Proximal Ulnar Reconstruction with Strut Allograft in Revision Total Elbow Arthroplasty

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Background: The growing frequency of joint arthroplasty has led to increasing numbers of patients requiring revision surgery. In the treatment of a failed total elbow arthroplasty not associated with infection, one of the main issues is poor or absent proximal ulnar bone stock due to osteolysis. We report our experience with the use of strut allograft reconstruction of the proximal part of the ulna as an adjunct to revision total elbow arthroplasty with a noncustom implant. Our aim was to better define the indications, outcomes, and complications of this technique in a population of patients with a failed total elbow arthroplasty.

Methods: We reviewed the cases of patients with aseptic failure of a total elbow replacement and proximal ulnar bone deficiency who were treated with allograft bone struts. The patients had had an average of 2.5 (range, one to four) prior open osseous operations addressing the elbow joint. In addition to revision of the prosthetic components, the deficient bone stock was treated 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. Twenty-one patients (twenty-two elbows) were followed for an average of four years (range, two to eleven years).

Results: The mean Mayo Elbow Performance Score improved from 34 points preoperatively to 79 points at the time of the latest follow-up. The scores for pain, stability, and activities of daily living improved most; there was little change in motion. Complications, consisting of four soft-tissue and four osseous problems, occurred in eight patients. Three patients had incorporation of 26% to 50% of the graft; five, 51% to 75%; and fourteen, 76% to 100%.

Conclusions: Most deficiencies of proximal ulnar bone stock and fractures complicating revision total elbow surgery can be treated with allograft strut grafting. Although the complication rate is high, this technique is suitable for discrete cortical lesions, periprosthetic fractures, and an expanded proximal part of the ulna, which also requires augmentation with impaction grafting. The technique has been unreliable, however, in restoring deficient olecranon bone stock.

Level of Evidence: Therapeutic study, Level IV (case series [no, or historical, control group]). See Instructions to Authors for a complete description of levels of evidence.

With the increasing number of total elbow arthroplasties being performed, a parallel increase in revision surgery has been noted, as it has in the experience with hip and knee arthroplasties. The literature contains little information concerning techniques and outcomes of revision surgery following total elbow arthroplasty. Most of the principles regarding stem length, stem diameter, and bypassing defects in revision elbow surgery were derived from experiences with revision hip and knee arthroplasty. Although this transfer of principles has had encouraging results, revision surgery on the elbow poses some unique problems.

A major issue in revision total elbow arthroplasty is the loss of proximal ulnar bone stock due to osteolysis, which can occur with loosening of the ulnar implant. The aim of revision of a failed total elbow replacement due to aseptic loosening, implant fracture, or periprosthetic fracture in combination with compromised bone stock is to restore a stable pain-free functional elbow with reconstitution of proximal ulnar bone. In the past twenty-five years, the use of allografts to restore skeletal defects has become increasingly popular, mostly following tumor resection but also in lower-limb revision surgery. There has also been increasing use of allograft bone about the elbow for reconstruction of osseous deficiencies due to trauma and following arthroplasty. Most reports in the
elbow literature address the use of massive osteochondral allografts or allograft-prosthesis composites. We report our experience with the use of strut allografts in the reconstruction of a deficient proximal part of the ulna in association with a failed total elbow arthroplasty. One goal was to better define the indications and outcomes of this specific technique for revision total elbow surgery.

**Materials and Methods**

We retrospectively reviewed the records on 734 total elbow arthroplasties performed by the senior author (B.F.M.) over a period of twenty-two years; 189 (26%) were revision procedures. Since 1996, the percentage of revision total elbow replacements has risen from 17% to >40% at our institution. Among the revisions, we identified twenty-two, in twenty-one patients, in which a major proximal ulnar osseous deficiency was treated with a reconstructive procedure; a revision of the ulnar component was also performed in twenty-one elbows. Only patients who had been followed for a minimum of two years from the time of the index revision procedure were included in this study. The investigation was approved by the institutional review board.

The study cohort comprised seventeen women and four men, with an average age at the time of the index ulnar reconstructive surgery of fifty-seven years (range, thirty-seven to seventy-nine years). The operation was performed in eight dominant extremities and fourteen nondominant ones (see Appendix). The original implant had been in situ for an average of 6.7 years (range, eighteen months to eleven years). The primary diagnoses included rheumatoid arthritis with joint destruction (ten elbows), juvenile rheumatoid arthritis (three), and sequelae of trauma (nine) consisting of posttraumatic arthritis (seven), posttraumatic ankylosis with nonunion (one), or multiple failed attempts at open reduction and internal fixation (one). One patient had bilateral elbow fracture (Cases 4 and 10), with a twelve-year interval between fractures. Eleven patients were known to have a major coexistent pathological condition that was thought to influence the final outcome. Eight patients; seven of whom had rheumatoid arthritis, were taking steroid medications; two patients were diagnosed with osteoporosis; and one had non-insulin-dependent diabetes mellitus. The patients had had a mean of three (range, one to eight) operations about the elbow prior to the index reconstructive procedure at our institution and a mean of 2.5 (range, one to four) open osseous operations specifically addressing the elbow joint.

