Chapter 9

Proximal Humeral Resection with Allograft Prosthetic Composite

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BACKGROUND

- Several types of resections are available for tumors of the shoulder girdle. The type of resection has a major influence on the choice of reconstruction.[6] Resections can range from intra-articular resection of the proximal humerus to extra-articular resection of the humerus and scapula. Varying amounts of soft tissue also can be resected.
- Functional recovery is related to preservation of the axillary nerve and the shoulder abductors. If the glenoid and abductor mechanism can be preserved, a "functional" arthroplasty can be performed.
- Three types of arthroplasty are possible:
  - A metallic humeral prosthesis can be implanted. The soft tissues (rotator cuff, capsule, and deltoid) cannot be sewn to the prosthesis effectively; therefore, limited function is achieved.
  - The most common arthroplasty is an osteoarticular allograft, in which the upper humerus and joint are replaced with a frozen bone allograft. The soft tissues can be repaired to the graft, allowing significant functional recovery. This reconstruction, however, is associated with joint collapse, fracture, and secondary arthritis.
  - Another alternative is an allograft prosthetic composite. This procedure replaces the removed bone stock with an allograft but combines it with a metallic implant. It allows for soft tissue attachment to the allograft. The rotator cuff, deltoid, and capsule can be sewn to the soft tissues of the humeral allograft to maintain shoulder stability and improve shoulder active range of motion. The metallic device has potential to decrease long-term complications of the osteoarticular allograft.
- A "functional" arthroplasty is possible only after an intra-articular resection with abductor preservation (**FIG 1**). It makes little sense to do an arthroplasty if neither the axillary nerve nor the abductors are available. In that case, other reconstructive options, including arthrodesis to a "spacer" metallic hemiarthroplasty, are more appropriate.

INDICATIONS

- Intra-articular resection of the upper end of the humerus is indicated for benign but aggressive tumors, such as giant cell tumors or low-grade sarcomas, including chondrosarcoma. It also may be a reasonable choice for a sarcoma that has been pretreated with chemotherapy with a good response, including osteosarcoma, Ewing sarcoma, and malignant fibrous histiocytoma.
- Appropriate imaging studies should be performed to ensure that the axillary nerve and abductor muscles, along with the rotator cuff, can be preserved.
- If an intra-articular resection can be performed, the two most functional reconstructions to maintain shoulder stability and elevation include an allograft prosthetic composite arthroplasty and an osteoarticular allograft. Allograft prosthetic composite (APC) arthroplasty potentially avoids long-term complications of a frozen osteoarticular allograft, including fracture, joint collapse, and arthritis.

ANATOMY

- Tumors of the upper end of the humerus either are contained within the bone or have soft tissue extension. Soft tissue extension can be either very limited or extensive. The critical musculature of the upper end of the humerus includes the deltoid, innervated by the axillary nerve, and the rotator cuff, innervated by the suprascapular nerve (**FIG 2**).
- Other important muscles that must be detached from the upper humerus include the pectoralis major, latissimus dorsi, and teres major. The biceps and coracobrachialis, along with the musculocutaneous nerve, usually can be preserved by dissection and displacement. In the area of the coracoid, the brachial plexus nerves and the axillary artery and vein that become the brachial artery and vein must be dissected and protected.
- The axillary nerve and posterior humeral circumflex artery that pass through the quadrangular space before innervating the deltoid must be preserved to maintain abductor function. It also is important that the radial nerve be protected as it passes behind the humerus distal to the deltoid insertion. The subscapularis is detached away from the tumor and the lesser tuberosity. An arthrotomy then is performed to ensure there is no contamination of the shoulder joint by tumor, and then a circumferential arthrotomy is performed so that the upper end of the humerus can be detached once the bone is divided.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Patients with a tumor of the upper end of the humerus present with pain, loss of function, and a mass. Restricted range of motion typically occurs. Some patients actually present with neuropathic symptoms, including anesthesia or paresthesia involving nerves around the upper end of the humerus. Pain is the most common complaint. The pain is both activity-related and at night and usually requires analgesia. It is not uncommon for the patient to report some form of work-related or athletic injury at the time of presentation. Symptoms can last anywhere from days to months.
- Examination of the shoulder girdle includes range of motion, palpation, and a careful neurologic examination.
  - Range of motion can vary considerably but usually is diminished, especially abduction and flexion.
  - Palpation of the shoulder girdle and axilla may detect a mass or lymph node enlargement. It is important to note the location of the mass, especially if it extends into the axilla or in other areas of the shoulder girdle.
  - The neurologic examination includes examination of the axillary, radial, median, ulnar, and musculocutaneous nerves. Loss of any function of these nerves is a more ominous physical finding that often precludes an intra-articular resection of the upper humerus.

