Proximal Humerus Resection with Endoprosthetic Replacement: Intra-articular and Extra-articular Resections

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Chapter 10

BACKGROUND
- The proximal humerus is a common site for both primary osteosarcomas and chondrosarcomas. Metastatic tumors occasionally involve the shoulder girdle and often are treated using the same resection and reconstruction techniques (Fig 1A).
- Limb-sparing resection of the proximal humerus is challenging. Despite their complexity, these resections can be performed in about 95% of patients with high- or low-grade sarcomas. Amputations rarely are required.
- Endoprosthetic reconstruction is the most common technique for reconstructing large proximal humeral defects. It is used following both intra-articular (type I) and extra-articular (type V) resections. This type of reconstruction is combined with local muscle transfers to create shoulder stability, cover the prosthesis, and provide a functional elbow, wrist, and hand (Fig 1B).
- The surgical and anatomic considerations of limb-sparing procedures of the proximal humerus and the specific surgical techniques for type I and type V resection and reconstruction are described in this chapter. Total humeral replacement is described briefly.
- The proximal humerus is one of the most common sites for high-grade malignant bone tumors in the adult, and it is the third most common site for osteosarcoma.1 Tumors in this location tend to have a significant extraosseous component. The proximal humerus also may be involved by metastatic cancer (especially renal cell carcinoma) and secondarily by soft tissue sarcomas, which require a resection similar to that used for primary bone sarcomas with extraosseous extension.
- About 95% of patients with tumors of the shoulder girdle can be treated with limb-sparing resections.
- The Tikhoff–Linberg resection and its modifications are limb-sparing surgical options for bone and soft tissue tumors in and around the proximal humerus and shoulder girdle. Portions of the scapula, clavicle, and proximal humerus are resected in conjunction with all muscles inserting onto and originating from the involved bones. Careful preoperative staging and selection of patients whose tumor does not encase the neurovascular bundle or invade the chest wall are required.
- A classification system for resection of tumors in this location is described in Figure 1B. The most common procedure for high-grade sarcomas of the proximal humerus, type VB, is described.
- We do not recommend type I resection for high-grade tumors, due to the increased risk of local recurrence.
- Optimal function is achieved with muscle transfers and skeletal reconstruction. A prosthesis is used to maintain length and stabilize the shoulder and distal humerus following resection. A stable shoulder with normal function of the elbow, wrist, and hand should be achieved following most shoulder girdle resections and reconstructions performed using the techniques described.

INDICATIONS
- Indications for limb-sparing procedures of the proximal humerus and shoulder girdle include high-grade and some low-grade bone sarcomas, as well as some soft tissue sarcomas that secondarily invade bone.
- Occasionally, solitary metastatic carcinomas to the proximal humerus are best treated by a wide excision (ie, type I resection).
- The decision to proceed with limb-sparing surgery is based on the location of the tumor and a thorough understanding of its natural history. Recently, we have treated patients with pathologic fractures with induction chemotherapy, immobilization, and limb-sparing surgery if there is a good clinical response and fracture healing.
- Absolute contraindications include tumor involvement of the neurovascular bundle or extensive invasion of the adjacent chest wall (Fig 2).
- Relative contraindications include chest wall extension, tumor contamination of the operative site from hematoma following a poorly performed biopsy or pathologic fracture, a previous infection, or lymph node involvement.

UNIQUE ANATOMIC CONSIDERATIONS
- Resection and reconstruction of the proximal humerus and shoulder girdle is a technically demanding procedure.
- The local anatomy of the tumor often determines the extent of the operation required. The surgeon should be experienced with all aspects of shoulder girdle anatomy and the unique considerations it may present.

Proximal Humerus
- Malignant tumors often present with large soft tissue components (stage IIB) underneath the deltoid that extend medially and displace the subscapularis and coracobrachialis muscles.2 Periscapular and rotator cuff involvement occur early and must be evaluated.

