Chapter 11

Distal Humeral Resection with Prosthetic Reconstruction

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BACKGROUND

- The distal humerus is a relatively rare site for primary bone sarcomas. It is more commonly involved by neoplasm through metastatic spread. The distal humerus or elbow joint also can be secondarily involved by soft tissue sarcomas arising from the adjacent musculature or intermuscular soft tissues. Sarcomas that arise from the most proximal portions of the flexor–pronator group or common forearm extensor muscles may involve the distal humerus by direct invasion or by growing around the circumference of the distal humerus. Sarcomas that arise from the distal brachialis muscle or triceps muscle also may secondarily involve the distal humerus.
- Tumors arising in this area that involve the soft tissues are technically challenging to resect. These tumors usually are juxtaposed to and displace the adjacent neurovascular structures that lie in immediate proximity to the distal humerus and within the antecubital fossa.
- The key to a safe and successful resection lies in identifying and mobilizing all important neurovascular structures (eg, brachial artery and vein, median nerve, ulnar nerve, and radial nerve) away from the neoplasm and distal humerus. The biceps muscle must be preserved in order to restore elbow flexion after reconstruction.
- Each of the neurovascular structures is identified proximal to the tumor, in normal tissue, in the distal one third of the arm. These structures are dissected in a proximal-to-distal direction, separated from the neoplasm, and mobilized across the elbow joint. Once these structures are mobilized and protected, it is safe to proceed with removing the distal humerus and tumor en bloc.
- In most cases, even the most extreme cases, the neurovascular structures are displaced and not encased by neoplasm, making limb-sparing surgery an option in lieu of an amputation (**FIG 1**). Gross tumor involvement of a single nerve is not an absolute indication for an above-the-elbow amputation. Involvement of more than one major nerve or the main vascular supply is an indication for an above-the-elbow amputation when treating a sarcoma with curative intention. In cases of metastatic carcinomas, where treatment is palliative, adjuvant treatments such as radiation or chemotherapy should be considered before proceeding with an amputation.
- Prosthetic reconstruction of the distal humerus and elbow joint with a modular, segmental, tumor prosthesis including a semiconstrained, hinged elbow joint is a reliable means of skeletal reconstruction following resection. Multiple muscle rotation flaps, retensioning the biceps muscle, and flexorplasty of the forearm musculature are key steps to restoring elbow flexion power.

ANATOMY

Neurovascular Structures

- To resect tumors involving the distal humerus safely and adequately, the major neurovascular structures around the distal humerus should be exposed and identified.
- In the middle one third of the arm, most of the important neurovascular structures lie within a fibrous sheath, in the groove between the biceps and triceps muscles, along the medial side of the arm, just medial to the brachialis muscle. These structures include:
  - The brachial artery, which is surrounded by two small brachial veins
  - The median nerve, which lies directly anterior to the brachial artery
  - The cephalic vein and medial antecubital cutaneous nerve, which lie superficial to the brachial artery
  - The ulnar nerve, which is surrounded by the superior ulnar recurrent artery and two veins that lie just medial and posterior to the brachial artery
  - The medial brachial cutaneous nerve, which lies in the superficial subcutaneous tissue at this level.
- At this level, the radial nerve lies within the spiral groove of the humerus along the posterolateral aspect of the arm.
- The brachial artery and veins are the continuation of the axillary artery and vein at the level of the lower border of the subscapularis muscle. The brachial artery and veins travel distally along the medial side of the arm, deep to the fascia, in the interval between the biceps and triceps muscles, medial to the brachialis muscle.
- The profunda brachii artery arises proximally from the brachial artery at the lower border of the latissimus dorsi muscle. It traverses dorsally and laterally with the radial nerve and enters the spiral groove.
- The brachial artery gives off several branches along its course to the biceps, brachialis, and triceps muscles. In the antecubital fossa, the brachial artery lies on the anterior surface of the brachialis muscle, immediately adjacent and lateral to the median nerve. The brachial artery passes just deep to the bicipital aponeurosis to enter the forearm. The inferior ulnar collateral artery arises from the brachial artery just proximal to the bicipital aponeurosis and passes medially just along the proximal aspect of the medial condyle of the humerus. After the brachial artery passes underneath the bicipital aponeurosis, it branches into the ulnar artery, radial recurrent artery, and radial artery.
- The median nerve travels distally in the arm, closely applied to the anterior aspect of the brachial artery. As the median nerve approaches the antecubital fossa, it crosses over medially so that it occupies a position immediately medial to the brachial artery and lateral to the pronator teres muscle in the antecubital fossa.
- The ulnar nerve occupies a position slightly more medial and posterior to the brachial artery in the mid-arm. In the distal one third of the arm, the ulnar nerve travels posteriorly and pierces the medial intermuscular septum. It travels along the medial side of the triceps muscle and enters a groove (cubital tunnel) along the posterior aspect of the medial epicondyle of the humerus. The ulnar nerve is tethered within this groove by ligamentous tissue. It then travels distally and enters the forearm by passing through the humeral and ulnar heads of the pronator teres muscle. In the forearm, the ulnar nerve lies along the deep surface of the flexor carpi ulnaris muscle.