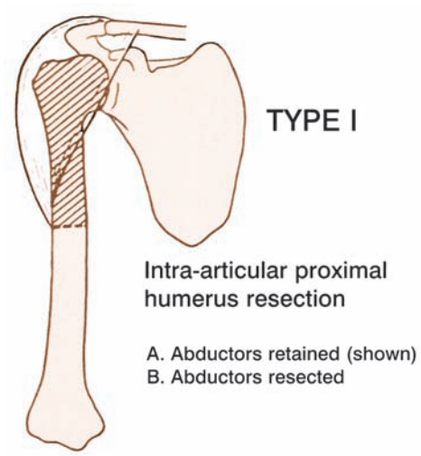


FIG 1 • Type 1 (intra-articular) resection. Note the retained abductors. (Courtesy of Martin M. Malawer.)

- It also is important to check the circulation of the limb, starting with the axillary vessel, and examining the brachial vessel all the way to palpation of the radial artery, and to perform an Allen test to make sure there is an ulnar artery.

IMAGING AND OTHER STAGING STUDIES

Imaging

- For tumors of the upper end of the humerus, a series of imaging studies is performed to determine resectability and reconstruction.
- Radiographs, including anterior–posterior, external rotation lateral, and axillary lateral views, (**FIG 3A,B**), give important clues to the diagnosis. The plain radiograph is the most important initial diagnostic tool in coming up with a differential diagnosis of the type of neoplasm present. Three-dimensional imaging of the upper end of the humerus also is important.
- MRI is very useful for looking at the soft tissue extent of the tumor and its relation to the neurovascular bundle (**FIG 3C**). MRI also is very helpful in determining the intramedullary extent of the tumor. This is particularly important for tumors such as chondrosarcoma, where the intramedullary extension goes well beyond the prediction by the plain radiograph.
- CT scans are better for defining bone involvement and may be helpful for some tumors.
- A bone scan is performed to determine whether there are skip lesions or involvement of other bones, suggesting polyostotic disease (**FIG 3D**). Multicentric osteosarcomas, for instance, are not terribly rare and can be detected by a technetium Tc 99m bone scan.
- Angiograms rarely are needed nowadays because of the availability of sophisticated three-dimensional imaging with infusion, such as MRI.
- If the plain radiograph suggests a sarcoma, then a CT scan of the chest for staging typically is performed before the biopsy so that the area is not distorted by general anesthesia and postanesthesia atelectasis.

Biopsy

- The biopsy of tumors of the upper end of the humerus is very important for ultimate resectability. The types of biopsies can be fine needle, for cytology; core needle, for histology; or open incisional.
- Placement of the biopsy is critical (**FIG 4**). The location usually is determined by the MRI scan and the presence of a soft tissue mass.
- Typically, the soft tissue component of the tumor is biopsied rather than going deep into the bone. The biopsy site should be located so that it can be resected along with the upper end of the humerus when the definitive operation is performed.
- The biopsy site for the soft tissue mass usually is reached by going through muscle. Because most surgical resections of the upper end of the humerus use the deltopectoral groove, this groove should be avoided during the biopsy. The surgeon should, instead, go through muscle, either the deltoid or the pectoralis, on one side of the groove or the other.
- An adequate amount of tissue should be biopsied to obtain a correct diagnosis.
- The surgeon consults with the pathologist to determine the appropriate type of biopsy.

