Bone Grafting in Shoulder Arthroplasty

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**educational objectives**

As a result of reading this article, physicians should be able to:

1. Describe options for managing posterior glenoid bone loss in primary anatomic total shoulder arthroplasty.

2. Describe the indications for and results of bone grafting for glenoid loss in revision anatomic total shoulder arthroplasty.

3. Describe options for managing superior glenoid bone loss and discuss the role of bony lateralization in primary reverse total shoulder arthroplasty.

4. Describe the design features of fracture stems and options for bone grafting augmentation in the treatment of proximal humerus fractures.

**ABSTRACT**

Shoulder arthroplasty is one of the fastest-growing fields in orthopedic surgery. Deficiency of the glenoid or humeral bone stock is a major challenge that can result from degenerative arthritis, component loosening or extraction, fracture, or malignancy. Approximately 15% of primary reconstructions will require bone grafting, and the rate is higher for revisions. The authors present a systematic review of the current literature focused on the indications for and results of bone grafting techniques. This provides the practicing surgeon with a set of strategies to address bone loss in the primary and revision settings, whether using an anatomic or reverse design.

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doi: 10.3928/01477747-20121202-11
Shoulder arthritis is a common cause of pain and function loss among older adults. The number of total shoulder arthroplasties (TSAs) performed yearly is increasing.¹ Twenty-seven thousand TSAs were performed in 2008, and that number is increasing by 3000 to 4000 per year.² In primary glenohumeral arthritis, 10% to 15% of patients have enough posterior glenoid erosion to make prosthetic implantation impossible without bone grafting.²,³ Glenoid deficiency can also occur from the asymmetric superior forces of the humeral head in cuff tear arthropathy. In revision TSA, glenoid component loosening or removal frequently compromises available bone. Humeral defects are rarely degenerative. Rather, they result from the removal of well-fixed components at the time of revision, periprosthetic fractures, or the excision of proximal humeral malignancies. Shoulder surgeons should have a detailed understanding of the indications for and techniques of bone grafting.

**Classification of Bone Loss**

Primary posterior glenoid wear from glenohumeral arthritis was first described by Neer and Morrison (known as Neer’s classification).³ Walch et al.⁴ would later define a classification system that encompasses the various glenoid erosion patterns. In a type A glenoid, the humeral head is centered. This group is subdivided based on the amount of erosion into type A1 (minor erosion) and type A2 (marked erosion). In a type B glenoid, the humeral head is subluxated posteriorly. A type B1 glenoid shows asymmetric narrowing of the posterior joint space, whereas a type B2 glenoid has more extensive posterior wear resulting in a biconcave glenoid. Finally, a type C glenoid has retroversion in excess of 25°. In addition, Hill and Norris⁵ proposed a standardized radiographic assessment based on an axial radiograph or computed tomography scan. Posterior glenoid defects are described based on the version of the defect relative to the normal glenoid version; the extent of the defect relative to the entire glenoid surface, expressed as a percentage; and the maximum depth of the defect at the glenoid margin.

In contrast to primary glenohumeral osteoarthritis, cuff tear arthropathy results in superior glenoid wear from the high-riding humeral head. These frontal plane changes were described by Favard et al.,⁶ who proposed 4 stages: E0 through E3, with E0 representing a normal glenoid, E1 symmetric wear in the frontal plane, E2 asymmetric superior wear with biconcavity of the glenoid, and E3 severe superior wear.⁵

Glenoid defects resulting from component removal at the time of revision are more complex. Antuna et al.⁷ described a system based on intraoperative assessment of the glenoid. Defects were described as central, peripheral, or combined. Within each group, the defect was described as mild, moderate, or severe. They found this classification useful in guiding surgical decision making.⁶

Although multiple classifications exist for glenoid bone loss, no currently accepted classification system exists for bony defects of the proximal humerus. For research purposes, the zones of osteolysis of the hip proposed by Gruen et al.⁸ have been used to describe osteolysis around humeral implants, but this classification is not used widely for clinical decision making.