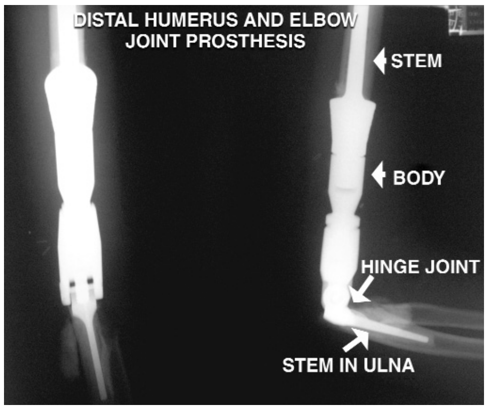


FIG 1 • Postoperative radiograph showing a distal humeral prosthesis and elbow joint. This prosthesis was inserted to avoid an amputation.

- The medial antebrachial cutaneous nerve is a small nerve that lies deep to the fascia between the median and ulnar nerves at the mid arm level. In the distal one third of the arm, the nerve occupies a more superficial position in the subcutaneous tissue.
- The radial nerve arises from the posterior cord of the brachial plexus. At the inferior border of the latissimus dorsi muscle, the radial nerve passes posteriorly, along with the profunda brachii artery, through the interval between the long head of the triceps and the humerus. The radial nerve enters the spiral groove of the humerus and travels distally, wrapping around the posterior aspect of the humerus, in the interval between the medial and lateral heads of the triceps muscle. In the distal one third of the arm, the radial nerve passes through the lateral intermuscular septum and enters the anterior compartment of the arm, where it resides in the interval between the brachioradialis muscle and brachialis muscle. The radial nerve continues distally into the forearm. At the lower, lateral border of the brachialis muscle, just proximal to the supinator muscle, the radial nerve divides into the posterior interosseous nerve and the superficial radial nerve. The posterior interosseous nerve passes through the substance of the supinator muscle. The superficial radial nerve travels distally along the deep surface of the brachioradialis muscle.

INDICATIONS AND CONTRAINDICATIONS

Indications for Surgical Resection

- High-grade and some low-grade bone sarcomas
- Soft tissue sarcomas that surround or invade the distal humerus or elbow joint secondarily
- Solitary metastatic carcinomas to the distal humerus
- Metastatic carcinomas that have destroyed a significant portion of the distal humerus, which precludes other methods of resection and fixation
- Local complications resulting from other treatments for tumors involving the distal humerus, eg, nonunion of a pathological fracture following radiation

Contraindications to Surgical Resection

- Absolute contraindications include tumor involvement of the neurovascular bundle.
- Involvement of a single major nerve is not an absolute contraindication. The nerve can be resected with the neoplasm.
- Encasement of the brachial artery and veins or two or more major nerves usually precludes a limb-sparing resection.
- Final determination regarding the need for an amputation is made at the time of surgery, after the neurovascular structures are explored. Adjuvant treatments such as radiation and chemotherapy should be considered for palliation of metastatic carcinomas prior to proceeding with an amputation.
- Relative contraindications include tumor contamination of the operative site from hematoma following a poorly performed biopsy or pathologic fracture or a previous or active infection. Recently, we have successfully treated patients with pathologic fractures with induction chemotherapy, immobilization, and limb-sparing surgery if there is a good clinical response and fracture healing; survival has not been compromised, and local recurrence is less than 10%.

IMAGING AND DIAGNOSTIC STUDIES

- The most useful imaging studies are plain radiography, CT, MRI, arteriography, and bone scan. These studies are useful for diagnosis, evaluating local and distant extent of disease, and, for select sarcomas, gauging the response to preoperative chemotherapy. Radiologic studies are necessary to determine the exact anatomic extent of the neoplasm so that the surgical procedure can be planned accurately.

Plain Radiographs

- Plain radiographs of the humerus and elbow are used to localize the anatomic origin of the tumor, formulate a differential diagnosis, and estimate tumor extent (**FIG 2A**).
- After preoperative chemotherapy for an osteosarcoma, plain radiographs can be used to estimate the response of the tumor to the chemotherapeutic agents. A good response (> 90% tumor necrosis) is indicated by extensive tumor calcification, periosteal new bone formation, and healing of pathologic fractures.

Computed Tomography

- CT is most useful for evaluating cortical bone changes and extent of cortical destruction by tumor. In the case of a metastatic carcinoma, it aids with decision making regarding the indication for a resection and prosthetic reconstruction versus curettage and internal fixation. Extensive cortical destruction throughout a significant circumference of the bone is an indication to proceed with a resection of the distal humerus and prosthetic reconstruction.
- CT also is useful for detecting subtle mineralization, calcification, or ossification within the neoplasm that may assist in diagnosis.
- CT is considered complementary to MRI in evaluating the soft tissue component of the neoplasm and proximity to the neurovascular structures, particularly a contrast-enhanced CT scan.
- CT also assists with detection of subtle cortical erosion and frank invasion of the distal humerus by adjacent soft tissue sarcomas that may not be clearly delineated on MRI or plain radiographs.
- After preoperative chemotherapy of an osteosarcoma, CT characteristically shows a rimlike calcification in those tumors that have had a good response.
- Chest CT is most sensitive for detecting lung metastases.