The predominant symptom at presentation was pain in twenty-one elbows, whereas one patient was primarily concerned about instability. The source of the pain was thought to
be the loose components, which were apparent on radiographs. Additional symptoms included weakness in five patients, reduced motion in six patients, and deformity and ulnar nerve symptoms in one patient each.

Six patients had weakness of elbow extension, with two demonstrating antigravity weakness of the triceps, and one had a flail elbow. Four patients had an irreparable ulnar nerve located in the cubital tunnel, with a positive Tinel sign and mild paresthesias in the ulnar nerve distribution. The preoperative workup for infection included aspiration of the elbow in patients who had pain at rest as well as measurement of the erythrocyte sedimentation rate and the C-reactive protein level.

The implants in situ at the time of index revision included seven Coonrad-Morrey, two Coonrad-I, eight Pritchard-Walker, and two London prostheses as well as one GSB (Gschwend-Scheier-Bahler), one Triaxial, and one Swanson prosthesis. The radiographic diagnosis was aseptic loosening of the ulnar component in seventeen elbows. One patient had a well-fixed ulnar component associated with substantial proximal bone loss, and one patient had a well-fixed ulnar component with a periprosthetic fracture. Additional diagnoses included symptomatic loosening of the humeral component in five elbows, periprosthetic fracture at the component tip in the proximal part of the ulna in eight (Fig. 1-C), periprosthetic fracture of the humerus in two, and fracture of the stem of the ulnar component in two. The Coonrad-Morrey ulnar component that fractured did so partially through the proximal beaded area, which was a feature designed to enhance the cement bonding interface. Subsequently, this area was recognized as an area of increased stress and the implant was redesigned. One elbow had been treated with an ulnar component with a precoating of polymethylmethacrylate (Figs. 1-A, 1-B, and 1-C), which subsequently has been associated with premature loosening following some hip replacements. The primary indication for reimplantation in this series was aseptic failure. The primary indications for the allograft strut reconstruction of the proximal part of the ulna are presented in Table 1.

Although some of the humeral components were not obviously loose on preoperative radiographs, twelve elbows required revision of both the humeral and the ulnar component. In one elbow, the ulnar component remained firmly fixed distally but was associated with substantial proximal ulnar osteolysis. The component was retained, and the revision consisted of reconstruction of the proximal part of the ulna alone. Cortical perforations occurred in two elbows during cement removal with a high-speed burr; they were recognized intraoperatively and were covered with corticocancellous bone grafts.

**Surgical Technique**

The choice of surgical approach depended, in part, on the previous skin incision, but the Bryan-Morrey deep exposure was possible in sixteen elbows and a structurally incompetent triceps or olecranon allowed a triceps-detaching approach in two. The medullary canal was débrided of cement and pseudomembrane, and osseous defects were delineated.

Containment struts (Fig. 2, A) were used in eight elbows in which the defect was contained within a minimum of three cortical surfaces (for example, it was used for a defect of the anterior aspect of the ulna in the region of the ulnar stem). All grafts were attached with 16 or 18-gauge cerclage wires. The primary function of containment struts was to provide local bone stock for incorporation, and a secondary function was to add support to the lesion. Structural struts were used to directly strengthen an incompetent ulna-prosthesis unit with a periprosthetic fracture in eight elbows and with an impending fracture in three (Figs. 2, B, and 3-A). A secondary function of the grafts in these elbows with a fracture was to provide local bone stock for incorporation. The grafts were obtained from AlloSource (Centennial, Colorado) and were either fresh-frozen or freeze-dried. Eight fibular, six humeral, two ulnar, five femoral, and three rib grafts were used. Graft selection was dictated by the structural elements required and the graft availability. Whereas a large structural defect in a small person could be adequately addressed with a fibular graft, the same defect in a larger person required a femoral graft. We attempted to match the graft thickness to the thickness of the underlying host cortical bone. Hence graft selection was tailored to the size of the patient, the size of the ulnar bone defect, whether the humeral side required support as well, and the quality of the surrounding cortical bone stock. Because the grafts were ordered prior to the surgery, we were not always able to tailor the graft exactly to the lesion and we erred on the side of selecting stronger and thicker grafts. With regard to length, the graft was cut to extend two cortical diameters distal to the lesion. In two patients with deficient olecranon bone stock (Fig. 1-C), a structural graft was required for the proximal part of the ulna and was extended proximally in order to secure a triceps attachment site with a number-5 nonabsorbable suture (Fig. 2, C). Additionally, the graft was intended to increase the triceps lever arm and decrease the likelihood of impingement on the prosthesis. One elbow had an old nonunion of the olecranon combined with a periprosthetic fracture at the tip of the ulnar component. The olecranon fracture fragment was refreshed at its nonunion site and was securely fixed with the proximal cerclage wire to the posterior strut.

