JSES Reviews, Reports, and Techniques 3 (2023) 356–361

Contents lists available at ScienceDirect

JSES Reviews, Reports, and Techniques

journal homepage: www.jsesreviewsreportstech.org

Review of bone deficiency in total elbow arthroplasty revision

Jaime A. Quirarte, BA[a,*], Jose M. Gutierrez-Naranjo, MD[b], Eduardo Valero-Moreno, MD[b], Svaksha Iyengar, BS[a], Bernard F. Morrey, MD[b], Anil K. Dutta, MD[b]

[a]*Long School of Medicine, UT Health San Antonio, San Antonio, TX, USA*
[b]*Department of Orthopaedics, UT Health San Antonio, San Antonio, TX, USA*

ARTICLE INFO

Keywords:
Total elbow arthroplasty
Bone loss
Bone deficiency
Revision
Infection
Trauma
Aseptic loosening

Level of Evidence: Level V; Review Article Expert Opinion

Total elbow arthroplasty revision rates have been increasing over time due to the increasing use of the procedure with the accompanying increase in complications. The most common complications that typically require revision surgery include aseptic loosening, periprosthetic fractures, infection, and component failure. The associated instability has an overall revision rate reported to be as high as 13%. One important factor when performing a revision surgery is bone quality and bone loss; this represents a challenge during the clinical decision-making process. Currently, there are several strategies used to address bone loss such as arthrodesis, resection arthroplasty, impaction grafting, allograft-prosthetic composite reconstruction, and custom prostheses. The aim of this review article is to provide a comprehensive review of the current strategies to improve diagnosis of failed total elbow arthroplasty and improve management and outcomes of this patient population.

Total elbow arthroplasty rates have been increasing over time and subsequently the prevalence of revision surgery has been increasing as well.[7] Bryan et al identified five total elbow arthroplasty complications that typically require revision including aseptic loosening, fracture, infection, component failure, and instability.[23] It has been reported that there is a complication rate of approximately 44% of total elbow arthroplasties, noting the most common complications being aseptic loosening (22%), transient ulnar and radial nerve symptoms (21%), and periprosthetic fractures (15%).[12,13] The overall revision rate has been reported to be as high as 13%.[18] Total elbow arthroplasty revisions require meticulous planning, and it is imperative to consider several factors when determining the revision strategy. Two major factors are the quality of the current bone stock and the amount of bone loss observed with the current prosthetic joint. Often, bone loss guides the approach to the revision and will determine whether a standard prosthesis can be used or if alternative methods need to be explored. Currently, there are several strategies to approach bone loss in total elbow arthroplasty. The aim of this review article is to provide a comprehensive review of the current strategies starting with current definitions of bone loss, nonfunctional and functional revision options, bone and soft tissue implications, and concluding with recommendations based on the authors' experience with the various revision constructs.

Bone loss

King et al in 1997 described the severity of bone loss based on the humeral bone stock assessed with anteroposterior and lateral radiographs. Grade I is observed when subchondral architecture is intact. Grade II occurs when the medial and lateral supracondylar columns are preserved, grade III when these columns are absent, and grade IV when the entire distal humerus to the level of the olecranon fossa is absent.[16] Ulnar bone loss has previously been described as type I when involvement includes the olecranon process with triceps tendon attachment, type II when it involves proximal ulna including the previous prosthesis, and type III when the bone loss extends beyond the previous prosthesis.[21]

Arthrodesis

Historically, ulnohumeral arthrodesis was one of the techniques of choice for salvage treatment of failed total elbow arthroplasty in the setting of significant bone loss.[25] Koller et al described a case series of 14 patients who underwent elbow arthrodesis and found that all patients had a solid union of the fused elbow, 8 patients had no pain, and 4 patients had moderate pain.[17] This procedure was typically reserved for cases in which neither functional treatment options nor resection arthroplasty were feasible. This procedure is

Institutional review board approval was not required for this review.

*Corresponding author: Jaime A. Quirarte, BA, Long School of Medicine, UT Health San Antonio, 7703 Floyd Curl Dr., San Antonio, TX 78229, USA.

E-mail address: quirartej@livemail.uthscsa.edu (J.A. Quirarte).

https://doi.org/10.1016/j.xrrt.2023.02.010
2666-6391/

associated with a complete loss of functional motion, making it impractical for individuals who require any functional movement of their upper extremity.

