	A
F/17	25	9	2003	Giant cell tumor	Transverse osteotomy with cemented stem	Nonunion	C: APC removed and revised to mega-prosthesis
F/8	17	4	2016	Osteosarcoma	Transverse osteotomy, vascularized fibula, and cemented stem	Nonunion	A
F/58	37	4	2017	Failed rTSA	Transverse osteotomy with plate and cemented stem	Fracture of allograft	C: APC removed and revised to new APC
F/49	21	9	2000	Chondrosarcoma	Step-cut osteotomy with cemented stem	Instability	B: allograft retained and cut for placement of rTSA
M/52	237	22	2014	Chondrosarcoma	Stem-cut osteotomy with allograft strut and cables	Instability	C: APC removed and revised to new APC
F/65	28	4	1997	Periprosthetic fracture	Transverse osteotomy with plate and cemented stem	Instability	B: allograft split in half and proximal portion removed.
M/51	20	2	1997	Chondrosarcoma	Step-cut osteotomy with allograft strut and cables, as well as cemented stem	Nonunion	C: APC removed and revised to new APC
M/50	163	18	2014	Aneurysmal bone cyst	Transverse osteotomy with cemented stem	Instability	B: allograft retained and cut for placement of rTSA
F/70	2	4	2014	Failed rTSA	Intussusception of allograft into native bone	Fracture of allograft	A: longer stemmed prosthesis placed and original allograft cabled

APC, allograft-prosthetic composite; *M*, male; *C*, 0% of allograft; *A*, 100% of allograft; *F*, female; *B*, partial preservation of allograft; *rTSA*, reverse total shoulder arthroplasty.

new APC. All 3 patients underwent removal of the entire initial allograft during the revision surgical procedure (type C resection).

Revision was performed for recurrent shoulder instability in 5 patients (36%). Of these 5 cases, 4 (80%) had hemiarthroplasty components that were converted to a reverse total shoulder replacement during the revision procedure. In 3 of the 4 cases, the allograft was retained with modifications to allow placement of the reverse component (type B resection). In the fourth case, the entire allograft was removed (type C resection) (Fig. 1). The fifth revision case involved a reverse total shoulder arthroplasty with recurrent dislocations. The patient underwent revision to increase the polyethylene thickness at 7 months after the initial surgical

procedure. The entire allograft was retained during the revision procedure (type A resection).

Two patients underwent revision because of a fracture in the allograft. One underwent revision to a longer-stemmed prosthesis to bypass the fracture, and the allograft was retained and cabled (type A resection). The other patient underwent removal of the entire allograft with placement of a new APC (type C resection).

At the time of revision, there were 6 type A resections (43%), 3 type B resections (21%), and 5 type C resections (36%) (Fig. 2). When we compared patients who had at least a portion of their allograft retained (types A and B) vs. those who had the entire allograft removed (type C) at revision surgery, the average time to revision was significantly longer in those with a type C resection (88 ± 83 months vs. 30 ± 47.6 months, $P = .04$).

Discussion

APC reconstruction of the proximal humerus represents an attractive option for large bone defects at the time of reconstructive shoulder surgery. Several studies have reported on the outcome of this technique compared with other reconstructive options, such as osteoarticular allografts or mega-prostheses.[1,8,20] Purported benefits of these bulk allograft constructs range from having the ability to reattach soft tissues to using the allograft to restore bone stock for future revision procedures and reducing torsional stress on the implant.[6,9,16] Although this has been studied in other anatomic regions, no study, to our knowledge, has evaluated whether the humeral allograft bone is retained during a revision procedure of the APC.[27]

In our series, retention of the entire allograft was achieved in 43% of cases, with an additional 21% maintaining a portion of the allograft at the time of revision. There were 3 primary modes of aseptic failure in our patient population: nonunion at the allograft–host bone junction (with or without implant loosening), glenohumeral instability, and allograft fracture. Similarly to other series, our study found nonunion at the allograft–host bone junction to be the most common mode of failure.[1,10,14] APCs were most commonly fixed to the native bone using a transverse osteotomy and compression plating. It is unclear whether newer techniques that increase bone apposition can decrease the rates of nonunion.[19,26]