**Primary Anatomic Total Shoulder Arthroplasty Glenoid**

In primary TSA, posterior glenoid wear is the most common bone deficiency encountered. Some lesions can be overcome by asymmetric reaming, but in larger defects, overaggressive asymmetric reaming can lead to a smaller glenoid face, violation of the supporting subchondral bone, medialization of the joint line, and more frequent peg penetration.⁸ In a cadaveric study, the upper limit of glenoid retroversion that could be safely corrected with eccentric reaming was 15°.⁹ An alternative is to leave the glenoid retroversion unchanged, but data suggest that glenoid component retroversion greater than 10° results in increased stress at the cement mantle, increased motion at the bone–cement interface, higher shear stresses, and a higher likelihood of failure.¹⁰,¹¹ Therefore, overcoming large areas of posterior wear and excessive glenoid retroversion requires structural augmentation.

Augmented glenoid components with a thicker posterior than anterior polyethylene have been used for this purpose. Mid-term outcome data of 1 design suggested that it did not significantly improve outcomes.¹² Bone grafting of posterior glenoid lesions has a longer track record. It was first described by Neer and Morrison in 1988,² who used a custom-fashioned corticocancellous fragment of the patient’s humeral head to fill the posterior glenoid defect. When small, the bone graft was impacted into the remaining glenoid vault. Larger grafts were fixed with 2 cancellous screws using a lag technique.²

Three studies described the outcomes of this technique (Table 1).²,⁴,¹³ A total of 64 patients were followed for a minimum of 2 years. Radiographic union of the bone graft was achieved in 57 cases. Half (n=32) of the patients had an excellent Neer outcome score, 17 (27%) had a satisfactory score, and 15 (23%) had an unsatisfactory score. Complications occurred in 9 (14%) patients, with instability being the most common finding.

Bone graft can be used for more than its structural properties. Wirth et al.¹⁴ reported a technique in which morselized bone graft from the humeral head is inserted between flutes on the central peg. This technique is hypothesized to facilitate bony ingrowth. They provided radiographic outcomes for 44 patients at a mean of 3 years. Twenty shoulders had perfect seating and radiolucency grades, 30 had increased radiodensity between the flutes of the central peg, and 3 demonstrated osteolysis. No cases of clinical glenoid loosening were observed at a mean 4-year follow-up.¹⁴

**Humerus**

Bone grafting of the proximal humerus in primary TSA has been reported. In 2003,
Hacker et al\textsuperscript{15} described a technique in which cancellous bone from the humeral head is impacted into the humeral metaphysis and shaft, after which the humeral prosthesis is press fit using a standard technique. Although no clinical data were presented to suggest that impaction grafting improved patient outcomes, the radiographic appearance was improved. Using computed tomography, the authors demonstrated that the void between the prosthesis and the bone of the proximal humerus could be significantly decreased.\textsuperscript{15}

**Revision Anatomic Total Shoulder Arthroplasty**

**Glenoid Bone Loss**

Bone loss is encountered frequently in the revision setting due to glenoid loosening, bone loss during prostheses extraction, and osteolysis. Defects of the glenoid can present with a preserved or an absent vault. This distinction guides surgical decision making because the absence of a vault dictates the use of structural bone graft as opposed to cancellous graft.\textsuperscript{16}

Glenoid component removal with bone grafting is the most commonly described treatment for a loose, painful glenoid with significant bone loss. Four studies described the results of this treatment (Table 2).\textsuperscript{16-19} As a whole, the data suggest that modest pain reduction\textsuperscript{16,19} and patient satisfaction\textsuperscript{16-18} can be achieved. However, graft subsidence is the norm, with progressive medialization of the humeral head. In the only study that compared cancellous allograft with structural femoral head allograft, subsidence was higher with use of structural graft; however, the groups are so small that it is difficult to generalize this result.\textsuperscript{16}

