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Outcomes of Humeral Allograft-Prosthetic Composites with Plate Fixation in Revision Total Elbow Arthroplasty

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Background: Traditionally, the reconstruction of severe distal humeral bone loss at the time of revision total elbow arthroplasty (TEA) has used allograft-prosthetic composites (APCs) stabilized with cerclage wires or cables. We have migrated to plate fixation when revision TEA using a humeral APC is performed. This study shows the outcomes of patients treated with a humeral APC with plate fixation during revision TEA.

Methods: Between 2009 and 2019, 41 humeral APCs with plate fixation of distal humeral allograft to the native humerus were performed in the setting of revision TEA. There were 12 male patients (29%) and 29 female patients (71%), with a mean age of 63 years (range, 41 to 87 years). The mean allograft length was 12 cm. All elbows had a minimum follow-up of 2 years (mean follow-up, 3.3 years). Patients were evaluated for visual analog scale pain scores, range of motion, the ability to perform select activities of daily living, and the Mayo Elbow Performance Score (MEPS). Outcomes including reoperations, complications, and revisions were noted. The most recent radiographs were evaluated for union at the allograft-host interface, failure of the plate-and-screw construct, or component loosening.

Results: The mean postoperative flexion was 124° (range, 60° to 150°) and the mean postoperative extension was 26° (range, 0° to 90°); the mean arc of motion was 99° (range, 30° to 150°). The mean MEPS was 58 points (range, 10 to 100 points). Two surgical procedures were complicated by neurologic deficits. The overall reoperation rate was 14 (34%) of 41. Of the 33 patients with complete radiographic follow-up, 12 (36%) had evidence of nonunion at the allograft-host interface with humeral component loosening, 1 (3%) had evidence of partial union, and 1 (3%) had ulnar stem loosening.

Conclusions: Revision TEA with a humeral APC using compression plating was successful in approximately two-thirds of the elbows. Further refinement of surgical techniques is needed to improve union rates in these complex cases.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Total elbow arthroplasty (TEA) is used to treat many arthritic conditions, including primary osteoarthritis, rheumatoid arthritis, and posttraumatic arthritis[1-4]. It is also used for acute fractures in the elderly population that are not otherwise amenable to fixation, as well as tumors about the elbow[5-7]. Unfortunately, revision rates after TEA are high and growing[8,9].

Failed TEAs are challenging to treat and may present with extensive bone loss[10,11]. Resection arthroplasty for failed TEA generally results in unsatisfactory outcomes[12]; therefore, reconstructive options are often pursued. In particular, bone loss can be managed with impaction grafting, allograft struts, modular tumor megaprostheses, or allograft-prosthetic composites (APCs)[13-17].

Several studies have shown unacceptably high failure rates with use of APCs for the management of bone loss in revision TEA[18,19]. However, technique modifications that improve the contact area between the host and the allograft have been developed to hopefully improve outcomes[20]. With these modifications, Morrey et al. evaluated 25 patients, reporting incorporation of the graft in 92% of elbows and functional elbows in 84% of patients, albeit still with a high reoperation rate[20].

Most previous studies evaluating outcomes of APCs have used cerclage cables traditionally to secure the construct to the host bone[18,19]. These constructs do not confer absolute stability to the host-graft interface, do not follow the AO (Arbeitsgemeinschaft

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A562).

für Osteosynthesefragen) principles of fracture fixation[21], and are more susceptible to rotational stress than plate fixation. Farfalli et al. evaluated using allografts without prostheses for tumor reconstruction using 2 plate constructs and reported a 100% union rate[22]. As such, it appears promising to apply the same principles of plate fixation to APC reconstruction in revision TEA for massive humeral bone loss.

The principal objective of this study was to retrospectively evaluate radiographic and clinical outcomes of patients treated with a humeral APC with plate fixation in revision TEA. The secondary objective was to assess for a correlation between allograft characteristics, such as host-graft interface type or APC length, and failure of the reconstruction.

Materials and Methods

After obtaining approval from the institutional review board, the study cohort was identified via the institutional Total Joint Registry Database. Other details not found within the registry were garnered via direct assessment of the patients' electronic charts.