Resection arthroplasty

Resection arthroplasty is a staple procedure that can be used as definitive or temporary treatment following failed total elbow arthroplasty. It is typically only considered for situations involving deep infection and bone loss; however, the resultant flail elbow is only suitable for individuals with the slightest functional demands from their upper extremity.[6] Zarkadas et al described a case series of 50 patients (51 elbows) that involved the use of elbow resection as a salvage procedure for refractory infections following total elbow arthroplasty. The authors describe that the Mayo Elbow Performance Score improved from 37 preoperatively to 60 points postoperatively, with most of the improvement found in the pain component of the score. Overall, the authors described a high rate of complications, with 24 elbow infections, eighteen intraoperative fractures, and nine permanent nerve injuries.[29]

Impaction grafting

Impaction grafting is a classical technique often used in hip reconstruction. It is currently a pillar in the management of bone loss during total elbow arthroplasty revision with expansile bone loss and a thin but intact cortex. Loebenberg et al first described the use of impaction grafting for patients with a failed elbow arthroplasty, adopting the technique that was well established for similar use in the proximal femur. Their case series described 12 patients who underwent revision total elbow arthroplasty for aseptic loosening, three patients underwent impaction grafting on the initial revision while the remaining nine had undergone at least one prior revision before impaction grafting was instituted. Seven patients had a presenting diagnosis of rheumatoid arthritis, while five had a presenting diagnosis of post-traumatic arthritis. On average, patients were followed for 72 months with a minimum of 2 years. Eight of the elbow prostheses were intact at the latest follow-up, with two elbow revisions due to aseptic loosening, one periprosthetic fracture, and one infection suggesting that it is a feasible technique for treating osteolysis in patients undergoing revision total elbow arthroplasty.[19]

Building on work done by Loebenberg et al, Rhee et al published a case series of 16 revision elbow arthroplasties. Sixteen revision arthroplasties were performed following aseptic loosening of a semiconstrained total elbow replacement; 14 elbows had loosening of both humeral and ulnar components and two elbows had only humeral loosening. Impaction grafting was performed with only allograft in thirteen elbows and a combination of allograft and autograft in the other three elbows. MEPS for pain improved from 15 preoperative to 32.8 postoperative and the mean arc of flexion also increased from 60.3 to 115.6. The mean total MEPS improved from 41.0 to 82.8 points. Follow-up radiographs demonstrated fifteen cases with grade I resorption of the bone graft and one case with grade II resorption. A type I radiolucent line was observed in twelve of the elbows; type II, in three; and type IV, in one. Additional surgery was required in two cases.[26]

Allograft construct: allograft-prosthesis composite

The use of allograft as a strategy to approach bone loss in total elbow arthroplasty can be subdivided into its use as a prosthetic composite or as a strut. In 2004, Mansat et al published a case series of 13 patients using an allograft-prosthesis composite (APC). The authors found 13 patients between 1990 and 2000 with allograft placed on the humeral side in four and the ulnar side in nine. Nine patients had no or slight pain at an average of 42 months, with a mean arc of flexion of 97 degrees. There were seven complications affecting seven elbows, with five requiring reoperation with approximately a 55% complication-free revision. The most prevalent complication was a deep infection in four elbows, which required removal in three. The authors concluded that while this approach can be a valuable option in patients with extreme bone deficiency, deep infection is a concern, thus they recommend looking at other options such as strut graft reconstruction before turning to the APC approach.[21]

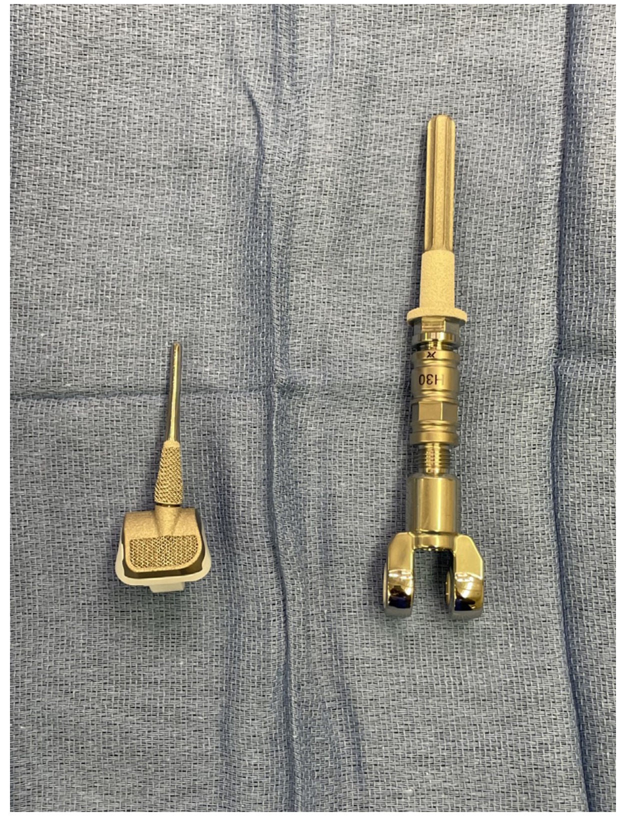

Figure 1 Custom total elbow arthroplasty prosthesis system, showing both components, ulnar (left) and humeral (right).