Wheeler et al[25] previously reviewed the biomechanical properties of retrieved allografts and found that their strength decreased over time, increasing the risk of failure. However, the low rate of fracture in our study is similar to findings in other reported series.[1,8,10] Cox et al[8] reported on 73 proximal humeral APCs at a mean follow-up of 68 months. In their series, 6 shoulders underwent reoperation for postoperative fractures. Of these shoulders, 3 sustained a fracture at the junction and were treated with revision to another APC (2 shoulders) or internal fixation (1 shoulder), whereas the

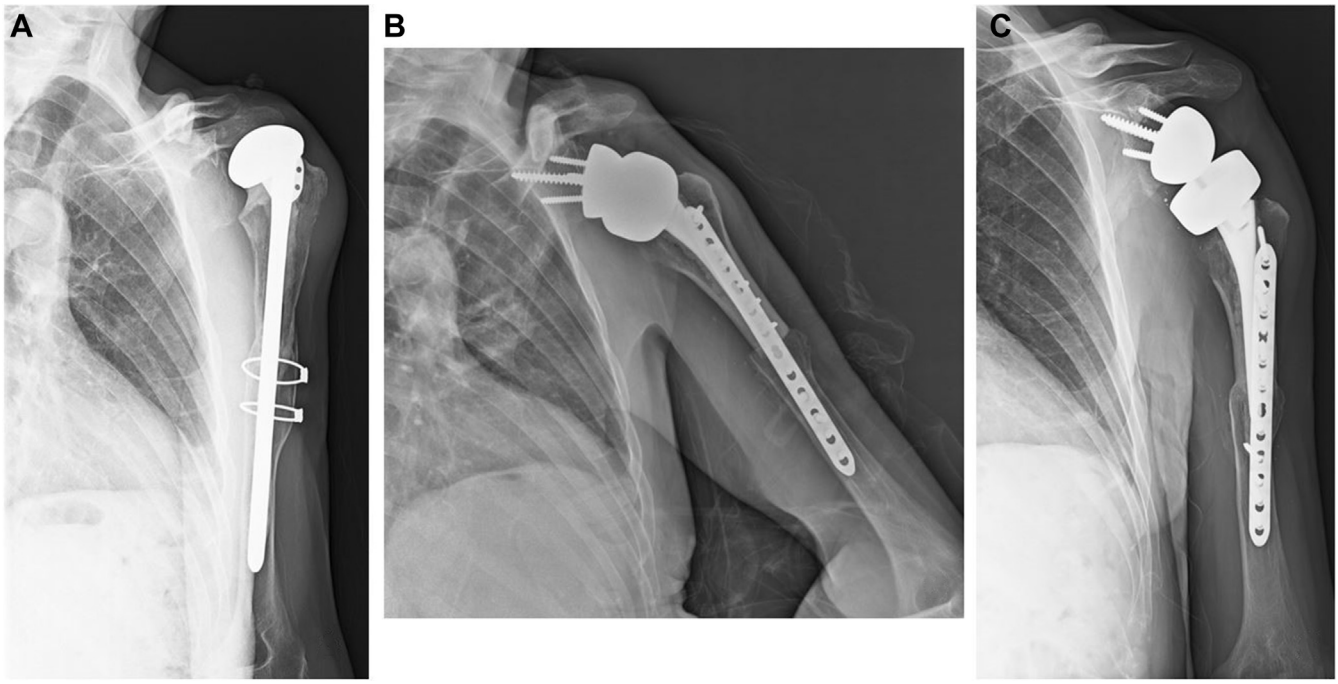

Figure 1 (**A**) A 52-year-old male patient underwent a proximal humeral allograft-prosthetic composite reconstruction after resection of a chondrosarcoma. (**B**) Because of persistent instability, the patient underwent revision to a new allograft-prosthetic composite (type C resection) with a reverse shoulder arthroplasty component. (**C**) At final follow-up, the junction site had healed and the patient was doing well.