For patients who have undergone glenoid removal and bone grafting but have persistent pain, the option of glenoid reimplantation remains. The procedure is uncommon, reported in only 18 patients across 4 studies.\textsuperscript{6,20-22} Antuna et al\textsuperscript{20} reported a case series of 3 patients with 2- to 8-year follow-up. Based on Neer’s classification, 1 had an excellent result, 1 had a satisfactory result, and 1 had an unsatisfactory result. Cheung et al\textsuperscript{21} reported 7 patients with a minimum 2-year follow-up. Pain visual analog scale score decreased from 4.6 to 2.4, and range of motion was unchanged. According to Neer’s classification, 1 patient had an excellent result, 1 had a satisfactory result, and 3 had an unsatisfactory result.\textsuperscript{21}

Only 2 studies directly compared outcomes between patients with glenoid bone grafting without resurfacing and those undergoing glenoid revision after bone grafting. Elhassan et al\textsuperscript{22} retrospectively compared 3 patients with glenoid bone grafting and revision TSA with 5 patients undergoing only glenoid bone grafting. No significant differences were found in Constant scores or range of motion.\textsuperscript{22} Antuna et al\textsuperscript{20} reported a larger study comprising a retrospective comparison of 18 shoulders with glenoid component removal and bone grafting and 5 shoulders that subsequently underwent glenoid component revision. The revision group had significantly better external rotation at a minimum 2-year follow-up. When the glenoid was not replaced, a mean of 7.5 mm of graft subsidence occurred.\textsuperscript{20}

**Humeral Bone Loss**

It is less common to lose enough bone in the proximal humerus to warrant bone grafting but still have enough intact soft tissue structures to allow for successful anatomic TSA. A single case report described the use of a cortical strut allograft in addition to impaction cancellous allografting for the treatment of proximal humeral deficiency in a multiply revised shoulder.\textsuperscript{23} At 29 months, the patient had no pain and was
Table 2
Summary of the Literature on Bone Grafting of Glenoid Defects During Revision Total Shoulder Arthroplasty

<table>
<thead>
<tr>
<th>Study</th>
<th>Level of Evidence</th>
<th>Population Characteristics</th>
<th>Grafting Technique</th>
<th>Graft Subsidence</th>
<th>Pain VAS</th>
<th>Functional Scores</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalise &amp; Iannotti</td>
<td>IV</td>
<td>11 patients, minimum 2-y follow-up</td>
<td>6 cancellous allograft chips and 5 femoral head structural allografts</td>
<td>3 &lt;5 mm, 6 between 5 and 10 mm, 2 &gt;10 mm</td>
<td>Penn Shoulder Score: 10-17</td>
<td>N/A</td>
<td>1 conversion to RSA, 1 explanation for septic arthritis</td>
</tr>
<tr>
<td>Young et al</td>
<td>IV</td>
<td>6 patients, minimum 1-y follow-up</td>
<td>Tricortical iliac crest</td>
<td>3 without erosion, 2 with partial erosion, and 1 with complete collapse</td>
<td>N/A</td>
<td>Penn Shoulder Score: 36.8-59.8; subjective, 5 satisfied, 1 unsatisfied</td>
<td>1 conversion to RSA</td>
</tr>
<tr>
<td>Neyton et al</td>
<td>IV</td>
<td>9 patients, minimum 2-y follow-up</td>
<td>Bicortical iliac crest</td>
<td>Mean, 4.1 mm</td>
<td>N/A</td>
<td>Neer, 5 satisfactory, 4 unsatisfactory; Constant, 46.3-49.9</td>
<td>1 graft erosion, 1 reoperation for massive rotator cuff tear</td>
</tr>
<tr>
<td>Phipatanakul &amp; Norris</td>
<td>IV</td>
<td>24 patients, minimum 2-y follow-up</td>
<td>Cancellous allograft chips</td>
<td>10 without, 6 between 3 and 6 mm, 1 between 7 and 9 mm, 3 &gt;10 mm</td>
<td>18/24 with satisfactory pain relief</td>
<td>N/A</td>
<td>4 glenoid reimplantations for persistent pain</td>
</tr>
</tbody>
</table>

Abbreviation: N/A, not applicable; RSA, reverse shoulder arthroplasty; VAS, visual analog scale.

able to perform all activities of daily living and play golf. However, the patient was unable to perform any overhead activities.23