Patient Demographic Characteristics

Between 2009 and 2019, 41 humeral APCs with plate fixation were performed in the setting of revision TEA. All patients who underwent this procedure were included in the study, regardless of the reason for revision, number of previous surgical procedures, or type of primary implant. There were 12 male patients (29%) and 29 female patients (71%). The mean age was 63 years (range, 41 to 87 years), and the mean body mass index (BMI) was 31 kg/m^2 (range, 21 to 48 kg/m^2). The mean follow-up was 3.3 years, and all elbows had a minimum follow-up of 2.1 years (Table I).

Surgical Procedure

Three highly experienced shoulder and elbow surgeons performed all of the surgical procedures. In most patients (37 of 41), the surgical procedure was performed with the patient supine and the surgical extremity across the chest, and the elbow was approached through a standard posterior skin incision. The remaining patients (4 of 41) had very limited proximal humeral bone stock, and the reconstruction was performed in the beach-chair position through a deltopectoral approach, to maximize plate fixation in the remaining proximal humerus. In all patients, deep exposure was achieved through either a para-olecranon approach or a para-tricipital approach. The failed humeral component was unlinked from the ulnar component. The humeral component was then removed and the native host bone was debrided. The ulnar component was revised if it was determined to be loose intraoperatively.

The frozen humeral allograft was then prepared on the back table. The medullary canal of the allograft was opened, and instrumentation for the selected implant was used to prepare the

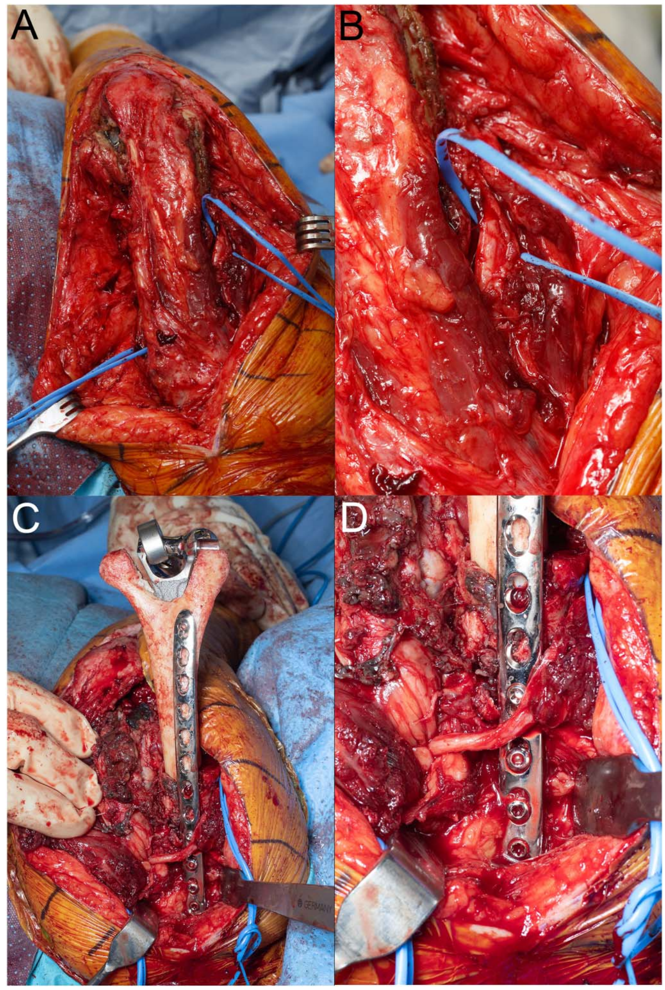

Fig. 1

Intraoperative photographs showing the surgical technique. **Fig. 1-A** A long posterior incision is used to expose the previous implant and humeral shaft. In this case, a para-olecranon approach was used. Both the ulnar (left) and radial (right) nerves are dissected and placed within vessel loops. **Fig. 1-B** Close-up view of the radial nerve, which has been dissected free. **Fig. 1-C** The APC is prepared and approximated to the residual proximal humerus via compression plating. **Fig. 1-D** The final construct at the host-graft interface, with the radial nerve overlying the plate.