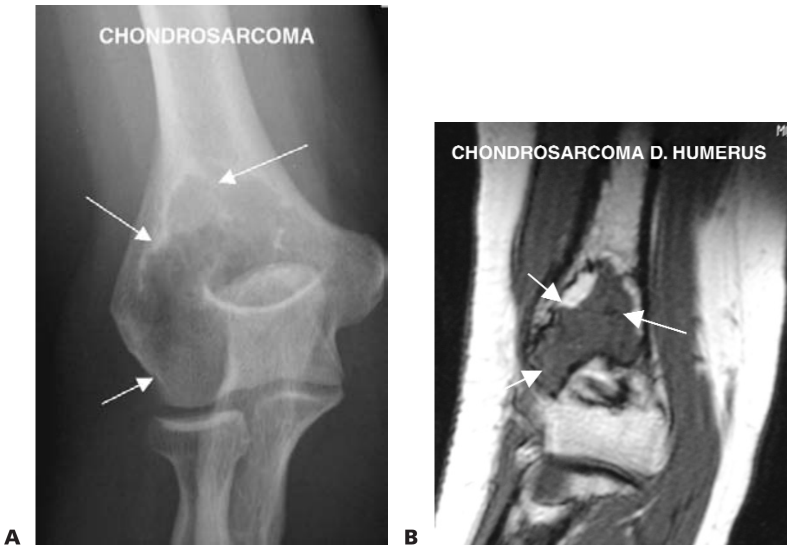


FIG 2 • **A.** Plain radiograph of a mesenchymal chondrosarcoma (*arrows*) of the distal humerus. Primary bone sarcomas are rare in this location. **B.** MRI scan showing the extent of the tumor. A distal humeral resection and reconstruction with a segmental prosthesis was performed.

Magnetic Resonance Imaging

- MRI is most accurate for determining intra- and extraosseous tumor extent as well as for detecting skip metastases. An appreciation of intraosseous extent is necessary for determining the length of bone resection.
- The humerus usually is transected approximately 2 to 3 cm proximal to the intramedullary extent of the neoplasm as visualized on a T1-weighted MRI scan.
- Proximity of the extraosseous component to the brachial vessels, median nerve, ulnar nerve, and radial nerve also can be evaluated, as can secondary involvement of the distal humerus and elbow joint by adjacent soft tissue sarcomas.
- Standard T1-weighted, T2-weighted, fat-suppressed, and gadolinium-enhanced images are recommended (**FIG 2B**).

Bone Scintigraphy

- Bone scintigraphy is used to determine intraosseous tumor extent and is compared to the MRI scan to ensure accuracy. It also is used to detect bony metastases and skip metastases.

Thallium Scintigraphy

- Thallium 201 is a potassium analog that is actively transported by the sodium–potassium ATPase pump. A quantitative thallium scan has been useful for determining viability of bone tumors, particularly osteosarcomas.
- The affected side is compared to the unaffected side; a ratio below 4:1 is consistent with tumor necrosis greater than 90% (a good response).

Angiography

- Angiography is extremely useful for evaluation of tumor vascularity and is considered the gold standard for evaluating tumor response to neoadjuvant chemotherapy. High grade sarcomas, such as osteosarcoma, demonstrate a tumor blush on an arteriogram when viable (fill with contrast dye because of extensive neovascularization of the tumor). The neovascularization and hence the tumor blush disappear when the tumor has had a good response to a preoperative chemotherapy regimen.
- It is also essential for determining the relationship of the brachial vessels to the tumor or the presence of anatomic anomalies. The soft tissue component of distal humeral tumors routinely displaces the brachial vessels. Soft tissue sarcomas that arise around the distal humerus also usually routinely displace the brachial vessels. The direction in which these structures are displaced can be determined with a biplanar arteriogram.

Biopsy

- Needle or incisional biopsies of tumors of the distal humerus should be performed through the brachialis muscle in line with the proposed skin incision so the biopsy tract can be excised at the time of the definitive procedure.
- The biopsy should never be performed through the biceps muscle; it should, rather, be performed along either side of the muscle. The biceps must be spared in order to be able to reconstruct the distal humerus and preserve elbow flexion.
- In general, the biopsy is best made directly anterior, just lateral to the biceps tendon or distal biceps muscle, close to the antecubital crease. In this manner, the biopsy tract can be excised with the transverse portion of the incision that crosses the antecubital crease.
- Occasionally, a very large soft tissue component that protrudes anteriorly and medially will displace the neurovascular structures medially. In these instances, it may be possible to biopsy the tumor, under CT guidance for visualization of the neurovascular structures, just medial to the medial margin of the distal biceps muscle or biceps tendon. The tumor will occupy a subcutaneous position in this location and is easily biopsied. With either approach it is important to perform the biopsy through the brachialis muscle and to avoid contaminating the biceps muscle. The portion of the brachialis muscle and biopsy hematoma are easily removed at the definitive resection.
- Biopsy of a tumor arising from the brachioradialis or common extensor muscle origin is performed anteriorly, directly over the mass, along the lateralmost 1 to 2 cm of the antecubital crease. Extreme care is taken to avoid contaminating the radial and posterior interosseous nerves.
- Biopsy of a tumor arising from the flexor–pronator muscle group is performed at the most medial extent of the antecubital crease, directly over the mass and at a distance from the median nerve and brachial artery.