Glenohumeral Joint
- The shoulder joint appears to be more prone to intra-articular or periscapular involvement by high-grade bone sarcomas than are other joints.
- Four basic mechanisms exist for tumor spread: direct capsular extension; tumor extension along the long head of the biceps tendon; fracture hematoma from a pathologic fracture; and poorly planned biopsy.
- These mechanisms place patients undergoing intra-articular resections for high-grade sarcomas at greater risk for local recurrence than those undergoing extra-articular resections.
FIG 1 • A. Anatomy of the shoulder girdle. B. Surgical classification of shoulder girdle resections. This system was initially proposed by Malawer in 1991. Types I through III are intra-articular resections, whereas types IV through VI are extra-articular. A, abductor muscles retained; B, abductor muscles resected.

The subclavian artery and vein join the cords of the brachial plexus as they pass underneath the clavicle. Beyond this point, the nerves and vessels can be considered as one structure (ie, the neurovascular bundle). Large tumors involving the upper scapula, clavicle, and proximal humerus may displace the infraclavicular components of the plexus and axillary vessels.

Musculocutaneous and Axillary Nerves
- The musculocutaneous and axillary nerves often are in close proximity or contact with tumors around the proximal humerus.
- The musculocutaneous nerve is the first nerve that leaves between the teres major and minor to innervate the deltoid muscle posteriorly.
- Tumors of the proximal humerus are likely to involve the axillary nerve as it passes adjacent to the inferior aspect of the humeral neck, just distal to the joint. Therefore, the axillary nerve and deltoid almost always are sacrificed during proximal humerus resections.

Radial Nerve
- The radial nerve comes off the posterior cord of the plexus and continues anterior to the latissimus dorsi and teres major. Just distal to the teres major, the nerve courses into the posterior aspect of the arm to run between the medial and long head of the triceps.
- Although most sarcomas of the proximal humerus do not involve the radial nerve, it must be isolated and protected prior to resection.

Axillary and Brachial Arteries
- The axillary artery is a continuation of the subclavian artery, and is called the brachial artery after it passes the inferior border of the axilla. The axillary vessels are surrounded by the three cords of the brachial plexus and brachial plexus. The axillary artery typically leaves the lateral cord just distal to the coracoid process, passes through the coracobrachialis, and runs between the brachialis and biceps. Preservation of the musculocutaneous nerve and short head of the biceps muscle is important to ensure normal elbow function.
- The path of this nerve may vary extensively (within 6–8 cm of the coracoid) and should be identified before any resection is performed, because the nerve can easily be injured.
- The axillary nerve arises from the posterior cord and courses, along with the circumflex vessels, inferior to the distal border of the subscapularis. It then is tethered to the proximal humerus by the anterior and posterior circumflex vessels.
- Early ligation of the circumflex vessels is a key maneuver in resection of proximal humeral sarcomas, because it allows the entire axillary artery and vein to fall away from the tumor mass.
- Occasionally, anatomic variability in the location of the branches of the nerve may lead to difficulty in identification and exploration if the variation has not previously been recognized. A preoperative angiogram is helpful in determining vascular displacement and anatomic variability.
- Final determination of tumor resectability is made at surgery. Early exploration of the neurovascular structures is performed following division of the pectoralis major muscle. This approach does not jeopardize subsequent formation of an anterior flap in patients who require forequarter amputation.