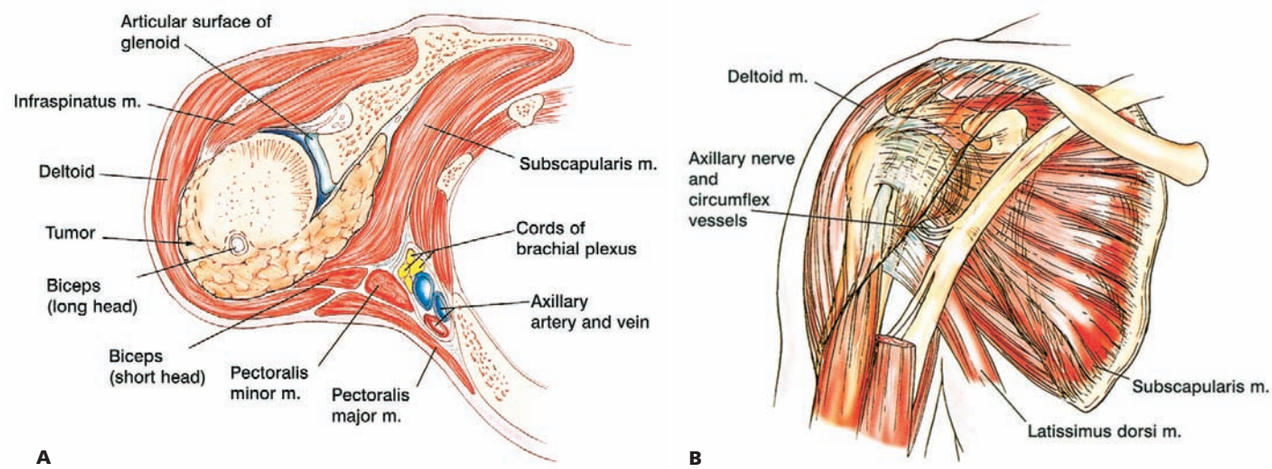


FIG 2 • Coronal (**A**) and transverse (**B**) diagrams of the anatomy of the shoulder and upper humerus. (Courtesy of Martin M. Malawer.)