TABLE I Demographic Characteristics

Variable	Value
Elbows	41
Male*	12 (29%)
Female*	29 (71%)
Age† *(yr)*	63.2 (41 to 87)
BMI† *(kg/m^2)*	31 (21 to 48)
Follow-up† *(yr)*	3.3 (2.1 to 5.8)

*The values are given as the number of elbows, with the percentage in parentheses. †The values are given as the mean, with the range in parentheses.

allograft to receive the humeral component. The arthroplasty implant systems used were the LATITUDE EV (Tornier), Discovery Elbow (DJO), and Coonrad-Morrey Elbow (Zimmer Biomet). If the ulnar component was retained (i.e., it was not loose), then the corresponding implant was always used. If both components needed revision, the LATITUDE EV implant was preferred on the basis of institutional surgeon preference and historical survivorship. Trials were then used in the native elbow to determine the ideal length of the graft.

The strategy for fixation of the APC varied depending on the amount of the humerus missing and surgeons' preferences. The humeral component was cemented across the host-graft junction in most elbows (34 [83%] of 41), but, in those elbows missing more than two-thirds of the humerus, the humeral component was cemented only into the allograft (7 [17%] of 41 elbows). The junction consisted of a simple transverse cut in 18 cases (44% of elbows), but, in the remaining elbows, the graft was fitted with a strut-like extension and various amounts of intussusception.

Fracture reduction forceps were used to compress across the junction, and 3.5-mm small-fragment plates were provisionally applied. Then, per AO principles, a non-locking screw was placed to compress the plate to the bone proximal to the junction. Next, another non-locking screw was placed eccentrically distal to the junction. This achieved compression across the junction site when the screw head engaged the plate. Then additional non-locking screws were placed to further compress the plate to the bone. Finally, locking screws were placed to create a rigid fixed-angle construct to maintain the compression previously achieved with the non-locking screws (Fig. 1).

Cerclage cables or wires were applied for supplemental fixation in 9 cases (22% of elbows), but they were not relied upon as the primary mode of fixation. In selected elbows where the anterior humeral flange did not contact the humeral surface or where the interface tended to flex and gap open posteriorly, an anterior strut or cement was used behind the flange. Care was taken to reconstruct the humerus in the correct rotation, and all elbow arthroplasties included in this study were performed in a linked configuration. Postoperatively, patients were placed in a splint until superficial incision healing was achieved in 1 to 2 weeks. Thereafter, institutional rehabilitative programs were implemented.

Clinical Assessment

Elbows were assessed using a visual analog scale (VAS) for pain, range of motion (flexion and extension), Mayo Elbow Performance Score (MEPS), and ability to perform select activities of daily living during postoperative follow-up with the primary surgeon and/or their assistant and/or by clinical surveys. Functional outcomes and range of motion data were available in 37 (90%) of the 41 elbows. Complications, reoperations, and revision procedures were also recorded.

Radiographic Assessment

Radiographs were made immediately postoperatively and at 6 weeks, 3 months, 6 months, 1 year, and then every year postoperatively. The most recent anteroposterior and lateral views of the elbow and humerus were evaluated for union at the allograft-host