IMAGING AND OTHER STAGING STUDIES
- Appropriate imaging studies are key to successful resections of tumors of the proximal humerus and shoulder girdle (FIG 3A–E).
FIG 3 • A. Osteosarcoma of the proximal humerus showing typical intramedullary ossification and an extraosseous soft tissue ossification. In general, a sarcoma of the proximal humerus involves one third to one half of the length of the bone. This length of bone must be resected in addition to the adjacent joint. B. Bone scan showing the amount of uptake corresponding to the radiograph shown in (A). In general, a resection is performed 3 to 4 cm distal to the area of uptake, as correlated with findings on an MRI scan, which is the imaging modality that best shows intramedullary extension of the tumor. C. Plain radiograph showing a radiolucent tumor of the proximal humerus. A needle biopsy confirmed that this was a giant cell tumor. CT shows minute fractures through the cortices, and the tumor was determined to be a stage III GCT. This patient was treated by primary resection of the proximal humerus. The procedure was classified as a type IA resection, and the humerus was reconstructed with an endoprosthetic modular prosthesis. Intra-articular resections are unusual for the proximal humerus, because most tumors are high grade with soft tissue components. D, E. Postoperative imaging studies are useful to determine response to induction chemotherapy. D. The CT scan shows complete reossification of a lesion of the proximal humerus without any major soft tissue component. The plain radiograph shows healing at the site of a former pathological fracture without any evidence of extraosseous formation. In general, CT scanning and plain radiography are reliable to demonstrate a good clinical response. E. Osteosarcoma of the proximal humerus, which does not show any evidence of an extraosseous component or any joint involvement. F. Schematic diagram of biopsy technique for tumors of the proximal humerus. The biopsy should be performed through the anterior one third of the deltoid, and the deltopectoral groove must be avoided. A core biopsy is recommended. (F: Reprinted with permission from Bickels J, Jelinek JS, Shmookler BM. Biopsy of musculoskeletal tumors. Current concepts. Clin Orthop Relat Res 1999;368:212–219.)
The most useful imaging studies are plain radiography, CT scans, MRI, arteriography, and bone scan. Venography occasionally is required.

**Computed Tomography**
- CT is most useful for evaluating cortical bone changes and is considered complementary to MRI in evaluating the chest wall, clavicle, and axilla for tumor extension (FIG 3D).

**Magnetic Resonance Imaging**
- MRI is useful to identify intraosseous tumor extent, which is necessary for determining the length of bone resection. It is the best imaging modality for evaluation of soft tissue tumor involvement, especially around the glenohumeral joint, supraclavicular region, and chest wall.

**Bone Scintigraphy**
- Bone scintigraphy is used to determine the intraosseous tumor extent and to detect metastases (FIG 3B).

**Angiography**
- Angiography is extremely useful for evaluation of tumor vascularity and tumor response to neoadjuvant chemotherapy. It also is essential for determining the relation of the brachial vessels to the tumor or the presence of anatomic anomalies. A brachial venogram also may be necessary if there is evidence of distal venous obstruction suggesting a tumor thrombus.
- Repeat staging studies are typically performed following surgical resection to determine patient response to chemotherapy.

**Biopsy**
- Needle or incisional biopsies of tumors of the proximal humerus should be performed through the anterior one third of the deltoid muscle, nor through the deltopectoral interval (FIG 3F).
- A biopsy through the anterior one third of the deltoid results in a limited hematoma that is confined by the deltoid muscle.
- This portion of the muscle and any biopsy hematoma are easily removed at the definitive resection. A biopsy taken through the deltopectoral interval will contaminate the major pectoralis muscle, which is necessary for reconstruction, increase the risk of hematoma spread along the axillary vessels to the chest wall, and make a local resection difficult, if not impossible.
- If an open biopsy is required, a short longitudinal incision should be made just lateral to the deltopectoral interval. The dissection should be directly into the deltoid muscle and proximal humerus.
- The bone should be exposed lateral to the long head of the biceps. No flaps should be developed, and the glenohumeral joint should not be entered.