SURGICAL MANAGEMENT

Preoperative Planning

- Staging studies are thoroughly reviewed before the surgical procedure.
- The T1-weighted coronal MRI scan of the entire humerus is reviewed. The length of the bone resection is based primarily on this study. The transection level is determined so that it will permit a 2 to 3 cm margin proximal to the intraosseous tumor extent. In the case of an adjacent soft tissue sarcoma, the bone is transected 2 cm to 3 cm proximal to the soft tissue involvement of the humerus. Surgical resection is modified to account for skip metastases, both intraosseous and transarticular. The length of the resection can be determined preoperatively to ensure all components of the prosthesis needed for reconstruction will be present. Nowadays, modular segmental prostheses are utilized that are assembled intraoperatively. The size can be adjusted intraoperatively to accommodate for the resection.
- The MRI and CT scans are reviewed to evaluate the exact degree of soft tissue extension and proximity to the neurovascular structures. CT and MRI results are evaluated to determine areas of the distal humerus or elbow joint that may be directly involved by an adjacent soft tissue sarcoma.
- The arteriogram provides a "road map" showing the direction of displacement of the neurovascular structures and also alerts the physician to any anomalies that may be encountered during surgery.
- Flexible reamers, sagittal saw, drill or high-speed burr, osteotomes, cement, cement gun, ball-tip guide wire, no. 5 nonabsorbable sutures, vessel loops, and 1/4-inch Penrose drain will be required.

Positioning

- The patient is placed in a supine position with the arm abducted and placed on a padded and draped Mayo stand. A small bump is placed under the ipsilateral scapula, to elevate the shoulder girdle slightly off the bed. The entire upper extremity, from the middle of the clavicle and shoulder girdle through the fingertips, is prepped and draped in a sterile manner.