A more common application of bone grafting in the humerus is to assist in the healing of a proximal humeral window. A window may be required to remove a well-fixed humeral component at the time of revision. Sperling and Cofield24 reported 20 patients who were followed for a minimum of 3 months. The humeral window was filled with cancellous allograft, after which a cemented humeral prosthesis was used and secured with cerclage cables. Clinical and radiographic union was achieved in all patients.24

**PRIMARY REVERSE TOTAL SHOULDER ARTHROPLASTY**

Glenoid bone deficiency can be an issue in reverse TSA. Frequently, the defect in cuff tear arthropathy is superior instead of posterior, as in osteoarthritis. Minor glenoid deficiency can be overcome by a modified reaming technique in which a cannulated reamer is directed down the centerline of the scapular spine. This allowed for correction of 34 of 56 glenoid deficiencies in a recent case series.25 If eccentric reaming does not allow for 80% bony coverage of the glenoid base plate, augmentation with humeral head bulk autograft provides satisfactory results.25 The defect is created by humeral head wear, and a section of the head generally fits well.

For massive uncontained glenoid lesions in the presence of a massive rotator cuff tear, a femoral neck allograft centrally packed with a humeral head autograft can be used to augment the glenoid bone stock for the glenosphere. Results of this technique have been reported in 5 patients with a minimum 1-year follow-up.26 Computed tomography scans at 6 months showed complete graft incorporation in all cases, but no pain or functional outcomes were reported.26

Boileau et al27 proposed the routine use of bone grafting to improve the outcomes of reverse TSA. The technique is called bony increased-offset reverse shoulder arthroplasty, or Bio-RSA. A cylinder of cancellous bone from the humeral head is cut with a guide to exactly match the size of the glenoid base plate. A central hole is then drilled in the disk of bone to allow it to slide over the central peg of the glenoid (Figure 1). By providing bony lateralization, this is hypothesized to reduce scapular notch, improve shoulder contour, and allow for a greater arc of motion. Once the graft incorporates, these benefits are achieved without increasing torque at the baseplate–bone interface, as may occur with prosthetic lateralization.28

Boileau et al27 reported their results with Bio-RSA in 42 patients with a minimum 2-year follow-up. Computed tomography and radiographic evaluations showed complete graft incorporation in 98% of patients. In addition, 86% of patients could internally rotate sufficiently to reach their back over their sacrum. Scapular notching occurred in only 19% of patients, as compared with the 50% to 90% reported in the literature. No graft resorption or glenoid loosening were observed during the short-term follow-up.27
REVISION REVERSE TOTAL SHOULDER ARTHROPLASTY

Glenoid Bone Loss

When faced with glenoid deficiency in revision reverse TSA, the humeral head is absent, and an alternate source of bone graft is needed. Satisfactory results have been obtained with the use of autologous iliac crest structural graft. Kelly et al.\textsuperscript{28} first described the technique for using an iliac crest–glenoid baseplate composite. The baseplate is implanted directly onto the pelvis, and the iliac crest is then cut and fashioned to match the glenoid defect (Figure 2). They reported the results of this technique in 12 patients as part of a larger series of 30 revision reverse TSAs. Constant and American Shoulder and Elbow Surgeons scores improved significantly, and 80% of patients were satisfied or very satisfied, according to the authors’ criteria.\textsuperscript{28}

Neyton et al.\textsuperscript{29} reported 9 reverse TSAs using iliac crest autograft, 6 of which were revisions or conversions from conventional implants. At 2-year follow-up, 5 patients were pain free (visual analog scale score, 0/10), 1 patient had significant pain (visual analog scale score, 8/10), and 3 patients had moderate pain (visual analog scale score, 2-5/10). All patients could elevate their arm at least 90°. According to the authors’ criteria, 4 patients were very satisfied, 3 were satisfied, and 2 were disappointed. No evidence was found of component loosening or graft failure.\textsuperscript{29}