**TABLE 1 Primary Indications for Proximal Ulnar Reconstruction**

<table>
<thead>
<tr>
<th>Indication for Reconstruction</th>
<th>No. of Elbows</th>
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<tr>
<td>Proximal granulomatous erosion around stem</td>
<td>14</td>
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<tr>
<td>Cortical deficiency with fracture</td>
<td>7</td>
</tr>
<tr>
<td>Incompetence of olecranon with erosion</td>
<td>3</td>
</tr>
<tr>
<td>Aseptic loosening with expanded proximal part of ulna</td>
<td>2</td>
</tr>
<tr>
<td>Impending fracture at ulnar component tip</td>
<td>1</td>
</tr>
<tr>
<td>Olecranon incompetence with fracture</td>
<td>1</td>
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graft. In two elbows, the proximal part of the ulna had expanded, with thinning of the cortices, around a loose ulnar component. They were treated with a combination of impaction grafting with morselized allograft and augmented with strut allografts (Fig. 2, D).

Intraoperative findings were categorized according to how many surfaces of the ulna were deficient. Seven specimens had a single-sided deficiency (five anterior and two lateral), four had a two-sided deficiency (three anteromedial and one anterolateral), three had a three-sided deficiency (lateral, anterior, and medial), and three had a four-sided deficiency that involved 4 to 5 cm of proximal ulnar loss. The four-sided deficiencies were managed with a combined technique, which consisted of insertion of a fibular allograft-prosthesis composite in one case and, in addition, anterior and posterior femoral struts and circumferential cortical strut grafts in the other two cases.

Follow-up
Follow-up evaluation was performed with use of the Mayo Elbow Performance Score (MEPS) and radiographs. The patients were interviewed over the telephone by an independent reviewer from our Total Joint Database who is specifically trained in such communications.

Twenty patients (twenty-one elbows) were available specifically for this final review. One patient, who was in a federal prison, could not be contacted, but the last clinical follow-up of that patient had been performed at five years after the revision. The final in-person assessment at our institution was conducted at an average of 3.5 years (range, two to six years). The final radiographic assessment of six elbows was carried out specifically for this study, radiographs of five elbows were sent to us by the local physicians, and the last radiographs made at our institution were used for the final follow-up of eleven elbows. The radiographs were assessed with respect to the bone-cement interface, proximal bone stock, and amount of graft surface area incorporated into the underlying host bone. The bone-cement interface was classified as one of five types, as previously described. Type 0 indicated no radiolucency of any part of the cement-bone interface; type 1, a nonprogressive radiolucent line involving <50% of the interface; type 2, a nonprogressive radiolucent line involving ≥50% of the interface; type 3, a progressive radiolucent line involving <50% of the interface; type 4, a progressive radiolucent line involving ≥50% of the interface; and type 5, gross loosening of the implant. Graft incorporation was graded according to the degree of host-graft distinction on both anteroposterior and lateral radiographs. Grade 0 indicated that the whole graft-host interface was clearly distinct and separate without any crossing trabeculae; grade 1, that ≤25% of the interface was indistinct with crossing trabeculae; grade 2, that 26% to 50% of the interface was indistinct; grade 3, that 51% to 75% of the interface was indistinct; and grade 4, that 76% to 100% of the interface was indistinct (Fig. 3-B).

Results
Clinical
The final follow-up of the twenty-one patients was performed at a mean of four years (range, two to eleven years). The interview for determination of the Mayo Elbow Performance Score (MEPS) was completed for twenty of the twenty-one patients, whereas information on the incarcerated patient was derived from the medical records at a five-year examination. All twenty-one patients had radiographs of the elbow made at least two years after the strut-graft procedure.