In 2013, Morrey et al attempted to improve on their previous case series outcomes by extending the allograft prosthesis composites. Twenty-five patients from 2003 to 2008 underwent revision total elbow arthroplasty with an APC in the humerus (6), ulna (18), or both (1). Three reconstructive strategies were used: (I) intussusception (Fig. 1), (II) strut-like coaptation (Fig. 2, *A* and *B*), and (III) side-to-side contact between the cortices of the allograft. The authors found a mean MEPS improved from 30 points preoperatively to 84 postoperatively. Ninety-two percent of APCs incorporated with eight major and four minor complications in nine patients leading to nine reoperations in 6 patients. Complications included three infections, three fractures, one nonunion, one malunion, one skin necrosis, one case of triceps insufficiency, and one ulnar nerve paresthesia. At the final follow-up, 84% of the original 25 patients ended up with a functional elbow. Importantly, 7 out of 25 (28%) had the bone deficiency due to resection for a deep infection.[24]

Most recently, Burnier et al addressed proximal ulnar bone loss and triceps insufficiency with an APC-like construct involving a combined proximal ulnar and triceps tendon allograft. The authors

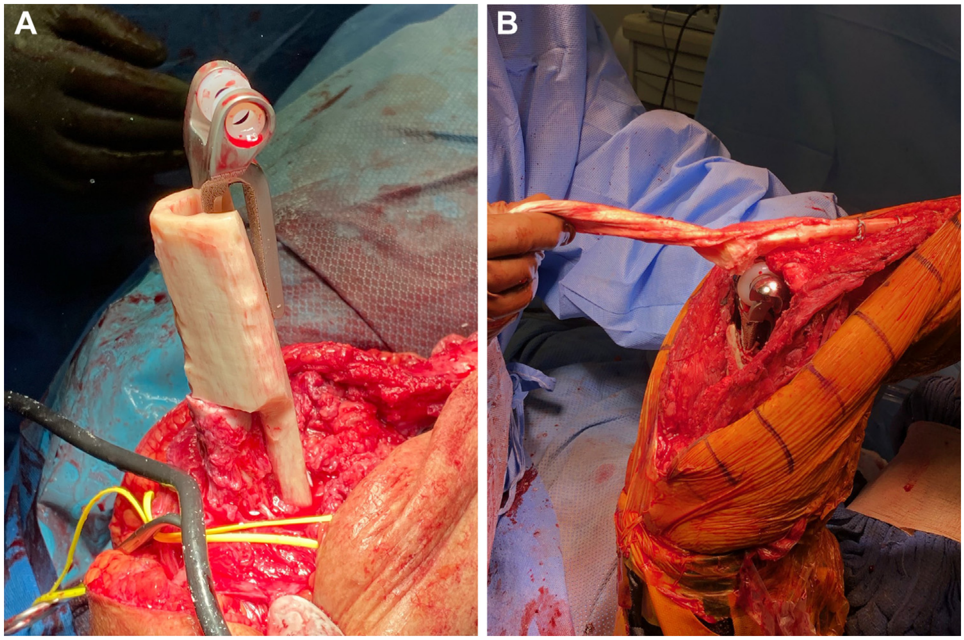

Figure 2 Intraoperative images of total elbow arthroplasty revision of a 38-year-old female that underwent primary arthroplasty after a complex open fracture of the elbow. (**A**) Custom APC humeral component after placement. (**B**) Custom APC ulnar component after it was fitted. *APC*, allograft-prosthesis composite.