### RESECTION TECHNIQUES

- It is important to be extremely familiar with shoulder girdle anatomy and axillary and vascular structures.
- A utilitarian incision is used (TECH FIG 1A–D). The anterior component is an extended deltopectoral incision that exposes the pectoralis major muscle, which is then released and retracted toward the chest wall. This exposes the axillary contents and permits exploration and safe dissection of the vascular structures and infraclavicular plexus (TECH FIG 1E).
- An extra-articular resection is performed. Thus, the axillary nerve is identified and transected. The musculocutaneous nerve is identified and preserved (TECH FIG 1F). The radial nerve, which crosses the humerus posteriorly at the level of the deltoid insertion, is preserved.
- Approximately one half to two thirds of the humerus is resected (TECH FIG 1G).
- An extra-articular resection is performed by exposing the glenohumeral joint both anteriorly and posteriorly. The scapula is osteotomized medial to the coracoid along with the distal portion of the clavicle. The resected specimen consists of the proximal one half of the humerus, the glenohumeral joint, and the distal clavicle en bloc.
- A modular replacement proximal humeral prosthesis is used to reconstruct the skeletal defect (TECH FIG 2).
- Attention must be paid to the reconstruction of the muscles for soft tissue coverage of the prosthesis. Static suspension is performed with Dacron tape, and the muscle reconstruction is performed with the pectoralis major muscle sutured to the remaining scapula. The remaining muscles are then tenodesed to the pectoralis major muscle. This technique permits immediate stability and restores motor power to the upper extremity (TECH FIG 3A,B).
- An epineural axillary sheath catheter is used to control postoperative pain. A 28-gauge chest tube is used for drainage through a Pleurovac (TECH FIG 3C).
- Postoperatively, the patient uses a sling for 2 weeks.

### Endoprosthetic Replacement of the Proximal Humerus

- The Modular Replacement System (MRS), which is used for reconstruction of the shoulder girdle, is shown. Results of the MRS are predictable and successful, and the device is used for both intra- and extra-articular resections.
- Endoprosthetic reconstruction following tumor resection entails the following steps:
  1. Fixation of the endoprosthesis in the remaining distal humerus.
  2. Fixation and stabilization of the prosthetic humeral head to the scapula to provide a stable shoulder joint.
  3. Soft tissue reconstruction to cover the prosthesis completely and optimize postoperative function.

### Dual Suspension Technique

- A dual suspension (ie, static and dynamic) technique is used to create shoulder stability (TECH FIG 4). In the static reconstruction, drill holes are made in the distal...
TECH FIG 1 • A. Utilitarian incision used by the authors for exposure of the proximal humerus, scapula, or shoulder girdle. B. The utilitarian approach is used for extra-articular resections of the shoulder girdle. Exposure of the anterior aspect and the axillary space routinely is performed by releasing two layers of muscle. The pectoralis major is released from its insertion onto the proximal humerus and reflected back onto the chest wall. This step exposes the entire axillary area, including the infraclavicular portion of the brachial plexus, the axillary artery and vein, the coracoid and scapula, and the corresponding muscles. C. Following reflection of the pectoralis major, the second muscle layer must be developed and detached and retracted. This layer consists of the pectoralis minor and the short head of the biceps. Each of these muscles has attachments to the coracoid. It is important to dissect the musculocutaneous nerve from around the coracoid as it enters the short head of the biceps to avoid nerve injury. These muscles are detached and retracted medially and distally, respectively, to expose the entire axillary fascia, which then can be opened to accomplish the following dissection. It is important to dissect the musculocutaneous nerve from around the coracoid as it enters the short head of the biceps. (continued)
D. Position and incision. Antibiotics are begun preoperatively and continued until suction drains are removed. The patient is placed in an anterolateral position that allows some mobility of the upper torso. A Foley catheter is placed in the bladder, and an intravenous line is secured in the opposite extremity. The skin is prepared down to the level of the operating table, to the umbilicus and cranially past the hairline. The incision starts over the junction of the inner and middle thirds of the clavicle. It continues along the deltopectoral groove and then down the arm over the medial border of the biceps muscle. The biopsy site is excised, leaving a 3-cm margin of normal skin. The posterior incision is not opened until the anterior dissection is complete.