Humeral Bone Loss

Significant humeral bone loss in the setting of revision reverse TSA requires a more complex approach. The cylindrical nature of the humeral shaft does not provide torsional stability for the stem without the proximal humerus to cup the proximal part of the implant. In addition, it is felt that the lack of proximal humerus bone can lead to poor deltoid tension and concomitant implant instability and weakness.\textsuperscript{30} Chacon et al.\textsuperscript{31} described the use of a prosthesis–allograft composite for this application in 25 patients (Figure 3). They custom shaped a proximal humeral allograft to match each patient’s bone defect. The allograft was then secured to the patient’s proximal humerus with cerclage cables, and the humeral component was cemented into the construct. They reported excellent results in 19 patients, satisfactory results in 5 patients, and an unsatisfactory result in 1 patient, according to Neer’s criteria. American Shoulder and Elbow Surgeons scores improved from 31.7 to 69.4. Metaphyseal incorporation of the allograft was achieved in 84% of patients, and diaphyseal incorporation was achieved in 76%. Complications occurred in 4 patients: 2 dislocations, 1 as-

Figure 1: Use of the bony increased-offset reverse shoulder arthroplasty (Bio-RSA) technique and a bone graft–augmented fracture stem for treatment of a proximal humeral fracture in the setting of advanced glenohumeral osteoarthritis. Anteroposterior radiograph of the left shoulder of an 80-year-old patient showing advanced glenohumeral osteoarthritis (A). Anteroposterior radiograph of the left shoulder of the same patient showing a 2-part proximal humeral fracture after a fall from standing (B). Postoperative anteroposterior radiograph of the left shoulder showing the result of reconstruction with a reverse shoulder prosthesis (C). A conical piece of cancellous bone from the humeral head is harvested (D) and placed around the central peg of the glenosphere (E). A punch is then used to obtain a wedge of cancellous bone from the remaining humeral head (F), which is perfectly sized for insertion into the metaphyseal window of the humeral prosthesis (G).
ymptomatic allograft fracture treated conservatively, and 1 nondisplaced acromial fracture. Proximal femoral allograft is another option with benefits of greater cortical thickness and a large greater trochanter that tensions the deltoid.

**ARTHROPLASTY FOR FRACTURE**

When performing hemiarthroplasty for comminuted proximal humeral fractures,
The indications for bone grafting in the treatment of periprosthetic humeral fractures are unclear. The largest series of such fractures was reported by Kumar et al. They reported a retrospective series of 16 patients collected over a 25-year period. For a type A fracture (at the prosthesis tip with proximal extension) or a type B fracture (at the prosthesis tip with distal extension) with a stable stem, they recommended the use of autologous iliac crest bone graft to augment plate fixation. In the setting of a loose stem, they recommended revision TSA with a cemented long-stem prosthesis and cancellous allograft augmentation. They also reported the successful use of a free vascularized fibular graft for nonunion of a periprosthetic type B fracture. All 16 fractures healed at a mean of 278 days.35

For type C fractures (occurring distal to the prosthesis tip), internal fixation and strut allograft augmentation has been described. Martinez et al reported a series of 6 patients treated in this fashion. At a mean 14-month follow-up, all 6 fractures had united, and mean Constant score was 64. Patient satisfaction and range of motion were restored to prefracture status in all but 1 patient. On follow-up radiographs, 3 patients had evidence of graft–host union, and 3 had graft resorption.36

**ARTHROPLASTY IN THE SETTING OF MALIGNANCY**

A unique reconstructive challenge is encountered after resection of a humeral malignancy. Reconstructive options are limited because of the complex loss of bone, articular surface, and stabilizing soft tissues. An allograft–prosthesis composite can be used in such situations (Figure 4).37,38 The allograft can include the humeral head, the humeral shaft, the anterior shoulder capsule, the rotator cuff tendons, and the insertional segments of the deltoid, pectoralis major, and latissimus dorsi. The graft is cut at the anatomic neck, and a standard proximal humeral implant is placed within the medullary canal. The construct is then cemented into the humerus, and all of the soft tissues are repaired to their native counterparts.37,38

**CONCLUSION**

Various bone grafting techniques are available to surgeons faced with complex reconstructive challenges in the shoulder. The principal indications are inadequate glenoid or humeral bone stock and augmentation of component fixation in the setting of...
REFERENCES