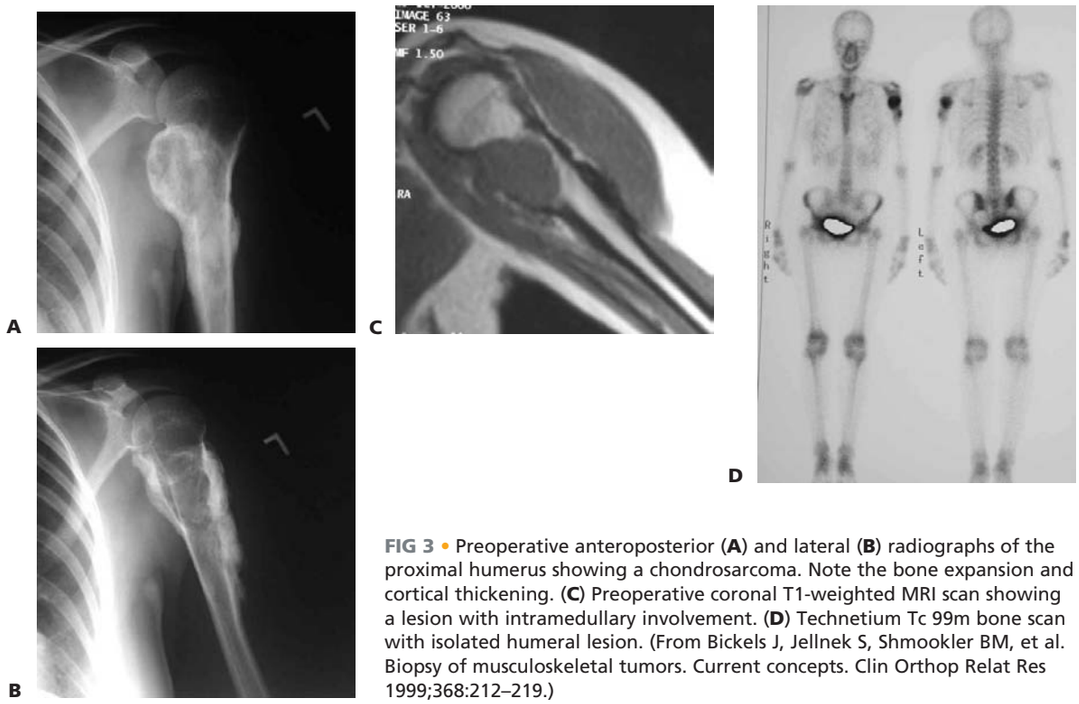


FIG 3 • Preoperative anteroposterior (**A**) and lateral (**B**) radiographs of the proximal humerus showing a chondrosarcoma. Note the bone expansion and cortical thickening. (**C**) Preoperative coronal T1-weighted MRI scan showing a lesion with intramedullary involvement. (**D**) Technetium Tc 99m bone scan with isolated humeral lesion. (From Bickels J, Jellnek S, Shmookler BM, et al. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219.)

- For most high-grade bone sarcomas, including osteosarcoma, Ewing sarcoma, and malignant fibrous histiocytoma, neoadjuvant chemotherapy is delivered prior to the primary resection.
- Neoadjuvant chemotherapy, if effective, causes tumor necrosis and margination. This makes limb salvage surgery, including an intra-articular resection of the humerus, a safer procedure.

SURGICAL MANAGEMENT

Preoperative Planning

- Special equipment is necessary for intra-articular resection of the humerus followed by an allograft prosthetic composite arthroplasty. The most notable is the frozen bone allograft, along with a long-stem humeral prosthesis. The surgeon must contact a tissue bank, preferably one accredited by the American Association of Tissue Banks, to ensure that a frozen humerus is available before the procedure.
- The surgeon should receive a radiograph of the allograft for sizing purposes. For an allograft prosthetic composite arthroplasty, the allograft must be long enough to replace the resected bone and of an appropriate size to accept a long-stemmed humeral prosthetic hemiarthroplasty device. A template of that device with a sizing ruler is helpful in choosing the right allograft. The allograft radiograph also should have a sizing device.
- The humeral allograft must have a retained soft tissue cuff for repair. Some humeral allografts come without this cuff; this operation cannot be done with that type of allograft.
- The surgeon also should template the glenoid to ensure that the appropriate metallic hemiarthroplasty is available (**FIG 5A**). A long-stem metallic device usually is used. Sometimes the long stem, which passes through the allograft and into the host bone, provides for a rigid press fit, and no additional internal fixation is necessary. In other cases, the stem acts only as a partial fixation device that provides bending stability, but an additional dynamic compression or locking plate will be necessary to provide rotational stability at the junction between the allograft and the host bone junction (**FIG 5B**).

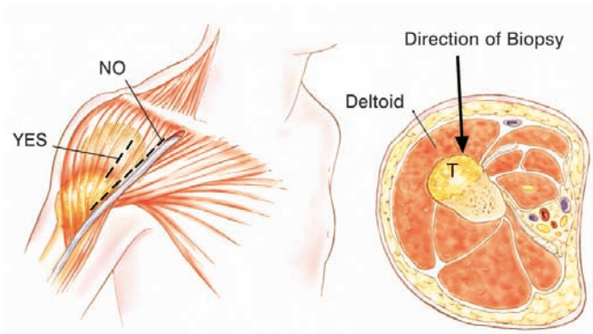
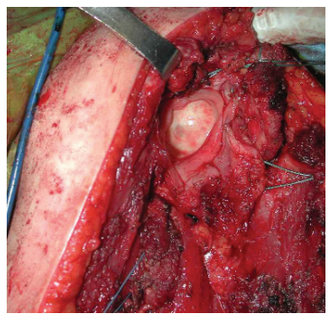


FIG 4 • Diagram of the correct biopsy incision for tumors of the upper humerus. The deltopectoral groove is avoided. (Courtesy of Martin M. Malawer.)