E. Exploration of the axilla to determine resectability. The skin is opened through the superficial fascia, but care is taken to preserve the deep fascia of muscles. Anteriorly, the skin flap is dissected off the pectoralis major muscle to expose its distal third, and the short head of the biceps muscle is uncovered. The pectoralis major muscle overlying the axilla is dissected free of axillary fat so that its insertion on the humerus can be visualized; this muscle is divided just proximal to its tendinous insertion on the humerus, and the portion of the muscle remaining with the patient is tagged with a suture. Next, the axillary sheath is identified and the coracoid process visualized. To expose the axillary sheath along its full extent, the pectoralis minor short head of the biceps and coracobrachialis muscles are divided at their insertion on the coracoid process. All proximal muscles are tagged with sutures for later identification and use in the reconstruction. (continued)
TECH FIG 1 • (continued) F. Dissection of the neurovascular bundle. Vessel loops are passed around the neurovascular bundle near the proximal and distal ends of the dissection. Medial traction on the neurovascular bundle allows visualization of the axillary nerve, posterior circumflex artery, and anterior circumflex artery. These structures are ligated and then divided. If the neurovascular bundle is found to be free of tumor extension, dissection for the limb salvage procedure proceeds. The musculocutaneous nerve is isolated and carefully preserved, although this nerve sometimes must be sacrificed to preserve tumor-free margins. Its loss results in lack of elbow flexion following surgery. The deep fascia between the short and long heads of the biceps muscle is divided below the tumor mass to separate the short and long heads of the biceps maximally, permitting easy visualization of the musculocutaneous nerve. The radial nerve is identified at the lower border of the latissimus dorsi muscle, passing around and behind the humerus into the triceps muscle group. The profunda brachialis artery that accompanies this nerve may be ligated. The radial nerve passes posterior to the humerus in its midportion (spiral groove). To dissect it free of the bone, a finger is passed around the humerus to bluntly move the nerve away from the bone. G. Division of the muscle groups anteriorly to expose the neck of the scapula. The short and long heads of the biceps are widely separated to expose the humerus. The site for the humeral osteotomy is determined, and then the long head of the biceps and brachialis muscles are transected at this level. The inferior border of the latissimus dorsi muscle is identified, and a fascial incision is made that allows one to pass a finger behind the latissimus dorsi and teres major muscles several centimeters from their insertion into the humerus or scapula. The latissimus dorsi and teres major muscles are transected using electrocautery. External rotation of the humerus exposes the subscapularis muscle, which is transected at the level of the coracoid process. Care must be taken not to enter the joint space. The portions of these muscles that are not to be removed during the resection are tagged for future reconstruction. By transecting these muscles the anterior portion of the neck of the scapula has been exposed. (C,D,F,G: Courtesy of Martin M. Malawer; E: Reprinted with permission from Malawer MM. Tumors of the shoulder girdle. Technique of resection and description of a surgical classification. Orthop Clin North Am 1991;22:7–35.)
Chapter 10 PROXIMAL HUMERUS RESECTION WITH ENDO PROSTHETIC REPLACEMENT

TECH FIG 2 • Various methods used for reconstruction of the proximal humerus following resection for high-grade sarcomas between 1960 and 1990. A. The first attempts to regain length used the Kirschner rod fixated into the distal humerus and sutured to the clavicle with wires or heavy sutures. This failed, and often caused proximal protrusion through the skin. B. The long-stemmed Neer prosthesis was developed to re-establish humerus length and to avoid the problem of proximal migration. C. The first custom prosthesis, developed in the mid-1970s to reconstruct the proximal humerus in an anatomic format. This had both external phlanges and a small stem. D. The Modular Replacement System (Stryker Orthopedics, Mahwah, NJ) is the type of prosthesis currently used. A modular replacement system has a head, body, and stem of various diameters and lengths so that it can be modified intraoperatively for each patient’s anatomic needs. No waiting period for a custom prosthesis to be made is required, as formerly was the situation. The first proximal humerus prosthesis of the MRS type was implanted in Washington, DC in 1988. (A–D: Courtesy of Martin M. Malawer.)