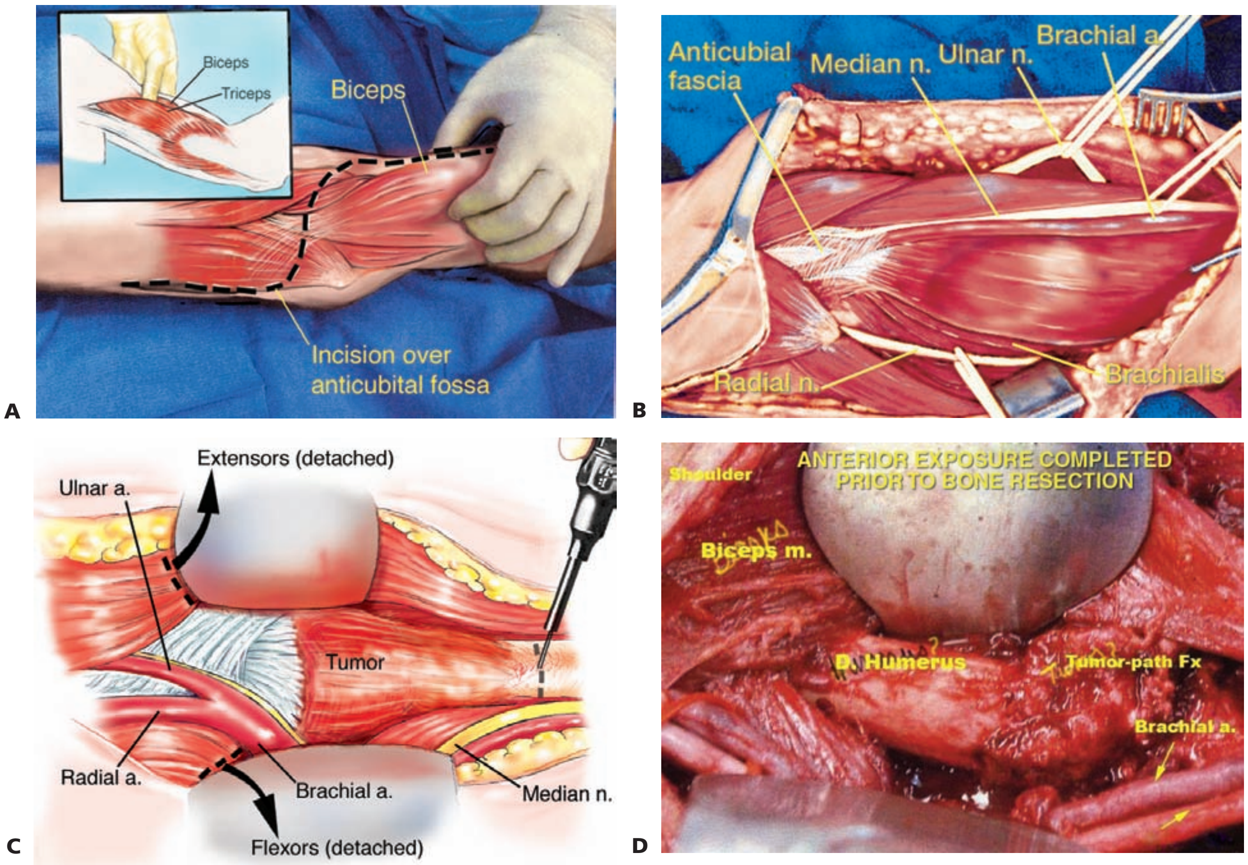
Approach

- A limb-sparing distal humeral resection has three major components:
  - Oncologic resection
  - Skeletal reconstruction
  - Soft tissue reconstruction or coverage (or both).
- The goal of the resection is to remove the entire tumor en bloc or, in other words, in one piece with the distal humerus. The key to the resection involves meticulously dissecting, separating, and mobilizing the important neurovascular structures away from the neoplasm.
- Skeletal reconstruction is done with a modular, segmental replacement that can be assembled and have its size adjusted intraoperatively. The length of the prosthesis may be downsized as much as a few centimeters to facilitate soft tissue coverage of the prosthesis, if necessary.
- Soft tissue reconstruction that involves rotating and reattaching muscles and restoring the length–tension relationship of the forearm muscles and biceps is most important for achieving a good functional result and for protecting the prosthesis from infection.

TECHNIQUES

DISTAL HUMERAL RESECTION

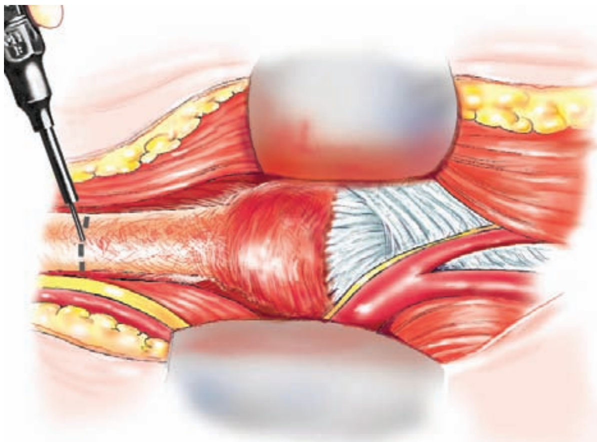
- The S-shaped incision begins in the middle of the arm along the medial side of the biceps muscle (**TECH FIG 1A,B**). It is extended distally along the medial border of the biceps muscle to the antecubital crease; the biopsy tract is included in the incision in an elliptical manner. At the antecubital crease, the incision curves laterally along the volar aspect of the elbow to the volar margin of the brachioradialis muscle, where it then turns distally and is extended distally along the forearm for a short distance.
- Medial and lateral cutaneous flaps are raised (**TECH FIG 1C,D**). Wherever possible, fasciocutaneous flaps are raised. Medial and lateral antebrachial cutaneous nerves are preserved.
- Proximally in the arm (proximal to the neoplasm in normal-appearing tissues), in the interval between the biceps and triceps muscles, the neurovascular structures are identified within their sheath. The deep investing fascia of the arm (superficial layer of the sheath) is opened longitudinally directly over these structures. While protecting the underlying structures, the fascia is opened from proximally to distally all the way down to the neoplasm or antecubital fossa. The neurovascular structures can be visualized easily, and the brachial artery can be palpated once the sheath is opened. Proximally, the brachial artery and accompanying veins are isolated and surrounded with a vessel loop. Likewise, the median, ulnar, and medial antebrachial cutaneous nerves are each identified, isolated, and individually surrounded with a vessel loop.
- The brachial artery and veins are meticulously dissected away from the surrounding tissues and from the pseudocapsule of the neoplasm down to and across the antecubital fossa. The biceps aponeurosis is incised to permit visualization of the brachial artery to the point where the ulnar and radial arteries arise. The radial and ulnar arteries are each identified and surrounded with a vessel loop. The inferior ulnar collateral vessels, as well as muscular branches to the biceps, brachialis or triceps muscle, may require ligation to mobilize the brachial vessels away from the neoplasm, depending on the location and position of the tumor. Once the artery is freed from the neoplasm, attention is turned to mobilizing the major nerves.
- The median nerve is dissected from a proximal to distal direction across the antecubital fossa, where it lies just medial to the brachial artery. It is dissected distally to where the anterior interosseous nerve arises from it and the median nerve continues deep to the flexor digitorum superficialis muscle.
- The ulnar nerve also is isolated and dissected from a proximal to distal direction. The medial intermuscular septum is opened to allow further dissection and mobilization of the ulnar nerve to the cubital tunnel along the medial



TECH FIG 1 • **A.** An anterior surgical incision is routinely used for resection and prosthetic replacement of the elbow joint and distal humerus. The surgeon can palpate the normal anatomic structures. The longitudinal incision is made along the biceps–triceps interval. The joint is exposed through an S extension of the proximal incision. **B.** Schematic drawing of the anterior exposure. The neurovascular structures are identified (ie, brachial artery, median nerve, radial nerve, ulnar nerve) and retracted. This is essential for a safe procedure. **C.** Wide medial and lateral flaps are required for adequate exposure. **D.** The biceps as well as the neurovascular structures are retracted

epicondyle of the distal humerus. The fascia or ligamentous tissue overlying the cubital tunnel is opened longitudinally, and the ulnar nerve is gently mobilized from the tunnel all the way to where the nerve passes between the humeral and ulnar heads of the pronator teres muscle. This enables the ulnar nerve to be retracted medially with the brachial vessels and median nerve.

