SUBSPECIALTY PROCEDURES

ALLOGRAFT-PROSTHETIC COMPOSITE RECONSTRUCTION FOR MASSIVE PROXIMAL HUMERAL BONE LOSS IN REVERSE SHOULDER ARTHROPLASTY

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Abstract

Background: Allograft-prosthetic composite (APC) reconstruction of the humerus represents an appealing surgical technique when implantation of a reverse prosthesis is considered in the setting of substantial proximal humeral bone loss¹⁻⁴. Humeral APCs have been successfully performed in the past with a non-reverse shoulder prosthesis^{4,5}. Reconstruction of the proximal part of the humerus with an allograft provides adequate support and fixation for the humeral component, allows restoration of length and lateral offset, and provides an opportunity for soft-tissue reattachment when needed. On the basis of the available peer-reviewed data, healing at the allograft-host junction is reliable, and complication rates, including instability, are relatively low^{3,6}.

Description: Once the glenoid reverse component has been implanted, a proximal humeral allograft is prepared to receive the humeral component of a reverse arthroplasty. The allograft is procured by our institutional bone and tissue bank, purchased from a number of vendors. The graft is selected after review of the description and radiographs provided by the vendor. The priority is to obtain a graft with sufficient length and soft tissues attached. If possible, the graft selected should have a diameter close to the diameter of the humerus of the recipient. The desired allograft length is selected on the basis of preoperative planning and intraoperative measurements, and the distal portion of the allograft is resected accordingly. Depending on the length of the defect, host bone quality, and surgeon preferences, the humeral component may or may not bypass the host-graft junction. The stem bypasses the host-graft junction for shorter APCs, as well as when the bone quality of the native humerus is compromised. Cemented fixation into the graft is universally used. Compression plating is used for graft-to-host fixation, supplemented by implantation of the stem across the junction in selected cases. Care is taken during the freehand cut to obtain optimal contact and compression. Once the ideal

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humeral bearing thickness has been selected, the polyethylene bearing is implanted and the joint relocated. If the posterior cuff can be repaired to cuff allograft, sutures are placed prior to relocation and are tied after relocation. Other musculotendinous units, such as the deltoid or pectoralis major, are repaired to the allograft if needed.

Alternatives: Implantation of a reverse prosthesis with a proximal humeral metal body (a so-called tumor prosthesis) is the main alternative to proximal humeral APC reconstruction. In patients with shorter defects, adequate soft-tissue tension may be obtained by implanting a glenosphere with a large inferior eccentricity and cementing the humeral component in a more proximal position than is usually performed. Alternatively, when implantation of the glenoid component of a reverse prosthesis is not possible, a hemiarthroplasty-APC construct may be performed^{1,4,5,7-10}, adding a synthetic sleeve such as an aortic Dacron graft to enhance soft-tissue stability if needed.

Rationale: When reverse arthroplasty is performed in the setting of substantial humeral bone loss, the humeral component may be poorly supported and at risk for loosening. In addition, the absence of proximal humeral bone stock may lead to shortening and/or loss of lateral offset. Finally, the posterosuperior cuff, subscapularis, deltoid, and pectoralis tendons may remain detached. The potential consequences of humeral bone loss in the setting of reverse arthroplasty include humeral loosening, dislocation, and poor active motion (particularly poor active elevation). Allograft reconstruction of the proximal part of the humerus provides an opportunity for better support of the component, restoration of humeral length and lateral offset, and attachment sites for the musculotendinous structures around the shoulder, if needed.

Introductory Statement

Allograft-prosthetic composite (APC) reconstruction of the proximal part of the humerus at the time of reverse arthroplasty allows restoration of adequate humeral length and lateral offset, provides good support and fixation of the humeral component, and facilitates soft-tissue repair when needed (Fig. 1).