- The head of the prosthesis is secured to the remaining portion of the scapula with 3-mm Dacron tape so that the prosthesis is suspended mediolaterally, to provide horizontal stability. It then is suspended, using more Dacron tape, in a cranio-caudal direction from the end of the clavicle to provide vertical stability.
- Dynamic suspension is provided by transfer of the short head of the biceps muscle to the stump of the clavicle (as described in the next section), which allows elbow flexion.

Soft Tissue Reconstruction
- The remaining muscle groups are tenodesed to the pectoralis major and osteomized border of the scapula with Dacron tape. This mechanism offers dynamic support, assists in the suspension of the prosthesis, and provides soft tissue coverage. Soft tissue coverage is essential to cover the prosthesis and prevent skin problems and secondary infections.

Type I Resection
- Intra-articular resection of the proximal humerus is indicated for low-grade sarcomas or high-grade sarcomas confined to the bone without extravascular extension (stage IIA; TECH FIG 3A,8).
- The abductor mechanism and axillary nerve usually are preserved. This procedure is not recommended for high-grade sarcomas with soft tissue extension.
- The prosthesis is suspended from the glenoid with a Gore-Tex graft, which is reinforced by any remaining capsule (TECH FIG 5C–E).
- Anterior utilitarian shoulder incision is not required. The posterior component is not used.
TECH FIG 3 • A. Securing the prosthesis. If a prosthesis is to be used, 5 to 7 cm of distal humerus must be preserved. A power reamer is used to widen the medullary canal of the remaining humerus; it is reamed until it is 1 mm larger than the stem of the prosthesis. The bony specimen is measured so that a prosthesis of appropriate length is used. Methylmethacrylate cement is injected into the medullary canal, and the prosthesis is positioned. The head of the prosthesis should be oriented so that it lies anterior to the transected portion of scapula while the arm is in neutral position. The radial nerve should be positioned anterior to the prosthesis so it does not become entrapped between muscle and prosthesis during the reconstruction. Drill holes are made through the scapula at the level of its spine, and also through the distal portion of the transected clavicle. The head of the prosthesis is secured by 3-mm Dacron tape to the remaining portion of the scapula so that the prosthesis is suspended mediolaterally, providing horizontal stability. It is suspended in a cranio-caudal direction by a second 3-mm Dacron tape from the end of the clavicle, for vertical stability. B. Reconstruction. The pectoralis minor muscle is sutured to the subscapularis muscle over the neurovascular bundle to protect it from the prosthesis. The pectoralis major muscle is closed over the prosthesis to the cut edge of the scapula and secured with nonabsorbable sutures through drill holes. Following this the trapezius, supraspinatus, infraspinatus, and teres minor muscles are secured to the superior and lateral borders of the transected pectoralis major muscle. The teres major and latissimus dorsi muscles are secured to the inferior border of the pectoralis major muscle. The tendinous portion of the short head of the biceps is secured anteriorly under appropriate tension to the remaining clavicle. The long head of the biceps and the brachialis muscles are sutured to the short head of the biceps muscle under appropriate tension so that these two muscles can work through the short biceps tendon. The remaining triceps muscle is secured anteriorly along the lateral border of the biceps to cover the lower and lateral portion of the shaft of the prosthesis. Ideally, when the proximal and distal muscular reconstruction is complete the prosthesis is covered in its entirety by muscle. C. Closure. Large-bore suction catheter drainage is secured. The superficial fascia is closed with absorbable suture, and the skin is closed with clips. Povidone-iodine ointment is applied to the incision along with a dry sterile dressing. A sling and swathe are applied in the operating room. (A,B: Reprinted with permission from Rubert CK, Malawer MM, Kellar KL. Modular endoprosthetic replacement of the proximal humerus: Indications, surgical technique, and results. Semin Arthroplasty 1999;10:142–153. C: Courtesy of Martin M. Malawer.)
Chapter 10 PROXIMAL HUMERUS RESECTION WITH ENDOPROSTHETIC REPLACEMENT

TECH FIG 4 • Reconstruction of the proximal humerus. A. The initial reconstruction is performed by suspending the humeral prosthesis from the subscapular fossa by transverse and horizontal tapes. These are brought through the prosthesis and the holes in the scapula and clavicle, providing for immediate stability. B. The prosthesis being placed anterior (not lateral) to the scapula and into the subscapular fossa. The pectoralis major and subscapularis muscle are sutured with 3-mm Dacron tape through drill holes of the axillary border of the scapula, providing immediate and excellent stability. C. Gore-Tex graft is used to reconstruct the capsule if an intra-articular resection is performed.