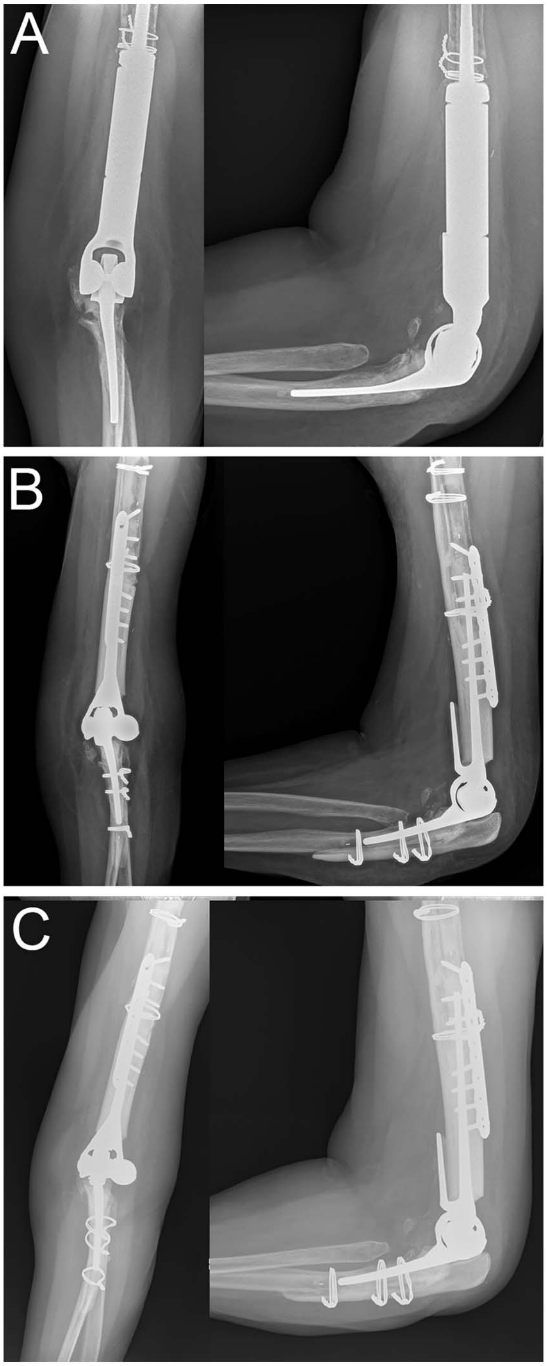

Fig. 2

Radiographs of a patient who underwent revision TEA with a humeral APC fixed with a plate. **Fig. 2-A** Preoperative anteroposterior and lateral radiographs of the elbow demonstrating loosening of the humeral stem of the distal humeral megaprosthesis. **Fig. 2-B** Early postoperative radiographs at 12 weeks demonstrating revision TEA with a humeral APC augmented with plate-and-screw fixation. An ulnar allograft strut was also placed in this patient for triceps reconstruction. **Fig. 2-C** Late postoperative radiographs, at 26 months, demonstrating intact instrumentation, no evidence of loosening of the humeral stem, and osseous union at the step-cut allograft-host interface.

interface, plate-and-screw fixation, and component fixation. Nonunion was defined as persistent lucency across the junction, lack of cortical bridging, or resorption of the end of the bone beyond 6 months postoperatively. The length of the allograft component of the APC was measured, and the type of allograft-host interface (end-to-end, step-cut, use of intussusception, use of an additional anterior strut behind the humeral flange) was noted.

Statistical Analysis

Data were analyzed using customary descriptive statistics. Continuous variables were reported using means and standard deviations, whereas categorical data were reported using counts and percentages. Chi-square analysis was used for subgroup analysis of the association between allograft-host interface type and instrumentation failure. Subgroup analysis of the association between APC length and instrumentation failure was performed via a Kruskal-Wallis analysis. Survivorship of the arthroplasty free of revision, with a 95% confidence interval, was calculated using Kaplan-Meier estimation. Significance was set at $p < 0.05$. The incidences of reoperations and other complications were also recorded. SAS (version 9.4M6; SAS Institute) was used for analysis.