Fig. 1

Fig. 1 Schematic representation of shoulder reconstruction using a humeral allograft-prosthetic reverse composite (reverse APC). (Reproduced, with modification, from: Sanchez-Sotelo J, Wagner ER, Sim FH, Houdek MT. Allograft-prosthetic composite reconstruction for massive proximal humeral bone loss in reverse shoulder arthroplasty. *J Bone Joint Surg Am*. 2017 Dec 20;99[24]:2069-76.)

Indications & Contraindications

Indications

- Revision of failed shoulder arthroplasty with substantial humeral bone loss.
- Reconstruction after resection of tumors involving the proximal part of the humerus.
- Reverse arthroplasty for sequelae of trauma resulting in substantial proximal humeral bone loss (e.g., proximal humeral nonunion).
- Second-stage reverse reimplantation after extensive debridement and bone removal for the management of deep infection.

Contraindications

- Uncontrolled deep infection.
- Severe impairment of bone-healing (e.g., need for radiation or chemotherapy); in such patients, a tumor prosthesis may be a better option than an APC.
- Absence of a minimum amount of the distal end of the humerus to allow stable graft-to-host fixation.
- Extremely contracted soft-tissue envelope (deltoid) not providing enough space for the bulk of the proximal humeral allograft.
- Paralysis not amenable to nerve procedures or tendon transfers.
- Contraindications for placement of a reverse glenoid component (e.g., severe glenoid bone loss not amenable to reconstruction).

Step-by-Step Description of Procedure (Video 1)

Video 1 Surgical technique for reconstruction of the shoulder using a reverse allograft-prosthetic composite (APC).

Step 1: Exposure

Expose the shoulder and humeral diaphysis through the deltopectoral interval proximally and through splitting of the brachialis (the Henry approach) distally (Figs. 2-A, 2-B, and 2-C).

- Incise the skin in a straight line. Proximally, the incision is at the junction between the medial third and the lateral two-thirds of the distance between the coracoid and posterolateral aspect of the acromion. Distally aim the incision toward the lateral aspect of the brachialis. Incorporate previous incisions as needed (Fig. 2-A).
- Perform a deltopectoral interval exposure (Fig. 2-B). Mobilize the deltoid laterally and the pectoralis and conjoint tendon medially. Identify and protect the axillary nerve throughout the procedure. If the subscapularis is intact, isolate and tag the subscapularis. If the posterosuperior cuff is intact, isolate and tag it as well. For longer defects, the deltoid and pectoralis may need to be isolated and tagged too.
- If the latissimus dorsi and/or teres major will be transferred to provide active external rotation, identify, mobilize, and tag their tendons as well.
- If the tendon of the long head of the biceps is still intact, divide and tag the tendon for tenodesis at the end of the procedure.
- If the distal third of the humeral shaft needs to be exposed for plate fixation, identify and isolate the radial nerve at the interval between the brachialis and common extensor group (brachioradialis).
- Split the brachialis in line with its fibers, leaving approximately 20% of the brachialis width laterally; protect the radial nerve when splitting the lower third of the brachialis.
- Expose a sufficient length of the distal aspect of the humerus to allow secure plate fixation (length for 5 to 6 holes for plate and screw fixation).
- Remove failed implants (e.g., failed arthroplasty components and failed internal fixation devices), if needed (Fig. 2-C).
- Consider obtaining samples for intraoperative pathology and cultures for patients with previous failed surgery.

Fig. 2-A

Fig. 2-B

Figs. 2-C

Figs. 2-A, 2-B, and 2-C Surgical exposure. **Fig. 2-A** Skin incision. **Fig. 2-B** Deltopectoral interval and brachialis split. SRS = Skeletal Replacement System (Zimmer-Biomet).

Figs. 2-C Failed prosthesis removed.

Step 2: Glenoid Component Implantation

Implant the glenoid component in a satisfactory position, ensure adequate contact with healthy native bone, and obtain secure component fixation (Fig. 3).