Positioning

- Positioning of the patient on the operating table must allow for an extensile exposure of the shoulder girdle. A towel roll typically is placed behind the medial border of the scapula so that access to the front and the back of the shoulder is obtained and the scapula and glenoid are stabilized. The limb is then prepped and draped in a free manner so that it can be manipulated during the operative procedure.


A


B

FIG 5 • **A.** Intraoperative view of the glenoid with the rotator cuff, deltoid, and pectoralis muscles tagged with wire suture for later repair. **B.** Postoperative short-stem construct (allograft–prosthetic composite) with compression plating at the allograft–host junction.

TECHNIQUES

Development of the Deltopectoral Groove

- The biopsy site must be excised as the deltopectoral groove is dissected. The cephalic vein is either retracted or suture ligated, and the groove is developed from the clavicle to the deltoid insertion. The dissection can be carried down between the insertions of the deltoid and the pectoralis major.
- The exposure can be extended distal to the lateral aspect of the biceps and brachialis if necessary (TECH FIG 1A).
- The musculocutaneous nerve and the biceps attachment to the coracoid are identified along with the nerves of the brachial plexus and vessels. These structures are dissected and retracted medially.

Soft Tissue Detachment

- The deltoid is detached from the deltoid tuberosity. The pectoralis major, teres major, and lattisumus dorsi muscles are detached from the humeral shaft. The rotator cuff tendons—subscapularis from the lesser tuberosity, and the supraspinatus, infraspinatus, and teres minor tendons from the greater tuberosity—are detached.
- The tendons are tagged with sutures for control and identification.
- The shaft of the humerus is isolated distal to the tumor.

Arthrotomy

- The anterior capsule is divided to determine tumor contamination of the joint. Then a circumferential arthrotomy is done until the humeral head can be dislocated. The inferior capsule must be released from the humeral neck, with the incision continued posteriorly. The axillary nerve can be protected by doing the release with the patient's arm adducted and progressively rotated externally while incising the capsule off the humerus.

Bone Division

- The humerus is then divided with a power oscillating saw distal to the tumor. The cut must have a significant margin of normal bone and marrow distal to the tumor, as determined by the preoperative MRI scan and measurements.
- Chandler retractors are placed around the bone to ensure protection of the radial nerve (TECH FIG 1B).

Dissection of the Quadrilateral Space

- The axillary nerve and the posterior humeral circumflex vessels are identified in the quadrilateral space and dissected and preserved all the way to the deltoid muscle.