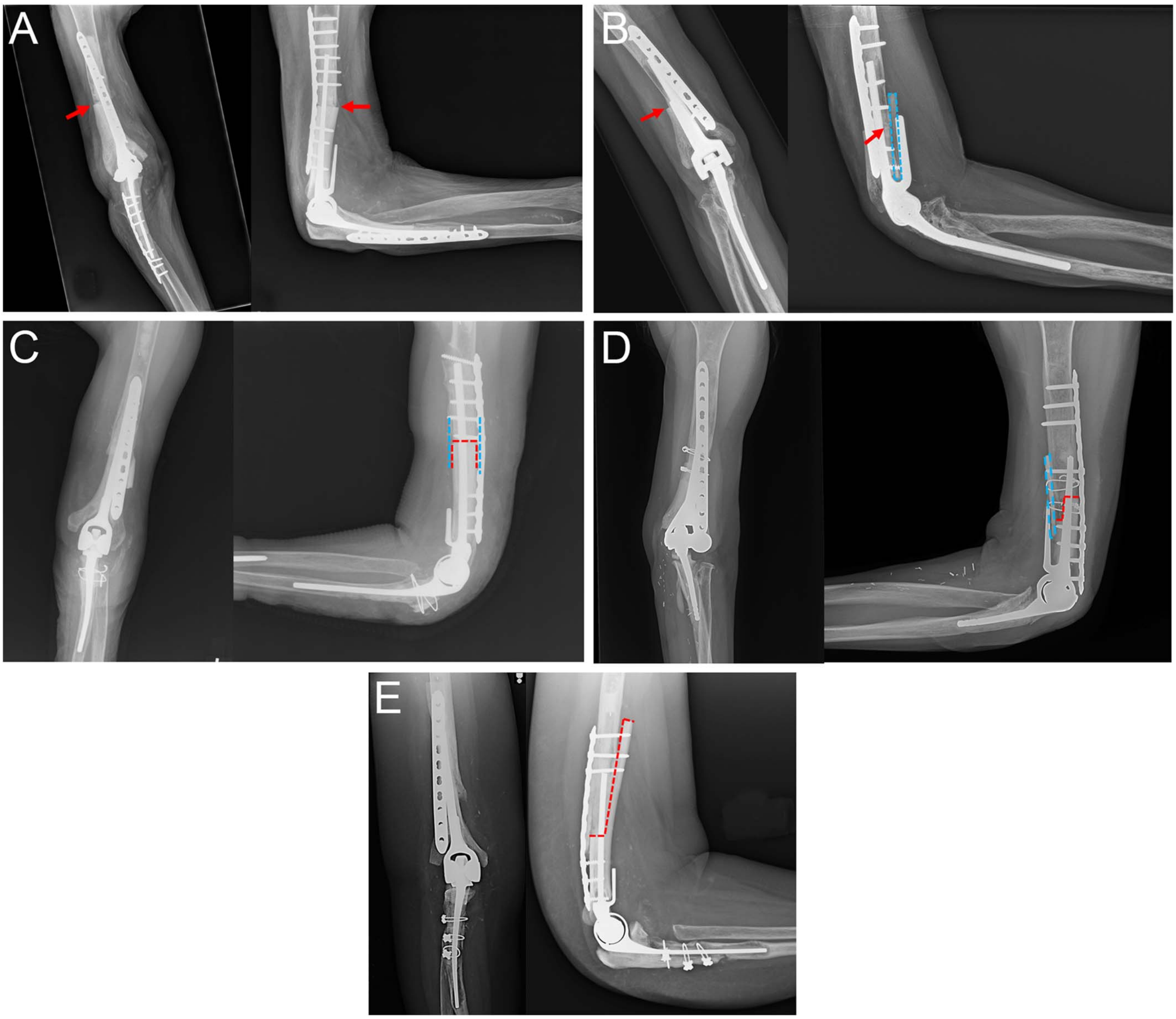

Fig. 3

Types of allograft-host interfaces. **Fig. 3-A** End-to-end interface (red arrows). **Fig. 3-B** End-to-end interface (red arrows) with an additional allograft strut behind the humeral flange (blue dashed rectangle). **Fig. 3-C** Intussusception of the allograft (red dashed line) into the native humerus (blue dashed line). **Fig. 3-D** Step-cut interface (red dashed line) with an additional allograft strut behind the humeral flange (blue dashed rectangle). **Fig. 3-E** Step-cut interface (red dashed line).

Source of Funding
There was no external funding for this study.

Results

Radiographic Outcomes

At the latest follow-up, 33 (80%) of 41 patients had complete radiographs available for review (Fig. 2). Twelve (36%) of the 33 had persistent nonunion at the allograft-host interface and 1 (3%) had partial union. Overall, 10 (42%) of 24 female patients and 3 (33%) of 9 male patients had nonunion or partial union. Fourteen (42%) of 33 patients had some degree of failure of the plate-and-screw construct, which ranged from backout of 1 screw to catastrophic failure of the instrumentation. Of the 33 patients, 12 (36%) had humeral stem loosening and 1 (3%) had ulnar stem loosening. The mean allograft length was 12 cm. There were 18 end-to-end, 9 end-to-end with anterior strut, 8 step-cut, 3 step-cut with anterior strut, and 3 intussusception types of allograft-host interfaces (Fig. 3, Table II).

Subgroup analysis of APC length in the humeral loosening group compared with the non-loosening group revealed a trend ($p = 0.06$) toward more failures when shorter APCs were required, although this did not reach significance. Subgroup analysis of the type of allograft-host interface in the humeral loosening group compared with the non-loosening group was underpowered to reveal any significant differences ($p = 0.27$).

