Treating Humeral Bone Loss in Shoulder Arthroplasty: Modular Humeral Components or Allografts

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Take-Home Points

- Proximal humeral bone loss presents a significant challenge for the shoulder arthroplasty surgeon.
- Unsupported long-stemmed humeral components in this setting are prone to early loosening.
- APCs can rebuild proximal humeral bone stock, but have concerns with graft resorption and long-term failure.
- Modular endoprosthetic reconstruction of proximal humeral bone loss potentially allows those deficiencies to be addressed in a more durable fashion.
- Longer-term and larger studies are needed to determine the optimal reconstruction technique for proximal humeral bone loss.

Shoulder arthroplasty is an established procedure with good results for restoring motion and decreasing pain for a variety of indications, including arthritis, fracture, posttraumatic sequelae, and tumor resection.\(^1\) As the population ages, the incidence of these shoulder disorders increases, with the incidence of total shoulder arthroplasty (TSA) and reverse total shoulder arthroplasty (RTSA) increasing at faster rates than that of hemiarthroplasty.\(^5,6\) These expanding indications will, in turn, result in more revisions that would present challenges for surgeons.\(^1,7,8\)

The glenoid component is much more commonly revised than the humeral component; however, the humeral component may also require revision or removal to allow exposure of the glenoid component.\(^9\) Revision of the humeral stem might be required in cases of infection, periprosthetic fracture, dislocation, or aseptic loosening.\(^10\) The survival rate of humeral stems is generally >90% at 10 years and >80% at 20-year follow-up.\(^7\) Despite these good survival rates, a revision setting the humeral component requires exchange in about half of all cases.\(^11\)
Humeral bone loss or deficiency is one of the challenges encountered in both primary and revision TSA. The amount of proximal bone loss can be determined by measuring the distance from the top of the prosthesis laterally to the intact lateral cortex. Methods for treating bone loss may involve monoblock revision stems to bypass the deficiency, allografts to rebuild the bone stock, or modular components or endoprostheses to restore the length and stability of the extremity.

Proximal humeral bone loss may make component positioning difficult and may create problems with fixation of the humeral stem. Proper sizing and placement of components are important for improving postoperative function, decreasing component wear and instability, and restoring humeral height and offset. Determining the appropriate center of rotation is important for the function and avoidance of impingement on the acromion, as well as for the restoration of the lever arm of the deltoid without overtensioning. The selection of components with the correct size and the accurate intraoperative placement are important to restore humeral height and offset. Components must be positioned <4 mm from the height of the greater tuberosity and <8 mm of offset to avoid compromising motion. De Wilde and Walch described about 3 patients who underwent revision reverse shoulder arthroplasty after failure of the humeral implant because of inadequate proximal humeral bone stock. They concluded that treatment of the bone loss was critical to achieve a successful outcome.

**Long-Stemmed Humeral Components Without Grafting**

There is some evidence indicating that humeral bone loss can be managed without allograft or augmentation. Owens and colleagues evaluated the use of intermediate- or long-stemmed humeral components for primary shoulder arthroplasty in 17 patients with severe proximal humeral bone loss and in 18 patients with large humeral canals. The stems were fully cemented, cemented distally only with proximal allografting, and uncemented. Indications for fully cemented stems were loss of proximal bone that could be filled with a proximal cement mantle to ensure a secure fit. Distal cement fixation was applied when there was significant proximal bone loss and was often supplemented with cancellous or structural allograft and/or cancellous autograft. Intraoperative complications included cortical perforation or cement extrusion in 16% of patients. Excellent or satisfactory results were obtained in 21 (60%) of the 35 shoulders, 14 (78%) of the 18 shoulders with large humeral canals, and 7 (41%) of the 17 shoulders with bone loss. All the 17 components implanted in patients with proximal humeral bone loss were stable with no gross loosening at an average 6-year follow-up.

Budge and colleagues prospectively enrolled 15 patients with substantial proximal humeral bone loss (38.4 mm) who had conversion to RTSA without allografting after a failed TSA. All patients showed improvements in terms of the American Shoulder and Elbow Surgeons (ASES) score, subjective shoulder value, Constant score, and Visual Analog Scale (VAS) pain score, as well as an improved active range of motion (ROM) and good radiographic outcomes at 2-year follow-up. Although the complication rate was high (7 of 15), most of the complications were minor, with only 2 requiring operative intervention. The only component fracture occurred in a patient with a modular prosthesis that was unsupported by bone proximally. Budge and colleagues suggested that concerns about prosthetic fracture can be alleviated using a nonmodular monoblock design. No prosthesis-related complications occurred in their series, leading them to recommend monoblock humeral stems in patients with severe proximal humeral bone loss.