- Glenoid exposure should be relatively straightforward in the absence of the proximal part of the humerus.
- Place the baseplate flush with the inferior rim of the glenoid and with a slight inferior tilt.
- Confirm adequate contact with healthy native bone.
- Obtain adequate component fixation.
- Implant the glenosphere. Selection of the diameter and lateralization of the glenosphere is based on surgeon preference, glenoid bone loss, and features of the system selected. The preference of the senior one of us (J.S.-S.) is to use a large-diameter glenosphere whenever possible. Beware of excessive glenoid lateralization when the system used lateralizes the humeral side as well, since it may be difficult to position the bulk of the allograft under the deltoid in patients with soft-tissue contracture.
- When the procedure is performed after tumor resection or for sequelae of trauma, ream the glenoid with extreme care; in the absence of glenoid subchondral sclerosis, it is very easy to mistakenly ream excessive bone.
- When the procedure is performed after failure of a previous arthroplasty, special components or bone-grafting techniques may be required for sound implantation of the glenoid component¹¹.

Fig. 3

Fig. 3 Baseplate and glenosphere implantation.

Step 3: Humeral Allograft Preparation

Prepare the allograft on the back table to receive the humeral stem and preserve the attached allograft tendon stumps, if needed (Fig. 4-A).

- Perform an osteotomy of the humeral head along the plane of the anatomic neck using an extramedullary guide, an intramedullary guide, or a freehand technique (Fig. 4-B).
- Ream and broach the humeral canal, preserving cancellous bone for cement interdigitation (Fig. 4-C and 4-D).
- If the tendons of the posterosuperior cuff, subscapularis, deltoid, or pectoralis will be used for repair, preserve these allograft tendon stumps. Otherwise, they can be sharply excised at this point.
- Keep the graft protected from contamination throughout the procedure.

Fig. 4-A

Fig. 4-B

Fig. 4-C

Fig. 4-D

Figs. 4-A through 4-D Allograft preparation. **Fig. 4-A** Humeral allografts may be used without soft tissues (left) or with allograft tendons preserved (right). **Fig. 4-B** Proximal humeral osteotomy at the anatomic neck level.

Figs. 4-C and 4-D Allograft reaming (**Fig. 4-C**) and broaching (**Fig. 4-D**).

Step 4: Determination of Allograft Length

Resect the distal portion of the graft to the correct length according to preoperative planning and intraoperative trialing.

- When a malignant tumor is resected, match the length of the allograft to the length of the resection as measured intraoperatively (Fig. 5-A). The allograft may be resected a few millimeters longer than the anticipated required length to allow fine adjustments in order to obtain optimal fit and the osteosynthesis junction.
- In other indications, the approximate length may be estimated using preoperative measurements on radiographs of both humeri obtained with magnification markers.
- Bring the allograft to the surgical field with a broach and humeral bearing trial component of intermediate thickness (usually the second thickest trial to allow fine-tuning of the soft-tissue tension with the definitive humeral bearing).
- Place the allograft-trial implant articulating with the glenoid component, drape the deltoid around the allograft, and overlay the humeral allograft with the native humerus under traction. Mark the appropriate resection level.
- Alternatively, a long, loose-fitting broach may be placed into the native humeral canal, the joint relocated, and traction applied to the arm, measuring the length of the broach proximal to the upper end of the native humerus once soft-tissue tension is considered to be adequate (Fig. 5-B).
- Resect the distal portion of the humeral allograft and save the resected portion in case it becomes necessary for strut augmentation (Fig. 5-C).
- Remove medial bone at the neck region to minimize impingement with adduction and rotation (Fig. 5-D). The humeral broach and handle may then be used to bring the allograft to the surgical field (Fig. 5-E).
- In selected shoulders with a narrow humeral cross-section, a larger graft may be prepared for intussusception. This typically requires thinning the upper end of the remaining host humerus, and widening the endosteal canal of the graft. Intussusception provides an opportunity for improved stability and a larger area of bone contact for healing. It is particularly useful when the remaining distal part of the humerus is very short.