TABLE II Radiographic Outcomes

Variable	Value
Rates* (n = 33)	
Nonunion	36% (12)
Plate or screw failure	42% (14)
Component loosening	39% (13 [12 humeral, 1 ulnar])
Type of allograft-host interface† (n = 41)	
End-to-end	18 (44%)
End-to-end with anterior strut behind flange	9 (22%)
Step-cut	8 (20%)
Step-cut with anterior strut behind flange	3 (7%)
Intussusception	3 (7%)
Length of allograft‡ *(mm)*	
Entire cohort	118
End-to-end	119
End-to-end with anterior strut behind flange	78
Step-cut	154
Step-cut with anterior strut behind flange	128
Intussusception	122

*The values are given as the percentage, with the number of elbows in parentheses. †The values are given as the number of elbows, with the percentage in parentheses. ‡The values are given as the mean.

TABLE III Postoperative Clinical Outcomes

Outcome Measure	Value
Elbow flexion*	124° (60° to 150°)
Elbow extension*	26° (0° to 90°)
Arc of motion*	99° (30° to 150°)
MEPS* *(points)*	58 (10 to 100)
Pain	
None or mild	62%
Moderate or severe	38%
Activities of daily living	
Can eat without difficulty	54%
Can comb hair	35%
Can perform hygiene	52%
Can put on shirt	49%
Can put on shoe	57%

*The values are given as the mean, with the range in parentheses.

Clinical Outcomes

All outcome scores are reported as the mean and the range. Overall, 62% of patients reported no or mild pain at the latest follow-up. The most recent flexion was 124° (range, 60° to 150°), and the most recent mean extension was 26° (range, 0° to 90°). The mean arc of motion was 99° (range, 30° to 150°). The most recent mean MEPS was 58 points (range, 10 to 100 points) (Table III), with a median of 65 points.

Postoperative Complications, Reoperations, and Implant Survival

Early complications included delayed wound healing in 1 elbow and neurologic deficits in 2 elbows, all managed nonoperatively. Acute deep infection occurred in 1 patient, who was treated with irrigation and debridement, bushing exchange, and retention of components, which was successful at the latest follow-up.

The overall reoperation rate was 34% (14 of 41) and the overall prosthesis revision rate was 32% (13 of 41) (Fig. 4). Twelve elbows underwent revisions due to humeral component failure secondary to nonunion at the allograft-host junction. One additional patient underwent revision for ulnar component failure, despite healing of the allograft-host junction and no evidence of humeral-sided failure.

Discussion

Revision TEA sometimes requires reconstruction of substantial segmental humeral defects. Although impaction grafting and strut augmentation may provide adequate reconstruction of contained defects or when augmentation of 1 cortex is all that is required, more extensive defects can only be addressed with custom prostheses or APCs. Modular segmental prostheses are not currently available for the elbow in