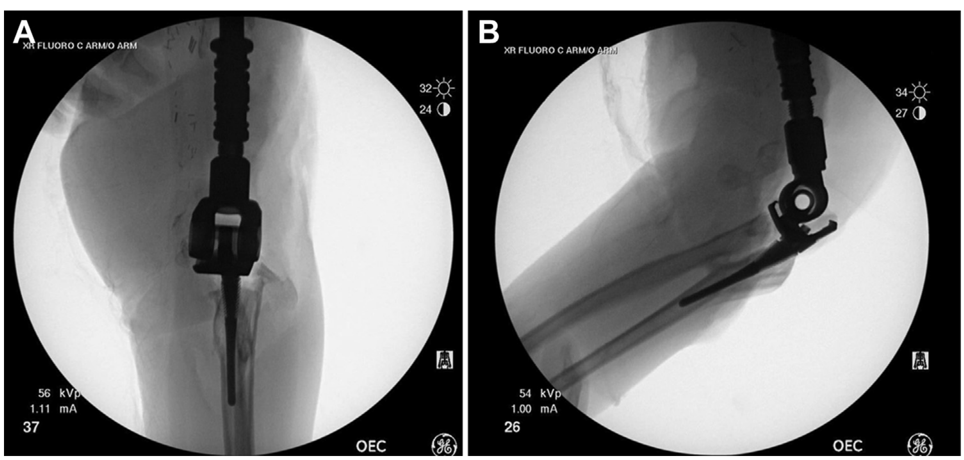

Figure 3 Intraoperative fluoroscopy x-rays. (**A**) Anteroposterior view. (**B**) Lateral view.

reported a case series of 10 revision arthroplasties with both proximal ulnar bone loss and triceps insufficiency. Indications for these surgeries included 4 aseptic loosening cases, 2 periprosthetic fractures, and 4 2-stage reimplantations. With a mean follow-up of 45 months, pain improvement was observed in all elbows, mean flexion-extension arc was 95 degrees, mean MEPS score is 76 points, and the mean triceps strength score was 4. Complications included 6 reoperations due to 3 humeral loosening, 1 deep infection, 1 ulnar allograft fracture, and 1 wound débridement and closure. For the 8 intact ulnar components, no loosening was observed, and the graft was radiographically intact.[5]

Allograft construct: strut

An alternate use of allograft for bone deficiency is its use as a strut. Kamineni et al published a series of cases presenting with aseptic failure demonstrating proximal ulnar reconstruction with strut allograft in revision total elbow arthroplasty. The series included 21 patients followed for four years who were treated with allograft bone struts. The average MEPS increased from 34 points preoperatively to 79 points at the latest follow-up. The deficient bone stock was approached with allograft strut grafts in one of four ways: (1) discrete cortical defects were contained, (2) periprosthetic fractures were splinted, (3) deficient triceps attachments were reconstructed, and (4) expanded segments were augmented with struts and filled with impaction graft. Complications consisted of four soft tissue and four osseous problems occurring in eight patients. Overall, three patients had an incorporation of 26% to 50% of the graft; five had an incorporation of 51% to 75% and fourteen had an incorporation of 76% to 100%. The authors concluded that while there is a high complication rate, it is suitable for discrete cortical lesions, periprosthetic fractures, and an expanded proximal part of the ulna, which also requires augmentation with impaction grafting. The authors noted that this technique is unreliable in restoring deficient olecranon bone stock.[15]

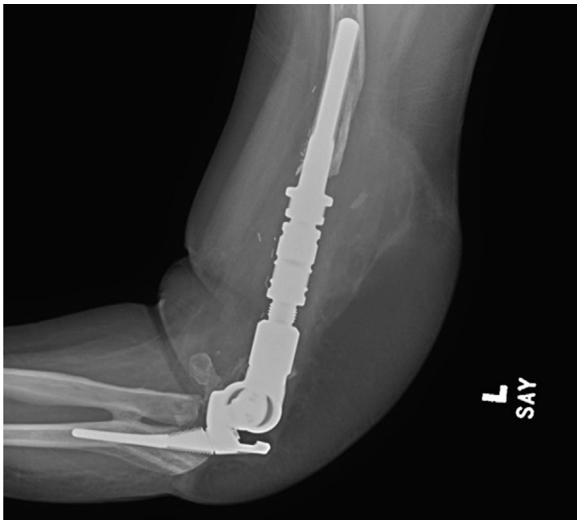

Figure 4 8 weeks postoperative x-rays, lateral view.

Table I
Management of skeletal defects.

Type of bone loss	Construct
Contained defect	Impaction grafting Type I APC
Unicortical defect	Type II APC Type III APC
Large segmental bone loss (including after infection)	Type III APC Custom prosthesis/megaprosthesis

APC, allograft-prosthesis composite.