- The radial nerve is identified in the interval between the brachioradialis and brachialis muscles. It is dissected distally across the elbow joint to the juncture where the posterior interosseous nerve originates from the radial nerve. It also is dissected proximally as it passes through the lateral intermuscular septum around the posterior aspect of the humerus in the spiral groove. The lateral intermuscular septum is opened, and the radial nerve is mobilized away from the posterior aspect of the humerus up to the latissimus dorsi muscle insertion.
- The biceps muscle is isolated, dissected away from neoplasm and the underlying brachialis muscle. Usually, the biceps is not involved by any neoplasm. If it is involved, a portion may require removal. (Be aware that the biceps or brachialis muscle is required for elbow flexion; removal of both in entirety prohibits elbow flexion postoperatively.) The biceps muscle is isolated so it can be retracted medially and laterally when necessary.
- The pronator teres and common flexor muscles are released from their origins from the distal humerus medially. The brachioradialis, extensor carpi radialis longus, and common extensor muscles are released laterally from the distal humerus. A small cuff of muscle is left around the tumor as needed. Occasionally, a distal humerus resection is performed for a soft tissue sarcoma that originates from one of these muscle groups. In such a case, the muscle or muscles that are involved by neoplasm are transected distal to the tumor in such a manner that an adequate margin is maintained. When resecting the flexor–pronator group, the branch of the median nerve that supplies the flexor digitorum superficialis is identified and protected, if possible. On the lateral side of the elbow, if the brachioradialis and common extensor muscles require resection, the posterior interosseous nerve is identified and protected to preserve wrist and digit extension.
- A portion of the brachialis muscle, or even the entire brachialis muscle, may require resection, depending on the extent of the tumor. If there is no soft tissue component arising from a distal humerus tumor or if the brachialis muscle is not involved by an adjacent soft tissue sarcoma, then the brachialis muscle is incised longitudinally along the anterior aspect of the distal humerus. The brachialis muscle is then elevated off the



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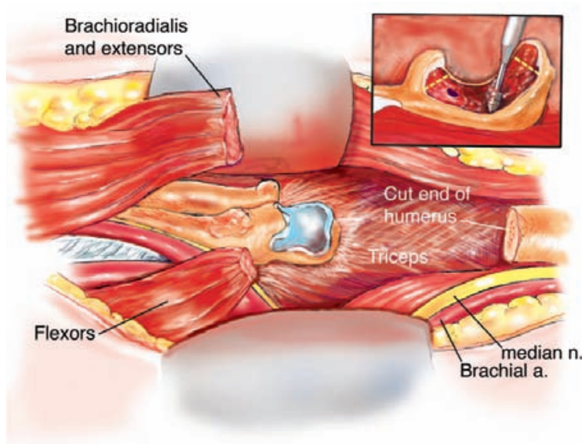

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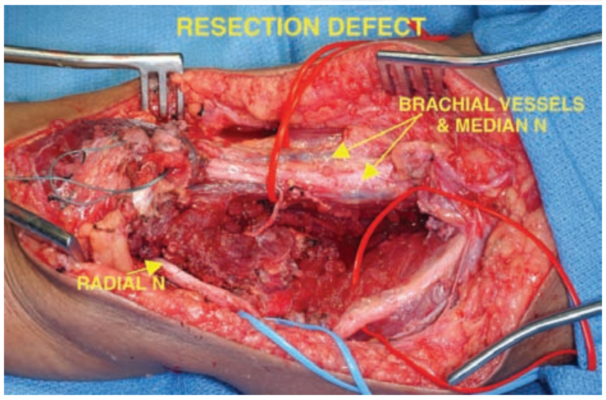

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TECH FIG 2 • **A.** The appropriate length of resection is determined preoperatively from the MRI scan. In general, a 2- to 3-cm margin of normal bone is removed. **B.** Schematic drawing of the resection defect. **C.** Operative photograph of the surgical defect. Note the wide exposure. This is required for accurate positioning of the prosthesis and reaming of the ulnar canal. The triceps remains attached to the surrounding soft tissues.

distal humerus and preserved. If there is a soft tissue component arising from a tumor of the distal humerus or if the brachialis muscle is involved by an adjacent soft tissue sarcoma, then the brachialis muscle is released in a subperiosteal manner from its insertion on the ulna or simply transected distal to the elbow joint.

- The triceps muscle is elevated off the distal humerus and may require partial or complete resection of the medial head, depending on tumor extent. The lateral and long heads usually can be preserved. 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 from the ulna–olecranon and radial head. The humero-ulnar and radiohumeral joints are then disarticulated.
- The humerus is osteotomized at a level approximately 2 to 3 cm proximal to the intramedullary extent of the neoplasm (**TECH FIG 2A**). The area where the humerus will be osteotomized is cleared of overlying brachialis muscle and triceps muscle. The radial nerve is identified and protected before cutting the bone. The bone usually is transected with a sagittal saw (**TECH FIG 2B,C**).