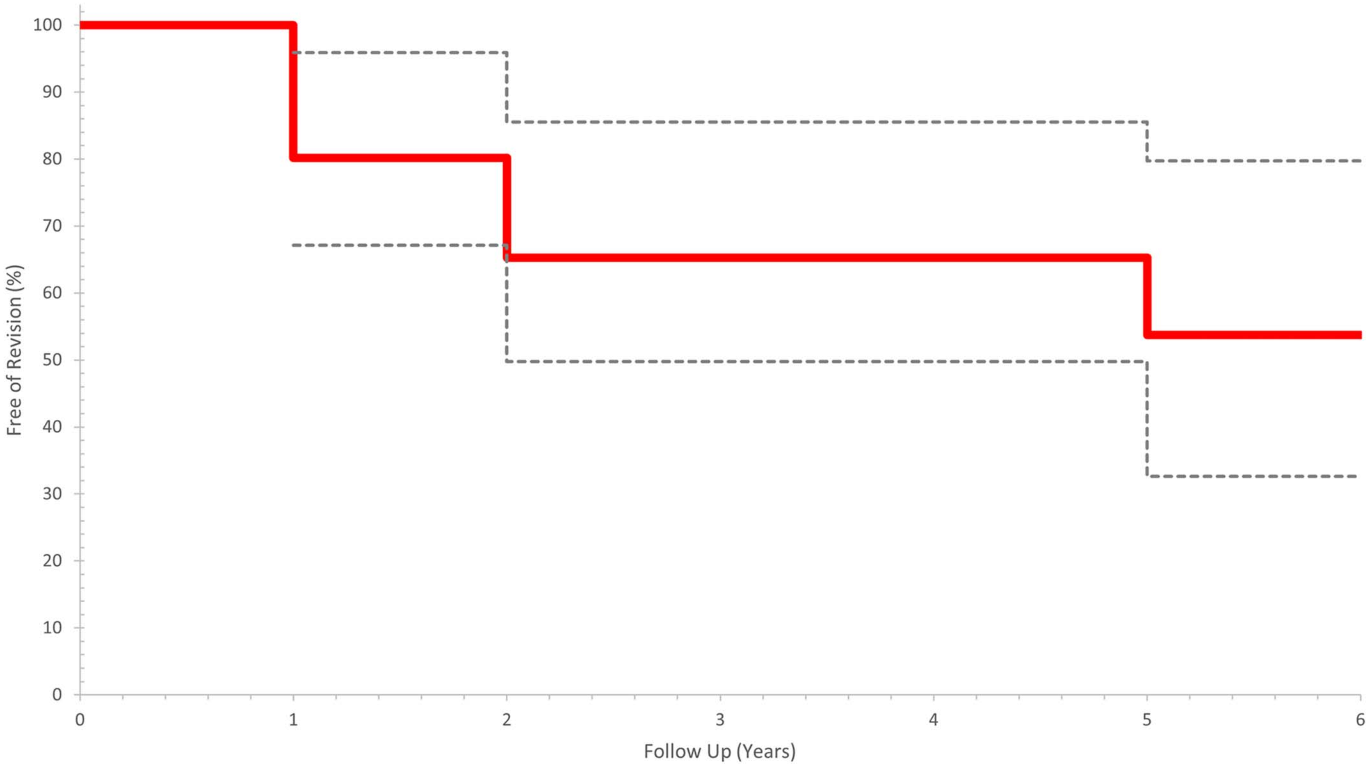

Fig. 4
Five-year Kaplan-Meier curve of revision-free implant survival after revision TEA requiring humeral APC with plate fixation. The gray dashed lines represent the 95% confidence interval.

the United States. Plate fixation is theorized to improve outcomes compared with those that can be obtained with cerclage fixation. The current study found plate fixation of elbow APCs for humeral revision of a failed TEA to be successful in approximately two-thirds of the elbows. Nonunion occurred much more frequently than anticipated and clearly requires improvements in APC reconstructive techniques or in the design of versatile modular segmental humeral components. On a positive note, when the reconstruction united, patients regained adequate pain relief and motion, although functional limitations persisted.

Despite the severity of bone loss and functional limitation present preoperatively in our patient cohort, the final range of motion was satisfactory. The mean range of motion has been reported as 28° to 131° for primary TEA[3] and 20° to 129° for revision TEA[18-20,23-25]. The final range of motion of our patient cohort is comparable with that previously published.

The mean MEPS for our patient cohort was 58 points, similar to that reported by Domos et al. in their series[24]. However, other series have shown better MEPS in revision TEA, including an MEPS of 74 points in the series by Amirfeyz and Stanley[19] and 84 points in the series by Morrey et al.[20]. However, both of those studies combined outcomes of both ulnar and humeral APCs, and this heterogeneity may explain the differences in MEPS between their series and ours.

In our study, patients reported limitations in their activities of daily living. Over 50% had difficulty combing their hair and putting on a shirt, whereas >40% had difficulty eating, performing hygiene, and donning shoes. Other cohorts have demonstrated similar difficulties with activities of daily living postoperatively, with Renfree et al.[26] reporting independent self-care in only 3 of 10 patients following TEA with an APC and Mansat et al.[18] reporting 8 of 13 patients having difficulties with activities of daily living. Although this represents a major challenge postoperatively, it is likely that these patients had challenges with activities of daily living prior to the surgical procedure as well.