Removal of Specimen and Inspection of Margins

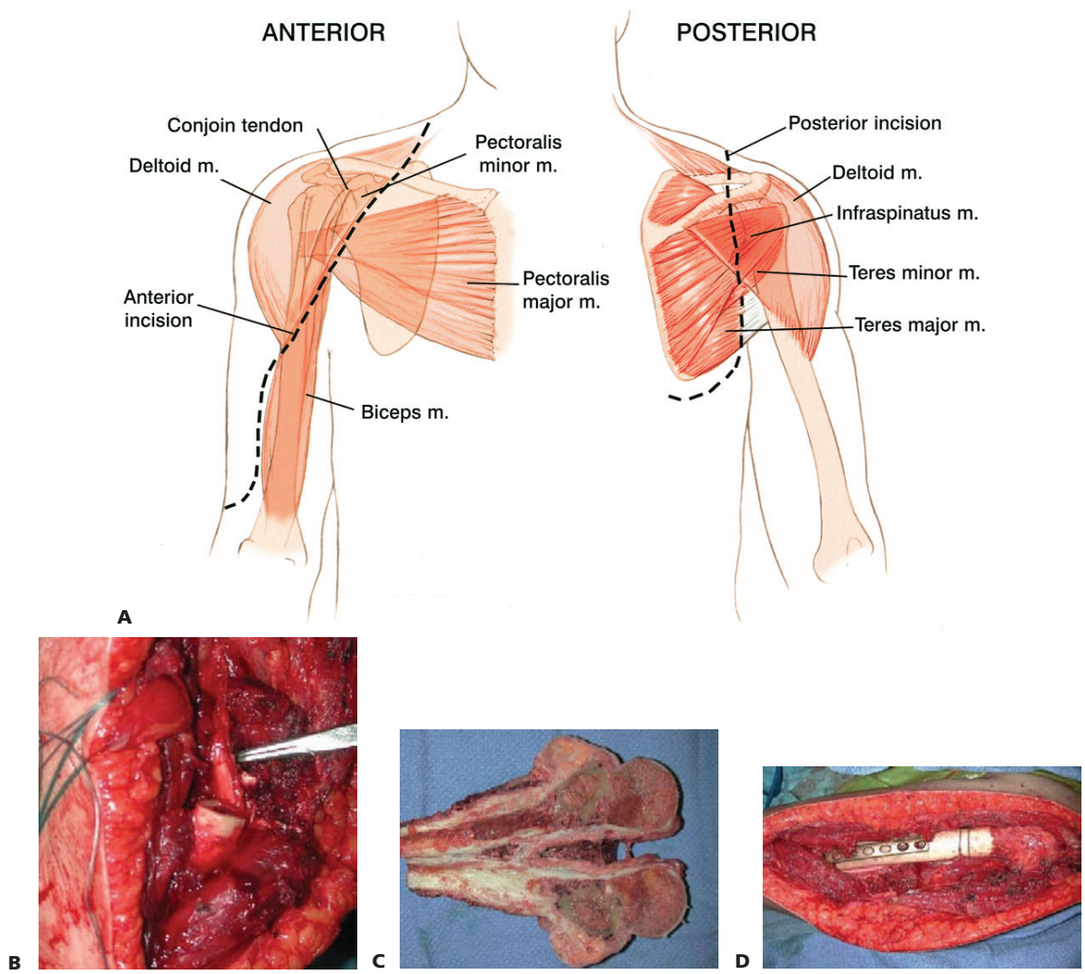
- The humeral specimen is removed after the remaining soft tissue attachments are cut. It usually is divided on the back table with a power oscillating saw, and gross inspection of margins is done (TECH FIG 1C). Microscopic margins also can be sent from the marrow space.

Reconstruction

- The reconstruction is performed with new gowns, gloves, and instruments. Before the resected specimen is removed, it is measured precisely. The allograft that has been procured is thawed in room-temperature lactated Ringer's solution.

Preparation of the Allograft

- After thawing, the allograft is measured and the soft tissue cuff inspected. The humeral allograft is divided with a power oscillating saw at the appropriate position to replace all resected humerus.
- The articular portion of the humeral allograft is resected at the anatomic neck, from the greater to the lesser tuberosity, with a power saw. The allograft is then prepared on the back table for the metallic humeral device using the system chosen by the surgeon.
- The bone of the upper end of the humerus typically is opened with a high-speed, high-torque burr. The humeral canal is prepared with the appropriate cylindrical reamers. The humeral allograft is then opened with the appropriate-sized rasps or broaches to accept the humeral component.



TECH FIG 1 • **A.** Diagram of the utilitarian incision for an intra-articular resection of the upper humerus. **B.** The radial nerve is identified adjacent to resected bone. **C.** Gross specimen of resected bone for inspection of surgical margins. **D.** Intraoperative view of finished reconstruction with compression plating and soft tissue repair. (**A:** Courtesy of Martin M. Malawer.)

- Long-stemmed humeral components are available in 170-mm and 200-mm lengths. Depending on the length of the humeral resection, the humeral component length is chosen to allow the stem to extend at least 2 cortical diameters into the host bone. The diameter of the prosthetic stem is determined by the size of the allograft canal and the size of the host bone canal.
- The long-stemmed humeral device is then inserted through the allograft with the stem extending beyond the end of the allograft to engage the host bone canal. All shoulder prosthetic systems now offer various humeral head sizes, and have eccentric offsets to match anatomy and fine tune stability. A trial humeral head is placed on the stem. A trial seating of the humeral construct intro the native canal and into the glenoid is performed to ensure humeral head size, height, and position within the glenoid. This also allows the surgeon to evaluate available rotator cuff length and soft tissue tension for repair around the prosthesis. If anything, a slightly larger humeral head is chosen.