Stephens and colleagues reported revision to RTSA in 32 patients with hemiarthroplasties, half of whom had proximal humeral bone loss (average 36.3 mm). Of these 16 patients, 10 were treated with monoblock stems and 6 with modular components, with cement fixation of all implants. At an average 4-year follow-up, patients with proximal bone loss had improved motion and outcomes, and decreased pain compared to their preoperative condition; however, they had lower functional and pain ratings, as well as less ROM compared to those of patients.
with intact proximal bone stock. Complications occurred in 5 (31%) of those with bone loss and in 1 (0.6%) of those without bone loss. Three of the 16 patients with bone loss had humeral stem loosening, with 2 of the 3 having subsidence. Only 1 patient required return to the operating room for the treatment of a periprosthetic fracture sustained in a fall. Of the 16 patients with bone loss, 14 patients demonstrated scapular notching, which was severe in 5 of them. Because patients with altered humeral length and/or standard length stems had worse outcomes, the authors recommended longer stems to improve fixation and advocated the use of a long-stemmed monoblock prosthesis over an allograft-prosthesis composite (APC).18

However, Werner and colleagues19 reported high rates of loosening and distal migration with the use of long-stemmed humeral implants in 50 patients with revision RTSA. They noted periprosthetic lucency on radiographs in 48% of patients, with more than half of them requiring revision. In 6 patients with subsidence of the humeral shaft, revision was done using custom, modular implants, with the anatomic curve being further stabilized using distal screw and cable fixation to provide rotational stability.

Using a biomechanical model, Cuff and colleagues20 compared 3 RTSA humeral designs, 2 modular designs, and 1 monoblock design in 12 intact models and in 12 models simulating 5 cm of proximal humeral bone loss. They observed that proximal humeral bone loss led to increased humeral component micromotion and rotational instability. The bone loss group had 5 failures compared to 2 in the control group. All failures occurred in those with modular components, whereas those with monoblock implants had no failures.

### Allograft-Prosthesis Composite

Composite treatment with a humeral stem and a metaphyseal allograft was described by Kassab and colleagues21 in 2005 and Levy and colleagues22 in 2007 (Figures 1A-1C) in patients with tumor resections21 or failed hemiarthroplasties.22 Allograft was used when there was insufficient metaphyseal bone to support the implant, and a graft was fashioned and fixed with cerclage wire before the component was cemented in place. In the 29 patients reported by Levy and colleagues,22 subjective and objective measurements trended toward better results in those with an APC than in those with RTSA alone, but this difference did not reach statistical significance. Several authors have identified a lack of proximal humeral bone support as 1 of the 4 possible causes of failure, and suggested that the allograft provides structural support, serves as an attachment for subscapularis repair, and maximizes deltoid function by increasing lateral offset and setting the moment arm of the deltoid.21-23

In a prospective study of RTSA using structural allografts for failed hemiarthroplasty in 25 patients with an average bone loss of 5 cm, 19 patients (76%) reported good or excellent results, 5 reported satisfactory results, and 1 patient reported an unsatisfactory result.1 Patients had significantly improved forward flexion, abduction, and external rotation and improved outcome scores (ASES and SST). Graft incorporation was good, with 88% and 79% incorporation in the metaphysis and diaphysis, respectively. This technique used a fresh-frozen proximal humeral allograft to fashion a custom proximal block with a lateral step-cut, which was fixed around the stem with cables. A long stem and cement were used. If there was no cement mantle remaining or if the medial portion of the graft was longer than 120 mm, the cement mantle was completely excised. The allograft stump of the subscapularis was used to repair the subscapularis tendon either end-to-end or pants-over-vest. The authors noted that the subscapularis repair provided increased stability; the only dislocation not caused by trauma did not have an identifiable tendon to repair. In this manner, APC reconstruction provided structural and rotational support to the humeral stem as well as bone stock for future revision.1,20

One significant concern with APC reconstruction is the potential for graft resorption, which can lead to humeral stem loosening, loss of contour of the tuberosity, or weakening to the point of fracture.24,25 This may be worsened
by stress shielding of the allograft by distal stem cement fixation. Other concerns include the cost of the allograft, increased risk of de novo infection, donor-to-host infection, increased operative time and complexity, and failure of allograft incorporation.

The use of a proximal femoral allograft has been described when there is a lack of a proximal humeral allograft. Kelly and colleagues described good results in 2 patients in whom proximal femoral allograft was used along with bone morphogenetic protein, cemented long-stemmed revision implants, and locking plate augmentation.