Custom implant or metal extension

The third construct used in the setting of massive bone loss is the use of a non-custom metal extension or custom implant (Fig. 3, *A* and *B*). This construct was developed prior to the aforementioned strategies discussed and has been used for bone loss in settings such as tumorous pathology, osteoarthritis, rheumatoid arthritis, infection, and complex trauma.[14,16] Figgie et al published a case series in 1986 describing patients who received a custom fit implant for bone loss in the setting of revision total elbow arthroplasty. This case series included 16 patients with 16 total elbow replacements with a follow-up average of 4 years. The authors reported 14 patients had a good or excellent result and overall elbow scores averaged 90 (range: 53-100). There were three reoperations and one case of nonprogressive circumferential lucent lines about a humeral component. Preliminary results show custom fit total elbows have acceptable functional results for revision arthroplasties when traditional methods are not available[11] (Fig. 4). Dent et al subsequently published a case series in 1995 describing 25 patients with rheumatoid arthritis who had 26 failed primary total elbow arthroplasties. These authors described satisfactory results at 35 months and concluded that revision surgery with custom implants allowed for a short- to medium-term period of pain-free function and should be the construct of choice in the absence of infection.[8]

It is important to note the significant implications in choosing a custom prosthesis over an APC. Custom prostheses more time to design and produce and are more expensive than off-the-shelf APC options. Certain companies produce megaprostheses that are not custom that mitigate both the time and cost associated with custom prostheses. Depending on the case, custom prostheses may avoid the use of cement if the conditions are appropriate. APCs rely on healing of the allograft to the host with creeping substitution and can resorb but have the added benefit that they utilize standard implants and are more widely available. When concern for infection is high, surgeons may hesitate to use allograft and choose to utilize a custom prosthetic or megaprosthesis option.

Periprosthetic fractures

Periprosthetic fracture is one of the main indications for elbow arthroplasty replacement. Athwal et al published a case series of 24 patients with 27 elbows treated between 1979 and 2003 for periprosthetic fracture of total elbow arthroplasties (TEAs) of varying components at a single institution. According to the authors, 9 of 10 humeri showed preoperative distal bone loss due to pre-existing fracture of nonunion. Three TEA exhibited proximal ulnar deficiency. The authors employed two separate techniques to perform the revision, a cement-within-cement technique (average MEPS 82) and a complete cement removal followed by insertion of the revision component (average MEPS 78). Complications in this series included seven intraoperative fractures, five nerve injuries, three triceps avulsions, and one deep infection.[3]

Soft tissue implications

Attention in dealing with the soft tissues surrounding the elbow is imperative to prevent infection. Unique anatomy of the elbow including the lack of a thick fibrous fascia makes this area prone to wound dehiscence, breakdown, and infection. Commonly, pedicled flaps and local tissue rearrangement are used for soft tissue reconstruction; however, there have been reports of the use of free flaps as well.[20]

Triceps insufficiency is a common complication following revision surgery in the setting of infection for total elbow arthroplasty, with rates approaching 22%.[22] This insufficiency can develop as a consequence of the surgery itself as well as the underlying infection.[9] A variety of methods for dealing with this triceps insufficiency have been described including but not limited to direct repair with bone suture, anconeus rotation flaps, triceps imbrication or plication, and Achilles tendon grafts.[22]

Infection

In contrast to other major joint replacements, primary total elbow arthroplasty carries an increased risk of infection, previously reported to occur at a rate of up to 12%.[1] While clinical parameters such as erythema, swelling, pain, presence of a sinus tract, elevated white blood cell count, erythrocyte sedimentation rate, and C-reactive protein are widely used to determine the presence of an infection, no clear definition has yet been established for an infected TEA. Moreover, a classification system proposed by Yamaguchi et al may be used to assist in the planning and treatment determination of an infected elbow prosthesis.[28]

Periprosthetic elbow infections tend to not involve standard parameters commonly used for periprosthetic hip and knee infections; however, the revision constructs can feasibly be used in the setting of infection for total elbow arthroplasty.[26] APC is a potential solution to bone loss following infected total elbow arthroplasties, though these constructs carry a high risk of infection themselves.[4,20] Similar to how constructs involving bone loss can be separated into functional and nonfunctional salvage options, surgical management can similarly be divided as such in the setting of TEA infection.

Morrey et al in 2013 described a case series of 25 patients, 7 (28%) of whom underwent an APC in the setting of TEA infection.

Table II
Summary of the data from studies on the management of massive bone deficiency in failed elbow replacements.