Our study shows a high revision rate of 32%, with 12 revisions due to failure of the humeral stem secondary to nonunion at the allograft-host junction, 1 due to infection, and 1 due to ulnar component failure. Mansat et al. reported a 38% revision rate, similar to our study. Four of those revisions were due to deep infection and 1 revision was due to nonunion[18]. Amirfeyz and Stanley reported a 10% revision rate, which resulted from a deep infection in 1 patient, but they reported union of the humeral APC in only 1 of 6 elbows[19]. Morrey et al. reported a 24% revision rate that was similar to the rate in our study, with 3 revisions due to infection and 3 due to component loosening[20].

Our fixation constructs were variable and included APC types previously reported in the literature, including end-to-end, intussusception, step cuts, and additional strut augmentation (Fig. 3)[20]. With the numbers available, the study was underpowered to detect differences in the rate of humeral stem loosening based on the type of allograft-host interface. Interestingly, there was a trend toward greater risk of treatment failure in patients with a shorter APC length. This may be because shorter grafts provide less bone stock for distal plate-and-screw fixation. One would hypothesize that a shorter allograft with more of the humeral stem bypassing the junction and being fixed to native residual bone would improve stability at the allograft-host interface and reduce failures; however, our study suggests that this may not hold true, perhaps indicating that stability from the plate fixation is more vital than stability from the stem fixation.

Nonunion of the allograft-host interface was evident in each case of humeral stem loosening. Therefore, achieving union is paramount to decrease revisions[22]. Nonunion is theoretically due to a combination of inadequate stability and biology. Farfalli et al. performed allograft reconstructions using a combination of a short anterior plate and a long lateral plate[22] and reported no nonunions among 19 cases. Although their series contained allografts without a prosthesis, it may be possible to improve outcomes by using similar dual plating for distal humeral APCs.

Biological augmentation may also improve the rate of union in APC constructs; options include vascularized free medial femoral condyle osteoperiosteal transfers wrapped around the APC-host junction[27] or vascularized fibular autografts used in an intramedullary capacity akin to the Capanna technique for tumor reconstruction[28,29]. However, many of these techniques require advanced microsurgical training. Whether the incremental benefit would outweigh the increased surgical time and the risk of infection is not known. We do not have data for commenting on the role of commercially available osteoinductive adjuncts such as bone morphogenetic protein (BMP)[30].

Megaprostheses can be used as an alternative to APCs. Much of the outcome data with regard to megaprostheses have been derived from the tumor literature and demonstrated high rates of failure[17,31]. This is commonly due to either infection or aseptic loosening. More data are needed for comparison of APC constructs with megaprostheses. Furthermore, in cases like those described in this study, there is often not enough residual native humeral bone stock into which a megaprosthesis can be cemented, and APCs are the only viable reconstructive option.

Our study had several limitations. First, there were limitations inherent to retrospective studies, including heterogeneity of surgical techniques and rehabilitation protocols as well as selection bias, indication bias, expertise bias, and surveillance bias. Our patient cohort was also small and may have been underpowered to capture the full scope of possible clinical or radiographic outcomes, although we believe that this study represents the largest study to date on this infrequently encountered problem. Third, the multiple allograft-host interface types could represent a confounding variable. Furthermore, our total joint database does not contain data with regard to medications that may interfere with bone healing. Additionally, TEA device designs are quite diverse and have variable survivorships; we acknowledge that multiple devices were used in this study and the effect on outcomes is unknown. Additionally, our follow-up was limited to a mean of 3.3 years; further follow-up beyond this time point might have resulted in inferior outcomes. Given the complexity of the problem, disparate clinical contexts and surgeon experience might have led to different outcomes, which would preclude global generalizability of the results.

In conclusion, the treatment of distal humeral bone loss in revision TEA remains a major challenge. Our study demonstrated an unacceptably high nonunion rate of 36% at the allograft-host junction. Nonetheless, approximately two-thirds of elbows were salvaged from a severe and debilitating condition. In those patients, the final range of motion remained satisfactory and most had either no pain or mild pain. More studies are also needed to evaluate the effects of different allograft-host interface types on union rates.

Although plating confers more stability to the allograft-host interface compared with historical techniques using cerclage cables, the nonunion rates remain high. Further mechanical stability, such as from dual plating or intramedullary fixation, may be required. Additionally, plating does not address any underlying biologic deficiencies that may prevent osseous union. As such, further refinement of surgical techniques, from both a mechanical and a biologic standpoint, is needed to treat extensive distal humeral bone loss in the revision TEA setting. ■

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