PROSTHETIC RECONSTRUCTION

- Reconstruction of the distal humerus and elbow joint is performed with a modular segmental distal humerus tumor prosthesis. The distal humeral component consists of a semiconstrained hinge component that is attached to an ulnar component to recreate the elbow joint.
- Proximally, the distal humeral component can be fit to a body segment via a Morse taper. The body segment is available in different lengths, so the size can be adjusted intraoperatively. The body segment is fit to a stem via a Morse taper. The stem then is cemented into the more proximal remaining humeral canal.
- The ulnar component consists of a stem that is cemented into the olecranon and proximal ulna. The ulna component is available in two lengths.
- The length of the prosthesis is chosen. It may be downsized 2 to 3 cm to help facilitate soft tissue closure. The prosthesis is assembled on the field.
- The remaining humerus is flexibly reamed to accommodate as wide a stem as possible. It is overreamed 1 to 2 mm to accommodate for a cement mantle. The olecranon fossa is opened with a small high-speed burr (**TECH FIG 3**) to enter into the medullary canal of the proximal ulna. The proximal tip of the olecranon is shaved slightly to accommodate the ulna stem, so that it can be inserted directly into the ulnar canal without being inserted on an angle. The canal of the ulna is reamed with hand reamers. Trial components are available to be used to ensure that the ulna component will sit properly within the medullary canal of the proximal ulna.
- Both components are cemented into place separately. The distal humerus is cemented so the hinge will face anteriorly. It is important to identify the anterior surface of the humerus before the distal humeral component is inserted. The ulna component is placed so that it sits as deep as possible within the olecranon fossa without

TECH FIG 3 • Technique of preparing the ulnar notch. A high-speed burr is recommended.

damaging the posterior cortex of the bone. After the cement cures, both components are attached to each other with the appropriate hinge.

SOFT TISSUE AND MUSCLE RECONSTRUCTION

- The brachioradialis and extensor carpi radialis muscles are sutured to the remaining biceps and triceps muscles to secure soft tissue around the flared distal portion of the humeral endoprosthesis. A flexorplasty is performed. With the elbow held in 60 degrees of flexion and the forearm fully supinated, these muscles are transferred to as proximal a position as possible and sutured to the biceps muscle with no. 5 nonabsorbable sutures. The biceps is pulled distally and placed under tension while these muscles are sutured to it. This step is especially important if the prosthesis has been shortened, because it restores the length–tension relation of the biceps muscle. The elbow is kept in 60 degrees of flexion and fully supinated for the remainder of the procedure.
- The origin of the flexor–pronator forearm muscles also is transferred as far proximal as possible and sutured to the medial border of the biceps and triceps muscles.
- At this time, for postoperative analgesia, an epidural catheter can be threaded proximally along the median nerve, deep to the vascular sheath, to a level where it can bathe the entire brachial plexus with bupivicaine. A drain is also placed at this time.
- The remaining muscles, usually the biceps–brachialis muscles and triceps muscles, are sutured to each other to close over the entire prosthesis and neurovascular structures (**TECH FIG 4**).
- Sometimes, depending on the amount of soft tissue that is resected with the neoplasm, it is useful to shorten the prosthesis an additional 2 to 3 cm to facilitate soft tissue coverage. The biceps requires retensioning with sutures if this situation arises. Likewise, proximal transfer (ie, tensioning) of the brachioradialis and forearm flexor origins (ie, flexorplasty) is beneficial for restoring elbow flexion power.

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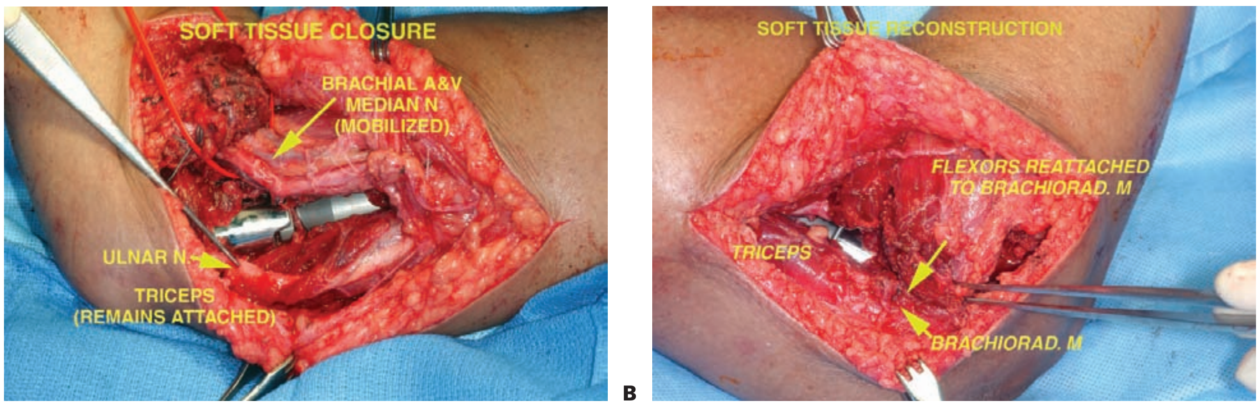

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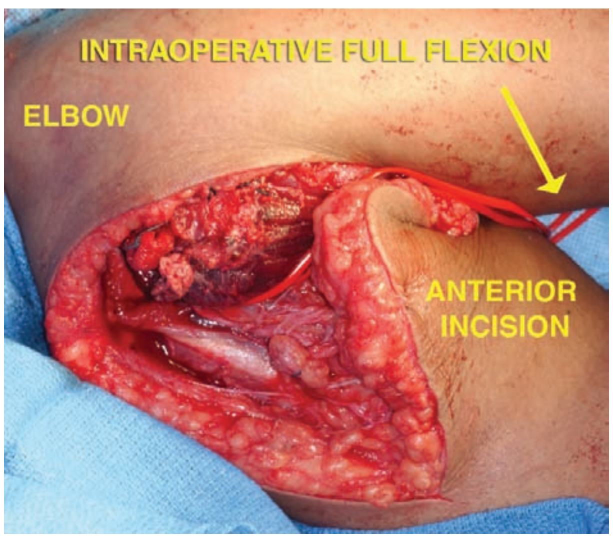