Fig. 5-A

Fig. 5-B

Fig. 5-C

Fig. 5-D

Fig. 5-E

Figs. 5-A through 5-E Determination of allograft length. **Fig. 5-A** After tumor removal, the length of the resected humerus should be recorded to assist in length planning. **Fig. 5-B** Length may also be determined by applying traction on the arm with a loose-fitting broach in place. **Fig. 5-C** Allograft osteotomy at the selected length.

Figs. 5-D and 5-E The medial part of the bone may be removed from the allograft to minimize impingement (**Fig. 5-D**), and the humeral broach and handle are used to bring the allograft to the surgical field (**Fig. 5-E**).

Step 5: Graft-to-Host Fixation and Humeral Component Implantation

Optimize contact, compression, and stability at the graft-host junction.

- If the stem will bypass the graft-host junction, place a cement restrictor in the native humerus just distal to the anticipated position of the distal end of the prosthesis.
- Bring the allograft to the surgical field with a broach and broach handle in place. Plate fixation with the broach in place will guarantee that the screws will not interfere with later insertion of the cemented prosthesis. The broach handle can be used to position the graft in the correct version (typically 30° of retroversion) (Fig. 6-A).
- Use a burr or microsagittal saw to fine-tune the distal end of the allograft and proximal end of the native humerus so that perfect contact at the junction will be obtained.
- Interfragmentary compression is obtained using a 3.5-mm locking compression plate (Fig. 6-B).
- Select a plate that will provide adequate fixation: 5 to 6 holes distal to the junction and enough proximal holes so that the plate will overlap with the stem (to avoid a stress-riser between the upper end of the plate and the lower end of the stem).
- Prebend the plate at the level where it will cross the junction so that plate application does not result in flexion of the construct and lack of contact at the junction posteriorly.
- Apply the plate so that screws can be placed lateral to the broach. Confirm adequate broach version and host-to-graft contact. The plate may be provisionally held with clamps.
- Insert the most proximal nonlocking screw into the allograft in compression mode but do not tighten fully. It is typically best to use a fully threaded cancellous screw when fixing the plate to the upper portion of the allograft.
- Keep the plate centered on the humeral shaft distally while displacing it distally using a nerve hook inserted in the most distal hole.
- Insert a second screw in compression mode through 1 of the holes distal to the junction.
- Tighten these 2 screws fully and confirm compression at the host-graft junction (Fig. 6-C).

Fig. 6-A

Fig. 6-B

Fig. 6-C

Figs. 6-A through 6-G Trialing and implantation of the humeral bearing. **Fig. 6-A** Bone allograft is positioned in 30° of retroversion with the aid of a broach handle. **Fig. 6-B** Compression plating across the host-graft junction. **Fig. 6-C** Note perfect contact and compression.

- Additional nonlocking and locking screws are inserted proximally and distally to obtain the most stable construct possible (Fig. 6-D).
- Occasionally, screw fixation proximally is not possible in every single hole; circumferential wire fixation through a hole in the plate may be alternatively considered.
- Once plate fixation has been completed, remove the humeral broach.
- Implant the cemented humeral component. Our preference is to add 1 g of vancomycin and 1 mL of methylene blue per batch of methylmethacrylate and to use vacuum mixing and retrograde cement insertion techniques with a flexible small nozzle connected to the gun (Figs. 6-E and 6-F).

Fig. 6-D

Fig. 6-E

Fig. 6-F

Figs. 6-D, 6-E, and 6-F Fixation of the component. **Fig. 6-D** Finalized internal fixation. **Fig. 6-E** Cemented fixation of the humeral component. **Fig. 6-F** Humeral component implanted in the reconstructed humerus.

Step 6: Trialing and Implantation of the Humeral Bearing

Determine the ideal thickness of the humeral bearing, implant the polyethylene bearing, and relocate the joint.

- Once the cement is completely cured, trial implants are used to select the ideal thickness of the humeral bearing.
- The ideal soft-tissue tension is judged by ease of relocation; tension on the deltoid, conjoined tendon, and other structures; and range of motion free of impingement.
- The humeral polyethylene bearing is impacted onto the upper portion of the humeral component, and the joint is relocated (Fig. 6-G).