Preparation of the Host Bone

- The diaphysis of the humeral host bone is cylindrically reamed to accept the allograft prosthetic composite implant. If a press fit is possible, then line-to-line reaming is performed. If not, the host bone is cylindrically reamed larger than the humeral stem but then will need to be additionally fixed with an internal fixation device.

Trial Seating of the Device

- The allograft prosthetic composite implant is inserted into the humeral host bone, and then the shoulder is reduced. The appropriate retroversion of the humeral head is selected.

TECHNIQUES

- Retroversion typically is 30 degrees from the epicondylar axis of the elbow to the humeral head. Another way to determine the correct rotation is to have the prosthetic humeral head pointing directly into the glenoid with the forearm in neutral rotation. The chosen retroversion position is marked at the junction between the allograft and the host bone.
- Rotation should be evaluated to ensure stability, because retroversion is a variable in the proximal humerus.

Cementing of the Allograft

- On the back table the humeral allograft is washed and dried, and cement is mixed. The cement is pressurized into the humeral allograft, and then the metallic prosthesis is inserted cephalad to caudad through the allograft with the stem extending beyond the bone cut. It is important to clean the stem of all cement while it is doughy so that the cement does not interfere with insertion into the humeral host bone.
- The cemented allograft prosthetic composite then is either press fit into the host bone or simply inserted, followed by internal fixation. Obviously, the more proximal the resection, the more native humeral canal is available, and the easier it is to obtain press-fit stability.
- The appropriate rotation for the 30 degrees of humeral retroversion is critical. If adequate rotational stability is not available at the allograft–host bone junction, a lateral dynamic compression plate or locking plate is used, applying the appropriate principles.
- If screws are used, they can be either unicortical or bicortical with compression principles at the allograft–host bone junction. Locking plates also allow for cerclage wire, which can be inserted around the humerus for additional fixation. It is important not to place unfilled screw holes in the allograft, because they act as stress risers and areas of revascularization that could lead to fracture.

Soft Tissue Repair

- The allograft prosthetic composite arthroplasty then is reduced into the shoulder joint, and a circumferential repair of soft tissue is performed. Nonabsorbable suture, of at least no. 2 or no. 5, is used for the repair. The capsule is repaired to the capsule of the allograft circumferentially in an interrupted manner.
- The supraspinatus, infraspinatus, and teres minor tendons are reattached to their appropriate tendons with nonabsorbable suture. It is easiest to begin the rotator cuff repair posteriorly and proceed to the supraspinatus and then the subscapularis.
- Subscapularis tendon repair is critical for anterior stability. The native capsule and rotator cuff tendons should be repaired to their corresponding allograft structures. The deltoid is reattached to the deltoid tendon on the allograft, and, if possible, the pectoralis major is reattached to its tendon.
- Using the appropriate tension for this repair is important. Placing the shoulder and arm in the "salute" position and then tying the tendons helps in obtaining the correct tension. Based on the compression obtained at the allograft–host bone junction, the surgeon can electively graft this junction with a bone graft substitute or even an autogenous graft (**TECH FIG 1D**).

Closure and Immobilization

- The wound is then closed over drainage tubes in multiple layers, and the shoulder is placed in an abduction shoulder brace, with the shoulder abducted 30 degrees and internally rotated 45 degrees.