**Endoprosthetic Reconstruction**

Various forms of prosthetic augmentation have been described to compensate for proximal humeral bone loss, with the majority of reports involving the use of endoprosthetic replacement for tumor procedures. Use of endoprostheses has also been described for revision procedures in patients with rheumatoid arthritis with massive bone loss, demonstrating modest improvements compared to severe preoperative functional limitations.

Tumor patients, as well as revision arthroplasty patients, may present difficulties with prosthetic fixation due to massive bone loss. Chao and colleagues reported about the long-term outcomes after the use of implants with a porous ongrowth surface and extracortical bridging bone graft in multiple anatomic locations, including the proximal humerus, the proximal and distal femur, and the femoral diaphysis. In 3 patients with proximal humeral reconstruction, the measured ongrowth was only 30%. Given the small number of patients with a proximal humerus, no statistical significance was observed in the prosthesis location and the amount of bony ongrowth, but it was far less than that in the lower extremity.

Endoprosthetic reconstruction of the proximal humerus is commonly used for tumor resection that resulted in bone loss. Cannon and colleagues reported a 97.6% survival rate at a mean follow-up of 30 months in 83 patients with modular and custom reconstruction with a unipolar head. The ROM was limited, but the prosthesis provided adequate stability to allow elbow and hand function. Proximal migration of the prosthetic head was noticed with increasing frequency as the length of follow-up increased.

Use of an endoprosthesis with compressive osteointegration (Zimmer Biomet) has been described in lower extremities and more recently with follow-up on several cases, including 2 proximal humeral replacements for oncology patients to treat severe bone loss. One case was for a primary sarcoma resection, and the other was for the revision of aseptic loosening of a previous endoprosthesis. Follow-up periods for these 2 patients were 54 and 141 months, respectively. Both these patients had complications, but both retained the endoprosthesis. The authors concluded that this is a salvage operation with high risk. In another study, Guven and colleagues reported about reverse endoprosthetic reconstruction for tumor resection with bone loss. The ROM was improved, with a mean active forward elevation of 96° (range, 30°-160°), an abduction of 88° (range, 30-160°), and an external rotation of 13° (range, 0°-20°).

Modular endoprostheses have been evaluated as a method for improving bone fixation and restoring soft-tissue tension, while avoiding the complications associated with traditional endoprostheses or allografts. These systems allow precise adjustments of length using different trial lengths intraoperatively to obtain proper stability and deltoid tension. Of the 12 patients in a 2 center study, 11 had cementless components inserted using a press-fit technique (unpublished data, J. Feldman). At a minimum 2-year follow-up, the patients had an average improvement in forward elevation from 78° to 97°. Excluding 2 patients with loss of the deltoid tuberosity, the forward elevation averaged 109°. There were significant improvements in internal rotation (from 18° to 38°), as well as in the scores of Quick Disabilities of the Arm, Shoulder and Hand (DASH), forward elevation strength,
ASES, and VAS pain. However, the overall complication rate was 41%. Therefore, despite these promising early results, longer-term studies are needed.

**Conclusion**

Proximal humeral bone loss remains a significant challenge for the shoulder arthroplasty surgeon. In the setting of a primary or a revision arthroplasty, the bone stock must be thoroughly evaluated during preoperative planning, and a surgical plan for addressing the deficits should be developed. Because proximal humeral bone loss may contribute to prosthetic failure, every effort should be made to reconstitute the bone stock.\(^{16}\) If the bone loss is less extensive, impaction grafting may be considered. Options to address massive proximal humeral bone loss include APCs and endoprosthetic reconstruction. The use of an allograft allows subscapularis repair, which may help stabilize the shoulder and restore the natural lever arm, as well as the tension of the deltoid.\(^{1,21-23}\) In addition, it helps avoid rotational instability and micromotion and provides bone stock for future revisions. However, concern persists regarding allograft resorption over time. More recently, modular endoprosthetic reconstruction systems have been developed to address bone deficiency with metal augmentation. Early clinical results demonstrate a high complication rate in this complex cohort of patients, not unlike those in the series of APCs, but clinical outcomes were improved compared to those in historical series. Nevertheless, longer-term clinical studies are necessary to determine the role of these modular endoprosthetic implant systems.

**Key Info**

**Figures/Tables**

Figures / Tables:

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Figure 1. (A) A 71-year-old woman presented with a long-standing atrophic nonunion of a proximal humeral shaft fracture. (B) The bone was removed and the allograft was fashioned and inserted. (C) Reverse total shoulder arthroplasty with an allograft-prosthesis composite.

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Figure 2. (A, B) A 22-year-old woman presented after failure of fixation and curettage for a proximal humeral giant cell tumor. (C, D) After modular endoprosthetic reconstruction, she retains a good outcome 3 years after surgery.
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