- The axillary nerve is explored early and preserved. If there is tumor extension to the nerve, then the procedure is converted to a type V resection.
- The humeral prosthesis is suspended from the glenoid labrum with 32-mm Gore-Tex. The remaining capsule is sutured to the new Gore-Tex capsule. This step avoids glenohumeral joint subluxation and dislocation.

Total Humeral Resection and Prosthetic Reconstruction
- Total humeral replacement is unusual but is indicated when the tumor involves a large portion of the diaphysis, such as in Ewing sarcoma, or when an extremely short segment of the distal humerus remains following adequate tumor resection.
- The surgical technique is a combination of that used for proximal and distal humerus resections. Reconstruction provides stability of both shoulder and elbow joints.

Exposure and Extension of Type V Procedure (TECH FIG 6)
- The surgical approach is similar to that used for a type V resection (ie, anterior utilitarian approach), but it requires additional distal exposure and identification and mobilization of the brachial artery and vein and the radial, ulnar, and median nerves.
- The incision and exposure are continued down the anteromedial aspect of the arm, across the antecubital fossa, and, if necessary, down the anterior aspect of the forearm. The brachial vessels, along with the median and ulnar nerves, are identified medially in the arm.
- The medial intermuscular septum is transected to allow further dissection and mobilization of the ulnar nerve so that it can be retracted medially with the brachial vessels and median nerve.
- The biceps is retracted medially with the neurovascular bundle. The radial nerve is identified where it passes around the humerus and into the interval between the brachialis and brachioradialis muscles and continues into the forearm.
- The pronator teres and common flexor origins are transected medially, and the brachioradialis, extensor carpi radialis longus, and common extensor origins are released laterally to expose the distal humerus. A small cuff of muscle is left around the tumor as needed. The medial triceps muscle usually is resected with the tumor, but the lateral and long heads are retained. The triceps tendon is kept attached to the olecranon. The olecranon is not osteotomized. The elbow joint is opened anteriorly and the capsule released circumferentially. The humero-ulnar and radiohumeral joints are then disarticulated.