PEARLS AND PITFALLS

Selecting an allograft with a retained soft tissue envelope is critical for success.	■ Some grafts come without these tendons, making this procedure impossible.
It is important to clean the prosthetic stem of all cement after it has been inserted through the allograft.	■ This cement can impede implantation into the host bone.
A trial reduction of the allograft prosthetic composite, marking rotation, is critical for function and shoulder stability.	■ Usually 30 degrees of retroversion is marked before internal fixation of the allograft to the host bone to prevent instability from component malposition.
When placing a lateral plate to stabilize the allograft prosthetic composite to the host bone, drilling through the cement can be challenging.	■ It is important to angle the screws away from the prosthetic stem when using a dynamic compression plate. This is not possible with a locking plate. Therefore, cerclage wires or unicortical screws are used with a locking plate around the stem.
No unfilled holes should be left in the allograft.	■ Such holes can lead to fracture.

COMPLICATIONS

- The risk of infection is 1% to 2% and the risk of nonunion is 10% to 20%.
- The most common problem is subluxation of the glenohumeral joint, depending on the amount of soft tissue available for reconstruction.

POSTOPERATIVE CARE

- The patient is maintained in an abduction orthosis for the early postoperative period. The Hemovac drain is discontinued, and the patient is discharged.
- Tendon healing and repair is allowed for approximately 4 weeks, after which gentle shoulder exercises are begun. At

first, pendulum exercises of the shoulder are performed, with some gentle passive and passive-assisted exercises to follow.

- Approximately 6 weeks postoperatively, gentle active exercises are initiated, but no resistance is applied to the soft tissue repair for 2 months. At that point, more aggressive range-of-motion and muscle exercises are started to maximize the functional recovery.
- Serial radiographs are performed to check for healing at the allograft–host bone junction. Typically, union at this junction occurs somewhere between 3 months and 12 months postoperatively. If a nonunion develops and 1 year has passed, then autogenous grafting is performed to augment the healing.

OUTCOMES

- Although allograft prosthetic composite arthroplasty is one reconstructive option available for most tumor surgeons, little has been published on this operation.[6]
- In 2003, Dudkiewicz et al[4] reported on 11 patients treated with an allograft prosthetic composite arthroplasty of the upper humerus. All patients were treated for an osteosarcoma, most of which were stage IIB. At the most recent follow-up, 10 of the 11 patients were alive, and they reported good function of the upper extremity. The function was not detailed in terms of range of motion, muscle strength, or joint stability. The authors reported several complications, including nonunion at the allograft–host bone junction and wound infections.
- Jensen and Johnston[7] reported on four patients with an allograft prosthetic composite using the Neer prosthesis and found excellent outcomes.
- In 2005, Kassab et al[8] reported on three patients with an allograft prosthetic composite of the humerus. The Musculoskeletal Tumor Society (MSTS) functional score for this small series was 76%.
- Damron et al[2] functionally evaluated shoulder reconstruction and concluded that the osteoarticular allograft procedure had the best outcomes if the abductors of the shoulder are preserved.
- O'Connor, Sim, and Chao[9] reported on one of the largest series of upper humerus reconstructions (57 patients). An osteoarticular allograft, which was used in eight patients, had the best functional outcomes in their cohort. Four of eight of these grafts fractured. Other authors reported outcomes with osteoarticular allograft reconstruction after an intra-articular resection.[1,10]
- DeGroot et al[3] reported a 37% allograft fracture rate and recommended the osteoarticular allograft be filled with cement to decrease this problem. Some of the fractured allografts were salvaged with an allograft prosthetic composite arthroplasty.
- Wang et al[11]reported osteoarticular allograft fractures in 14 of their 20 patients.
- In 1999, Getty et al[5] reported on 16 patients who had undergone intra-articular resection of the proximal humerus with an osteoarticular allograft reconstruction. The MSTS functional evaluation showed a mean recovery of 70%. Complications reported in this series included four fractures of the allograft and one infection. Survivorship of the frozen allograft at 5 years was 68%. Other complications reported included glenohumeral instability in three patients and dislocation of the glenohumeral joint in eight patients. The authors concluded that an osteoarticular allograft has a high complication rate, and were reluctant to continue to perform this procedure. Whether an allograft prosthetic composite arthroplasty will improve these outcomes remains to be seen.
- At this time, the advantage of allograft prosthetic composite arthroplasty over osteoarticular allograft arthroplasty remains questionable.

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