Method of revision		Success rate at follow-up	MEPS change	Complications													
				Pain	Infection	Nerve injury	Ulnar nerve paresthesia	Skin necrosis	Triceps weakness/ Insufficiency	Intraoperative fracture	Periprosthetic fracture	Unspecified fracture	Nonunion	Malunion	Aseptic loosening	Resorption of bone graft	
																Grade I	Grade II
Arthrodesis	Koller et al[16]	100% (14/14)	-	29% (4/14)	-	-	-	-	-	-	-	-	-	-	-	-	-
Resection arthroplasty	Zarkadas et al[28]	63% (19/30)*	+23 (37 to 60)	-	47% (24/51)	18% (9/5`1)	-	-	-	35% (18/51)	-	-	-	-	-	-	-
Impaction grafting	Loebenberg et al[18]	67% (8/12)	-	-	8% (1/12)	-	-	-	-	-	8% (1/12)	-	-	-	17% (2/12)	-	-
	Rhee et al[25]	88% (14/16)†	+41.8 (41.0 to 82.8)	-	-	-	-	-	-	-	-	-	-	-	-	94% (15/16)	6% (1/16)
Allograft-prosthesis composite	Mansat et al[20]	62% (8/13)‡	-	31% (4/13)	31% (4/13)	-	-	-	-	-	-	-	15% (2/13)	-	-	-	-
	Morrey et al[23]	84% (21/25)	+54 (30.0 to 80.0)	-	12% (3/25)	-	4% (1/25)	4% (1/25)	8% (2/25)	-	-	12% (3/25)	4% (1/25)	4% (1/25)	-	-	-
	Burnier et al[4]	40% (4/10)‡	-	-	20% (2/10)	-	-	-	-	-	10% (1/10)	-	-	-	30% (3/10)	-	-
Allograft strut grafts	Kamineni et al[14]	67% (14/21)	+45 (34.0 to 79.0)	-	-	19% (4/21) Unspecified soft tissue complication				19% (4/21) Unspecified osseous complication							
Custom fit implant	Figgie et al[11,¶]	88% (14/16)§	-	-	-	-	-	-	-	-	-	-	-	-	6% (1/16)	-	-
	Anmin et al[2]	88% (7/8)	-	-	12% (1/8)	-	-	-	-	-	12% (1/8)	-	-	-	-	-	-
Mixed study	Athwal GS, Morrey BF[3]	62% (13/21)‖	-	-	4% (1/23)	28% (5/23)	-	-	13% (3/23)	30% (7/23)	-	-	-	-	-	-	-

MEPS, Mayo Elbow Performance Score.
*8/30 good, 11/30 fair, and 11/30 poor. 21 elbows lost to follow-up (11 years postoperative).
†Success defined as no additional surgery. 4/16 excellent, 11/16 good, and 1/16 fair.
‡Success defined as no additional surgery.
§Success defined as a “good or excellent result” for a patient.
‖Success defined as a “good or excellent result” for a patient. 21 patients and 23 elbows.
¶Success defined as incorporation of 76% to 100%.

These authors describe their methodology in detail for treatment of these infections, that includes a staged procedure with implant removal and débridement, deep cultures, antibiotic spacers, and 6 weeks of IV antibiotics based on cultures. Stage 2 involved removing the spacers, repeat débridement, and culture. Based on the clinical picture and cultures, either an APC was placed or spacers were placed again followed by a new implant.[24]

Burnier et al's series used an APC construct as the second stage in 4 cases due to a periprosthetic joint infection. Of these 4 cases, 1 elbow was treated successfully, with the other 3 failures occurring due to graft nonunion and fractures, delayed humeral nonunion, and a persistent infection.[5]

Custom implant or metal extensions are also an option in the setting of TEA infections. Figgie et al's series of 16 elbows included three elbows that had been previously infected and had subsequent bone loss. Interestingly, 2 of 3 of the previously infected elbows required reoperation either directly due to infectious etiology or other unrelated etiologies. The authors did not comment on subsequent follow-up; however, the proof of concept was established in these patients.[11] While theoretically possible, management of these deep infections is challenging. Anmin et al described eight custom endoprosthetic implants of the distal humerus used for non-tumorous pathology, and the one implant placed in the setting of infection failed and resulted in excision arthroplasty.[2]

There are soft tissue implications associated with infections in TEA revision. Duquin et al described 93 total elbow replacements treated for deep infection at a single institution. The authors found that triceps weakness was found in 51 total elbow replacements (55%). At a mean follow-up of 5 years, only 13 patients had an intact extensor mechanism, and the remaining patients (38) had bone or soft tissue loss, showing that triceps weakness is a highly prevalent complication in this patient population.[9] It is important to note that the patients in this study were treated with the Bryan-Morrey approach, which may predispose this subset of patients to triceps insufficiency after infection causing failure to heal or due to débridement.