Prosthetic Reconstruction, Muscle Reconstruction, and Postoperative Management
- Reconstruction of the total humerus is similar to that of the proximal humerus. Distally, an ulnar endoprosthetic component with an intramedullary stem is cemented, with the olecranon left intact. Several articulating elbow devices are available.
- The reconstruction technique is similar to that used for the proximal humerus, with the addition of distal soft tissue and joint capsule reconstruction.
- The brachioradialis, pronator teres, and flexor carpi radialis muscles are sutured to the remaining biceps and triceps muscles to secure soft tissue around the flared distal portion of the humeral endoprostheses.
- The remaining muscles are closed in layers in an attempt to cover the entire prosthesis.
- A posterior splint is used to protect the elbow reconstruction for 7 to 10 days. The surgical incision and wounds are examined on the fourth to fifth postoperative day.
TECH FIG 5 • Intraoperative photographs of an intra-articular resection. A. The tumor has been removed, demonstrating the relation of the axillary nerve to the capsule and the glenoid. The brachial vessels have been mobilized and are seen in the vessel loop. The structures around the proximal humerus are in close proximity to the subscapularis muscle and the joint capsule. These vessels are initially identified and retracted prior to resection. B. Reconstruction of the proximal humerus is performed with the MRS. It is essential to reconstruct the capsule, because soft tissue reconstruction alone will not maintain any stability either of the humeral head or to the shallow glenoid. Therefore, a Gore-Tex graft is used and is sutured to the rim of the glenoid. The humeral head then is reduced within this sleeve and sutured, using Dacron tape, through holes in the humeral head. This is the technique routinely used for intra-articular resections of the proximal humerus. C–E. Schematic of a proximal humerus reconstruction with static and dynamic transfers as well as a proximal humeral prostheses. This technique, which has been used by Malawer since 1988, provides excellent coverage of the prosthesis and stability with active motion of the new glenohumeral joint. The prosthesis is suspended from the remaining axillary border of the scapula with two Dacron tapes, and with additional tapes from the prosthesis to the clavicle. Therefore, both longitudinal and horizontal stabilizing forces are in place. The soft tissue reconstruction consists of the long head of the biceps being attached to either the clavicle or the transferred pectoralis major muscle. The prosthesis is covered with four muscles. The pectoralis major and subscapularis muscles are sutured over the prosthesis to the remaining border of the scapula through drill holes using Dacron tape. This provides immediate stability and good coverage of the prosthesis. The prosthetic head is placed anterior to the scapula, not at the lateral border, and is then placed in the subscapular fossa. The remaining muscles of the teres and the infraspinatus are brought anteriorly and sutured, and the trapezius muscle is mobilized at the base of the neck to the area of muscle reconstruction. (C–E: Reprinted with permission from Rubert CK, Malawer MM, Kellar KL. Modular endoprosthetic replacement of the proximal humerus: Indications, surgical technique, and results. Semin Arthroplasty 1999;10:142–153.)
This chapter contains a complete description of the technique for a modified Tikhoff–Linberg procedure in patients with sarcomas of the proximal humerus. Modifications of the procedure also have been used for tumors at other anatomic sites. Proximal humeral lesions require resection of about two thirds of the humerus. The technique of resection and reconstruction requires a thorough knowledge of the regional anatomy and technique of musculoskeletal reconstruction. Essential aspects of the treatment plan should be emphasized.

**Biopsy**

- The initial biopsy should be performed through the anterior portion of the deltoid muscle for a lesion of the proximal humerus. The deltopectoral interval should not be used, because biopsy here would contaminate the deltopectoral fascia, the subscapularis, and the pectoralis major muscles, and would jeopardize the possibility of performing an adequate resection through uninvolved tissue planes.

**Incision**

- For the definitive resection, the initial incision extends along the medial aspect of the biceps muscle, divides the pectoralis major, and exposes the neurovascular structures, thereby enabling the surgeon to determine resectability early in the dissection.
- This incision does not jeopardize construction of an anterior skin flap in patients who will require forequarter amputation.
Resection

- The length of bone resection is determined preoperatively from a bone scan and MRI. To avoid a positive margin at the site of humeral transection, the distal osteotomy is performed 3 to 5 cm distal to the area of abnormality on the scan.
- Alternatively, other surgeons use autografts (usually fibulas) or allografts as spacers in obtaining an arthrodesis. We do not recommend osteoarticular allografts or intra-articular resections for high-grade bone sarcomas; those techniques were developed during the 1960s and 1970s and are inferior to current standards. Superior results routinely are obtained with modular prosthetic replacements combined with reconstruction of the soft tissues (FIG 4).

Reconstruction

- Segmental reconstruction of the resultant humeral defect is necessary to create shoulder stability. We do not leave a flail extremity. Reconstruction is necessary to maintain length of the arm and to create a fulcrum for elbow flexion. We recommend a custom or modular prosthesis.
- The key to success is reconstruction of the stability of the joint and soft tissue coverage of the prosthesis.

FIG 4 • Original photograph taken following an extra-articular resection of a large section of the proximal humerus and scapula involved by an osteosarcoma during the late 1960s. This was one of the first shoulder girdle resections performed in the United States. Notice the marked shortening of the limb, but the fairly normal functioning of the hand and elbow. Subsequently, multiple techniques have been utilized to maintain the length and function of the shoulder girdle. (Courtesy of Ralph C. Marcove, MD.)

REFERENCES