Fig. 6-G

Fig. 6-G The joint is relocated.

Step 7: Tendon Repairs or Transfers

If needed, attach the tendons of the posterosuperior cuff, subscapularis, deltoid, and/or pectoralis major to their allograft counterparts; alternatively, consider tendon transfers.

- If the posterosuperior cuff is still present at the time of reconstruction, place multiple nonabsorbable sutures to repair the native cuff to the tendon allograft prior to relocating the joint and tie the sutures after relocating the joint. Placement of the arm in abduction and external rotation facilitates tying these sutures securely (Fig. 7-A).
- If the subscapularis is still preserved at the time of reconstruction, the subscapularis tendon is repaired to the allograft subscapularis tendon (Fig. 7-B). Although controversy remains regarding the value of subscapularis repair at the time of primary reverse arthroplasty, it is important to provide as much stability as possible, since dislocation is one of the most worrisome complications after reverse shoulder arthroplasty in the presence of substantial proximal humeral bone loss.
- When the posterosuperior rotator cuff is absent, consideration may be given to attaching the latissimus dorsi and teres major to the posterosuperior cuff allograft; again, nonabsorbable sutures are placed prior to joint relocation and are tied after joint relocation. It is hoped that transfer of these tendons to the posterosuperior cuff will provide active external rotation.
- When the subscapularis is absent, the pectoralis major may be repaired to the subscapularis allograft tendon stump in an attempt to provide stability and potentially a better line of pull for internal rotation in abduction.
- For patients with very long humeral defects past the attachment site of the deltoid, the native deltoid tendon may also be connected to the tendon stump of the deltoid on the allograft.
- If the tendon of the long head of the biceps was intact and divided during exposure, it may be repaired with multiple sutures to the short head of the biceps (conjoined tendon) at the time of closure to avoid additional cosmetic deformities or cramping.

Fig. 7-A

Fig. 7-B

Figs. 7-A and 7-B Tendon repairs or transfers. **Fig. 7-A** Repair of the posterosuperior native cuff to the allograft cuff. **Fig. 7-B** Subscapularis repair.

Results

Between 2005 and 2012, the senior one of us performed 26 reverse shoulder arthroplasties using an allograft-prosthetic humeral composite (reverse APC) with compression plating across the host-graft junction⁶. There were 8 primary and 18 revision procedures. The reasons for proximal humeral bone deficiency included bone loss after trauma (5 shoulders), resection of a tumor (3), or revision surgery (18). The mean age of the patients at the time of surgery was 62 years, and the mean duration of follow-up was 4 years (range, 2 to 10 years).

Reverse APC resulted in significant improvements with respect to pain scores ($p < 0.0001$), elevation ($p < 0.0001$), and external rotation ($p = 0.004$). With the numbers available, there were no significant differences in clinical outcomes between patients who had a primary procedure and those who had a revision procedure. No patient needed revision surgery for nonunion at the host-allograft junction. The mean duration to union was 7 months. Complications included delayed union, dislocation, deep infection, graft fracture, delayed wound healing, and periprosthetic fracture distal to the previous APC construct in 1 shoulder each. At both the 2-year and 5-year follow-up evaluations, the revision-free survival rate was 96% (Fig. 8).

Fig. 8

Fig. 8 Anteroposterior (left) and lateral (right) radiographs after reverse APC reconstruction show graft-to-host healing, adequate fixation and stability of the humeral component, and restoration of the overall architecture of the arm skeleton.

Pitfalls & Challenges

Reverse APC reconstruction of the shoulder may be associated with the following potential challenges:

- Avoiding nerve injury, especially as it relates to the axillary and radial nerves.
- Selecting the right length of the humeral allograft.
- Achieving optimal positioning, contact, fixation, and compression across the host-graft junction.
- Achieving an adequate soft-tissue repair of the posterosuperior rotator cuff, subscapularis, deltoid, and pectoralis when needed, or considering tendon transfers.

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