As previously mentioned, Zarkadas et al described the use of elbow resection as a salvage procedure for refractory infections following total elbow arthroplasty. The authors described a high rate of complications but supported the option as a salvage option when necessary.[29] Ferlic et al described the revision of 14 TEAs, 3 for infectious etiology and 11 for non-infectious etiologies. The authors chose to treat the infectious etiologies with resection arthroplasty and had successful elimination of the infection. Those with noninfectious etiologies were treated with either a custom implant or semi-constrained device.[10]

Conclusions

As the implementation of TEA continues to increase, the need for improved revision constructs will continue to grow. Bone deficiency remains a significant issue in many TEA revision cases. While standard prostheses and cement may suffice for small defects, larger contained defects may require impaction grafting or a type I APC. Larger unicortical defects or uncontained defects may require the more technically challenging type II APC. Type III APCs may be utilized when the native canal is unreliable for stem placement in these scenarios. When there is concern for infection or with large segmental bone loss, surgeons may turn to type III APCs or the custom/megaprosthesis option (Table I). Other scenarios in which APCs may be considered may include simple fractures and soft tissue implications such as the loss of the extensor mechanism.[5,27]

In summary, great strides have been made and many studies performed regarding the management of massive bone deficiency in both the septic and non-septic failed elbow replacement (Table II). The employment of a variety of allograft prosthetic composites has provided great flexibility in the management of both proximal ulnar and distal humeral bone loss.[4] The proximal ulnar allograft with an intact triceps tendon has improved extension function. More primary procedures are being performed leaving the central triceps tendon attached to the olecranon process and it is anticipated this will lessen the very high incidence of triceps insufficiency that has been reported to be associated with managing the infected elbow implant.[5] The use of APCs provides more timely, more flexible, and less expensive revision options. The future of custom devices will reside in further perfection of the modular designs which also provide more real-time flexibility. This is especially true when the soft tissue envelope has contracted making the linear dimensional requirements of a custom implant extremely difficult to judge. Finally with the use of the proper staging and the osseous and soft tissue management of deep infections with excessive bone loss are now being reliably salvaged in a majority of patients.[23]