At the time of the final follow-up, the average MEPS had improved from 34 points (range, 15 to 55 points) to 79 points (range, 30 to 100 points). The prerevision functional score had been poor for all twenty-two elbows, whereas at the final review the score was poor for two elbows, fair for three, good for five, and excellent for seven. Of the twenty-one patients, only one had a lower functional level at the final review than before the revision, and this patient had had multiple operations and complications. The pain scores improved the most,
from an average of 9 points (range, 0 to 30 points) to an average of 32 points (range, 15 to 45 points). No patient had pain that was as severe as it had been before the revision, although four patients continued to have moderate pain and ten had mild pain. Seven patients were completely pain-free. The average stability score increased from 0.48 point (range, 0 to 5 points) to 7 points (range, 5 to 10 points). The average score for activities of daily living also improved considerably, from 8 points (range, 0 to 20 points) to 21 points (range, 5 to 25 points). The least improvement was seen in the flexion arc, which consisted of a 17° improvement (range, 5° to 20° improvement) in flexion and an 18° improvement (range, 5° to 20° improvement) in extension.

Complications
Eight (36%) of the twenty-two elbows underwent additional surgery after the index reconstructive revision operation for reasons related to the original pathological condition or the index revision surgery (Table II). Of these, six elbows had a single complication and two had two complications.

Two ulnar components loosened following the index revision surgery, at three and six years. One patient (Case 1), a prison inmate, had a history of narcotics abuse, a long history of rheumatoid arthritis with steroid use, osteoporosis, multiple documented falls, and insertion of a pre-coat ulnar component (Coonrad-Morrey) at the original revision procedure. This patient was treated with impaction cancellous allograft and strut grafts as well as reinsertion of an ulnar component. Two years later, she sustained a periprosthetic fracture about the tip of the ulnar stem in a fall, and this was successfully treated in a plaster cast. The other patient with aseptic loosening of the ulnar component, with an erosion and an impending fracture at the tip of the ulnar stem, had had excellent relief of symptoms and had returned to manual labor despite

<table>
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<tr>
<th>Complication</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>Case 1 Ulnar component loosening</td>
<td>Impaction and strut grafts; revision of ulnar component</td>
</tr>
<tr>
<td>Case 12 Ulnar component loosening</td>
<td>Strut grafts and revision with long-stem ulnar component</td>
</tr>
<tr>
<td>Case 10 Periprosthetic ulnar fracture</td>
<td>Strut graft and revision with long-stem ulnar component</td>
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<tr>
<td>Case 9 Deep osseous infection</td>
<td>Removal of prosthesis</td>
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<tr>
<td>Case 6 Sterile sinus</td>
<td>Sinus tract excision</td>
</tr>
<tr>
<td>Case 21 Sterile sinus</td>
<td>Sinus tract excision</td>
</tr>
<tr>
<td>Case 2 Wound breakdown</td>
<td>Multiple débridelements and antibiotic therapy</td>
</tr>
<tr>
<td>Case 7 Triceps detachment</td>
<td>Anconeus rotation flap</td>
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Figs. 3-A and 3-B Case 5. Fig. 3-A Lateral radiograph of the elbow shown in Figure 1, after revision with strut grafts that were used to bridge the fracture and augment the deficient olecranon. Fig. 3-B Four-year follow-up radiograph demonstrating good incorporation of the strut grafts but no visible remnant of the proximally extended strut.
postoperative instructions to limit usage of the elbow. The ulnar component was successfully revised with a longer stem and strut grafts.

A third patient sustained a second periprosthetic fracture at the tip of the ulnar stem, just distal to the original periprosthetic fracture, two years after the revision procedure. Poor bone quality, a history of long-term steroid use, and heavy cigarette smoking were possibly contributing factors. A revision procedure with use of a long-stem ulnar component bypassing the fracture and a postero-medial fibular strut to splint the fracture site was performed. The patient had a well-fixed implant and a healed fracture at the most recent assessment, at two years.

Radiographic Findings
Cement-Bone Interface
The cement-bone interface was type 0 in four elbows, type 1 in eight, type 2 in five, type 3 in two, type 4 in one, and type 5 in one. The two patients with a type-4 or 5 interface required component revision. Interestingly, the third patient who required a component revision had a type-1 interface.

Graft Incorporation
No elbow had grade-0 or 1 graft incorporation. Three had 26% to 50% incorporation (grade 2); five, 51% to 75% incorporation (grade 3); and fourteen, 76% to 100% incorporation (grade 4) (Fig. 3-B).