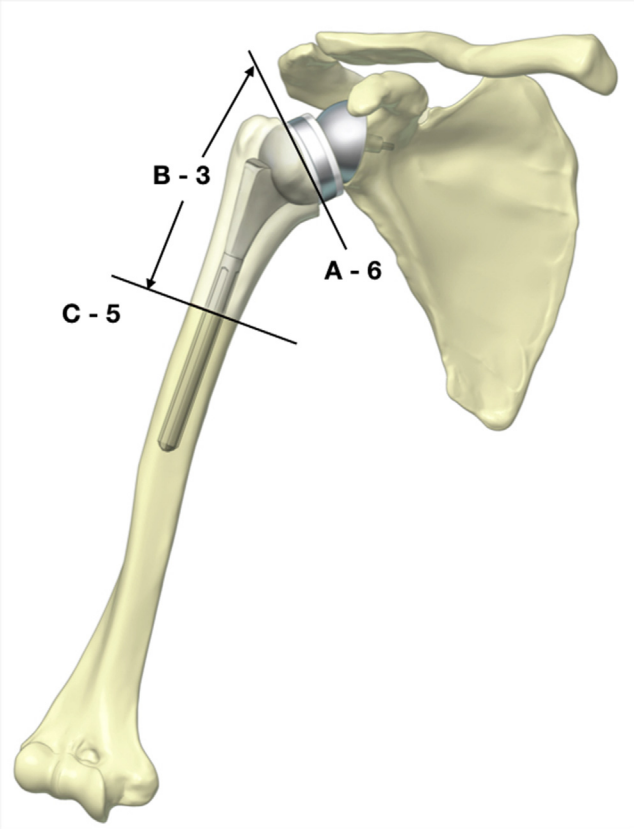

Figure 2 Representation of allograft retention at time of revision surgery. Type A (100% of allograft retained) occurred in 6 shoulders; type B (1%-99% of allograft retained), 3 shoulders; and type C (0% of allograft retained), 5 shoulders.

other 3 occurred below the APC and were managed with internal fixation (2 shoulders) or revision to another APC (1 shoulder).

Glenohumeral instability was another common reason for revision in our series. Previous authors have documented instability as a common complication of proximal humeral APC procedures.[1,14,20] Prior to the introduction of reverse shoulder arthroplasty, many shoulders undergoing APC procedures were treated with a hemiarthroplasty with attempted repair of the soft tissues. In the setting of failed healing of the native rotator cuff, these implants are at risk of dislocation or superior escape.[1,5,14,20,21] APC procedures performed with reverse shoulder arthroplasty components have increased stability and have been reported to have fewer complications related to instability.[7,15,17,22] It is now our belief that reverse total shoulder components should be preferentially used for proximal humeral APCs when possible.

Previous studies have touted restoration of bone stock as an advantage of an APC.[4,16,18] The definition, however, is not clearly defined in the literature. Prior retrieval studies have demonstrated that only a small portion of the allograft is replaced with new bone through creeping substitution after several years.[11-13] In the report by Wilke et al,[27] bone stock was considered "restored" only if the allograft incorporated (ie, healed) to the host bone and remained during future procedures. Our current study demonstrated that in 64% of revision APC procedures, the allograft bone was completely or partially retained at the conclusion of surgery, suggesting that APCs of the proximal humerus can indeed restore bone stock.

This study has several limitations. It was a retrospective review of reconstructive shoulder surgical procedures performed over a wide time frame. Surgical techniques and implants evolved during this period, and the effect of technique changes cannot be fully evaluated. In addition, we only evaluated APCs that underwent revision surgery for an aseptic cause and did not consider patients who underwent revision for septic arthritis or those who may have needed revision but were not candidates because of medical issues. Many of the patients in our cohort underwent an initial APC placement after tumor resection. The results of these patients may not be generalizable to patients who undergo an APC for a failed arthroplasty. Given the retrospective nature of the study, we were also unable to include functional outcome testing or histologic analysis of the allograft removed during the revision procedures. Given the rarity of the procedure, however, we believe it would be difficult to perform an appropriately powered prospective study that included those features. Although the overall numbers were low, the study was performed at 2 tertiary referral centers, further emphasizing the rarity of the procedure. To our knowledge, this is the only study evaluating the fate of the allograft bone during revision of a proximal humeral APC.

Conclusion

The results of this study demonstrate the common failure modes of proximal humeral APCs: nonunion, glenohumeral instability, and allograft fracture. In most cases, the majority of the allograft was retained during the revision procedure, and these cases can therefore be considered to have restored bone stock. This study supports the ongoing use of the APC reconstruction technique for large bone deficits.

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