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Dr. Anil K. Dutta: Reports he has acted as consultant for Lima and Zimmer Biomet. None of these activities are related to the content of this article. The other authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Aldridge JM 3rd, Lightdale NR, Mallon WJ, Coonrad RW. Total elbow arthroplasty with the Coonrad/Coonrad-Morrey prosthesis. A 10- to 31-year survival analysis. J Bone Joint Surg Br 2006;88:509-14. https://doi.org/10.1302/0301-620x.88b4.17095.
2. Anmin A, Suresh S, Sanghrajka A, Cannon SR, Briggs TW, Unwin P. Custom-made endoprosthetic reconstruction of the distal humerus for non-tumorous pathology. Acta Orthop Belg 2008;74:446-50.
3. Athwal GS, Morrey BF. Revision total elbow arthroplasty for prosthetic fractures. J Bone Joint Surg Am 2006;88:2017-26. https://doi.org/10.2106/jbjs.E.00878.
4. Barret H, Laumonerie P, Delclaux S, Arboucalot M, Bonnevialle N, Mansat P. Revision total elbow arthroplasty with the semiconstrained coonrad/morrey prosthesis: follow-up to 21 years. J Bone Joint Surg Am 2021;103:618-28. https://doi.org/10.2106/jbjs.20.00889.
5. Burnier M, Nguyen NTV, Morrey ME, O'Driscoll SW, Sanchez-Sotelo J. Revision elbow arthroplasty using a proximal ulnar allograft with allograft triceps for combined ulnar bone loss and triceps insufficiency. J Bone Joint Surg Am 2020;102:2001-7. https://doi.org/10.2106/jbjs.20.00414.
6. Cheung EV, Adams RA, Morrey BF. Reimplantation of a total elbow prosthesis following resection arthroplasty for infection. J Bone Joint Surg Am 2008;90:589-94. https://doi.org/10.2106/jbjs.F.00829.
7. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elbow Surg 2010;19:1115-20. https://doi.org/10.1016/j.jse.2010.02.009.
8. Dent CM, Hoy G, Stanley JK. Revision of failed total elbow arthroplasty. J Bone Joint Surg Br 1995;77:691-5.
9. Duquin TR, Jacobson JA, Schleck CD, Larson DR, Sanchez-Sotelo J, Morrey BF. Triceps insufficiency after the treatment of deep infection following total elbow replacement. Bone Joint J 2014;96-B:82-7. https://doi.org/10.1302/0301-620x.96b1.31127.
10. Ferlic DC, Clayton ML. Salvage of failed total elbow arthroplasty. J Shoulder Elbow Surg 1995;4:290-7.
11. Figgie HE 3rd, Inglis AE, Mow C. Total elbow arthroplasty in the face of significant bone stock or soft tissue losses. Preliminary results of custom-fit arthroplasty. J Arthroplasty 1986;1:71-81.
12. Geurts EJ, Viveen J, van Riet RP, Kodde IF, Eygendaal D. Outcomes after revision total elbow arthroplasty: a systematic review. J Shoulder Elbow Surg 2019;28:381-6. https://doi.org/10.1016/j.jse.2018.08.024.
13. Gschwend N, Simmen BR, Matejovsky Z. Late complications in elbow arthroplasty. J Shoulder Elbow Surg 1996;5:86-96.
14. Hanna SA, David LA, Aston WJ, Gikas PD, Blunn GW, Cannon SR, et al. Endoprosthetic replacement of the distal humerus following resection of bone tumours. J Bone Joint Surg Br 2007;89:1498-503. https://doi.org/10.1302/0301-620x.89b11.19577.
15. Kamineni S, Morrey BF. Proximal ulnar reconstruction with strut allograft in revision total elbow arthroplasty. J Bone Joint Surg Am 2004;86:1223-9. https://doi.org/10.2106/00004623-200406000-00015.
16. King GJ, Adams RA, Morrey BF. Total elbow arthroplasty: revision with use of a non-custom semiconstrained prosthesis. J Bone Joint Surg Am 1997;79:394-400.
17. Koller H, Kolb K, Assuncao A, Kolb W, Holz U. The fate of elbow arthrodesis: indications, techniques, and outcome in fourteen patients. J Shoulder Elbow Surg 2008;17:293-306. https://doi.org/10.1016/j.jse.2007.06.008.
18. Little CP, Graham AJ, Karatzas G, Woods DA, Carr AJ. Outcomes of total elbow arthroplasty for rheumatoid arthritis: comparative study of three implants. J Bone Joint Surg Am 2005;87:2439-48. https://doi.org/10.2106/jbjs.D.02927.
19. Loebenberg MI, Adams R, O'Driscoll SW, Morrey BF. Impaction grafting in revision total elbow arthroplasty. J Bone Joint Surg Am 2005;87:99-106. https://doi.org/10.2106/jbjs.B.00038.
20. Macken AA, Lans J, Miyamura S, Eberlin KR, Chen NC. Soft-tissue coverage for wound complications following total elbow arthroplasty. Clin Shoulder Elb 2021;24:245-52. https://doi.org/10.5397/cise.2021.00409.
21. Mansat P, Adams RA, Morrey BF. Allograft-prosthesis composite for revision of catastrophic failure of total elbow arthroplasty. J Bone Joint Surg Am 2004;86:724-35. https://doi.org/10.2106/00004623-200404000-00009.
22. Meijering D, Welsink CL, Boerboom AL, Bulstra SK, Vegter RJK, Stevens M, et al. Triceps insufficiency after total elbow arthroplasty: a systematic review. JBJS Rev 2021;9. https://doi.org/10.2106/jbjs.Rvw.20.00281.
23. Morrey BF, Bryan RS. Complications of total elbow arthroplasty. Clin Orthop Relat Res 1982:204-12.
24. Morrey ME, Sanchez-Sotelo J, Abdel MP, Morrey BF. Allograft-prosthetic composite reconstruction for massive bone loss including catastrophic failure in total elbow arthroplasty. J Bone Joint Surg Am 2013;95:1117-24. https://doi.org/10.2106/jbjs.L.00747.
25. Presnal BP, Chillag KJ. Radiohumeral arthrodesis for salvage of failed total elbow arthroplasty. J Arthroplasty 1995;10:699-701.
26. Rhee YG, Cho NS, Parke CS. Impaction grafting in revision total elbow arthroplasty due to aseptic loosening and bone loss. J Bone Joint Surg Am 2013;95:e741-7. https://doi.org/10.2106/jbjs.K.01737.
27. Sanchez-Sotelo J, O'Driscoll S, Morrey BF. Periprosthetic humeral fractures after total elbow arthroplasty: treatment with implant revision and strut allograft augmentation. J Bone Joint Surg Am 2002;84:1642-50.
28. Yamaguchi K, Adams RA, Morrey BF. Infection after total elbow arthroplasty. J Bone Joint Surg Am 1998;80:481-91.
29. Zarkadas PC, Cass B, Throckmorton T, Adams R, Sanchez-Sotelo J, Morrey BF. Long-term outcome of resection arthroplasty for the failed total elbow arthroplasty. J Bone Joint Surg Am 2010;92:2576-82. https://doi.org/10.2106/jbjs.I.00577.