Discussion
Over the past two decades, the functional outcomes and rates of prosthetic survival following primary total elbow arthroplasty have greatly improved. Because the candidates for elbow replacement include many steroid-dependent patients at one end of the spectrum and younger, more active patients at the other end, an increasing number of patients have required revision surgery. Revision of an ulnar component in a patient who has associated bone loss is a complex undertaking. Many factors, including joint instability, infection, periprosthetic fracture, olecranon nonunion, and difficulty with implant or cement removal, make revision of an ulnar component challenging. A concern with any revision arthroplasty is the quality and quantity of the remaining host bone and thus the mechanical integrity of the limb segment.

There are two opposing approaches to the management of a failed arthroplasty associated with an osseous deficiency: (1) replace the deficient segment of host tissue and the loose implant with a custom-made device that replaces the deficiency, or (2) restore bone stock in conjunction with reimplantation of a standard prosthesis. While several reports on the use of custom-made devices have been published, we are unaware of any reports on the technique of restoring bone stock. Our experience has been exclusively with the latter technique for appropriately selected patients.

Bone stock can be restored with autologous bone graft, which is the most effective grafting material since it provides all three elements required for bone regeneration: osteoinduction, osteoconduction, and osteogenic cells. Allograft material is attractive as it is readily available, eliminates the morbidity associated with harvesting, and shortens the surgical procedure. Concerns about transmission of infection (which occurs in up to 15% of cases), nonunion (which occurs in nearly 10% of cases), and fracture (which occurs in 18% of cases) have been documented.

Although there were no graft fractures in the present study, one of our patients, not in this series, who had a high level of activity had a fracture of the strut graft at six months postoperatively and, at the time of writing, was awaiting revision surgery.

Cortical onlay plate grafts have been used for as long as forty years. Most of the current knowledge of the behavior of onlay grafts was derived from experience with revision hip surgery. The use of onlay allografts in the upper limb has been less extensive. Gresham reported using such grafts to treat fracture nonunions in the forearm, with an 85% success rate in eighty patients, in whom host replacement of the allograft was observed. Structural bone grafts serve two functions: first, they provide strength to an otherwise structurally compromised construct, and, second, they restore bone mass. An advantage of the strut graft over a traditional allograft-prosthesis composite is that the former has a substantially larger surface area for incorporation with the host. Our experience corroborates this finding, as the bone-allograft junction was completely indistinct in thirteen of the twenty-two elbows.

There are four distinct patterns of proximal ulnar bone loss related to revision total elbow arthroplasty. These include discrete cortical defects, which were contained in this series; periprosthetic fractures, which were splinted; deficiency of the triceps attachment, which was reconstructed; and expanded segments, which were augmented with struts and filled with impaction graft. Granuloma formation, due to the host response to particulate debris, can lead to endosteal cortical erosion progressing to discrete, multiple, or multiply interconnected cortical perforations. When the cortical integrity is sufficiently compromised, periprosthetic fractures can occur, usually in the region about the tip of the ulnar stem or the olecranon process. The surgical goal is always the same: to restore bone stock and regain stability with function.

An area in which strut grafts failed to reconstruct the defect effectively was the territory of the olecranon process. The purpose of using strut grafts in this region, in elbows with circumferential proximal ulnar bone loss (two) or with nonunion of the olecranon (one), was to provide a secure attachment for the triceps and to increase its lever arm for function. None of these three attempts succeeded in preserving this segment of allograft, which lacked a stable and vascularized host tissue bed.

Technical features of graft application have been previously noted to affect graft behavior. Close contact between the cortical graft and the host bone has been shown to be of utmost importance in canine studies. With our technique of graft preparation, the deep surface of the graft is sculpted,
with a high-speed burr, to a shape reciprocal with that of the host, and the superficial surface is smoothed of sharp edges, while as much graft thickness as possible is maintained. However, because of the subcutaneous location of the ulna, the strut grafts were palpable by eight patients. Hence it is important to balance the reconstructive requirement with the capacity of the soft tissues. The grafts were secured with cerclage wires. We observed that cementation was improved when defects were digitally occluded during insertion of the cement and implant, with subsequent final graft placement and wire tightening.

To treat these elbows successfully, the surgeon needs to be familiar with a wide range of reconstructive techniques. Strut graft reconstruction appears to stabilize and reconstruct the proximal part of an ulna with cortical defects and a periprosthetic fracture. In conjunction with impaction grafting, strut grafts increase host cortical bone stock. However, osseous deficiencies in the region of the olecranon process and those that are not supported by stable and vascularized host bone do not appear to be amenable to this form of reconstruction. This type of complex reconstructive revision more than doubles the patients’ functional ability, especially in those with periprosthetic fracture. However, the considerable complication rate, even when there is successful incorporation of the graft, should be kept in mind.

### Appendix

A table showing demographic data on all twenty-one patients (twenty-two elbows) is available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM).

**References**