TECH FIG 4 • Soft tissue closure. **A.** It is important for the prosthesis to be completely covered by muscle. The flexors (from the medial condyle) and the brachioradialis (mobile wad of 3) from the lateral condyle are reattached to the adjacent soft tissue. It is not necessary to attempt reattachment to the prosthesis. **B.** Reattachment of the elbow flexors. An ulnar nerve transposition may be performed, although this is not done routinely. **C.** The passive range of motion of the elbow is tested prior to closure. If there is any restriction, the radial head should be examined or removed.

PEARLS AND PITFALLS

Evaluating intraosseous tumor extent	■ T1-weighted MRI scans are the most accurate for determining intraosseous tumor extent. The T2-weighted image often is associated with significant peritumoral edema, which overestimates tumor extent.
Biopsy	■ The biopsy should be taken through the brachialis muscle and in line with the proposed skin incision that would be used for definitive resection. The biceps must not be penetrated or contaminated. Preservation of the biceps muscle is crucial for restoring elbow flexion following reconstruction.
Neurovascular structures	■ The major neurovascular structures are all identified in normal tissue proximal to the neoplasm along the medial side of the mid-arm. Dissection is initiated in a proximal to distal direction. All important structures (ie, brachial vessels, median nerve, ulnar nerve, and radial nerve) are identified, separated, and mobilized away from the neoplasm and distal humerus. Once all vital structures are preserved and protected, the resection can begin. Care is taken to preserve the nerve to the flexor digitorum superficialis when tumors of the flexor–pronator group are resected. Likewise, care is taken to preserve the branches of the posterior interosseous nerve when tumors of the brachioradialis and common extensor muscle group are resected.
Skeletal/endoprosthetic reconstruction	■ The endoprosthesis is downsized 2 to 3 cm to facilitate soft tissue coverage, if necessary. The elbow flexors are retensioned to accommodate for the shortening. The prosthesis is cemented so that the hinge faces anteriorly. The ulna component must be seated as deep as possible within the olecranon.
Soft tissue reconstruction	■ It is important to maintain the elbow in 60 degrees of flexion and fully supinated when performing the soft tissue reconstruction. Proximal transfer under tension of both the common extensor muscle origin and the flexor–pronator origin to either side of the biceps muscle accomplishes a flexorplasty of the elbow that assists with restoring elbow flexion power. It may be necessary to restore the length–tension relation of the biceps by pulling the biceps distally and suturing it to the forearm musculature under tension.

POSTOPERATIVE CARE

- Edema control is essential in the early postoperative period. Patients are covered from hand to shoulder with a bulky dressing and a splint that maintains the elbow in 60 degrees of flexion. Elastic bandages are applied for light compression. The extremity is elevated and the patient remains primarily at bed rest for 3 to 4 days. Drains and the perineural catheter are removed at this time. The dressings are changed approximately 4 days postoperatively, and the splint is reapplied to maintain the elbow in 60 degrees of flexion.
- The extremity is kept in a splint for a total of 6 weeks to allow for sufficient muscle healing and scarring. Elbow motion is prohibited for 6 weeks.
- Immediately after surgery, active and passive range of motion of the wrist, hand, and digits, along with hand strengthening, is initiated and continued for 6 weeks while the arm is in the splint. Hand and wrist strengthening is continued throughout the entire rehabilitation process.
- At 6 weeks, the patient is placed in a hinged elbow brace and permitted active, active assisted, and passive range of motion from 30 degrees of flexion to 130 degrees of flexion. The patient is not permitted to extend the elbow for the next 6 weeks past approximately 30 degrees of flexion. At 12 weeks after surgery, the brace is adjusted to allow full motion of the elbow. Strengthening of the elbow is initiated at this time, with a 2-pound weight limit. The brace is worn for 6 more weeks, usually until approximately week 18. The patient can wear a sling after week 18 when necessary for comfort. At week 18, resistance strengthening can be increased to a 5-pound weight limit if the patient is now able to handle 2 pounds. At 6 months after surgery, the weight limit for resistance strengthening is increased to 10 pounds. Patients are advised not to lift more than 10 pounds with the extremity.

OUTCOMES

- **Oncologic results:** Local recurrence is less than 5%. In our series of 16 patients, there were no local recurrences.
- **Prosthetic survival:** In our small series of 16 patients, there were no instances of prosthetic loosening (**FIG 3**).
- **Function:** All patients are pain free and have stable elbows. Patients do not require a brace. Elbow, wrist, and hand function are virtually normal. All patients could flex their elbows up to 110 to 130 degrees. In general, patients lacked 10 to 30 degrees of terminal extension. All patients could carry out activities of daily living. The Musculoskeletal Tumor Society score ranged from 24 to 27 of 30 possible points (80% to 90%). The main restrictions are in recreational

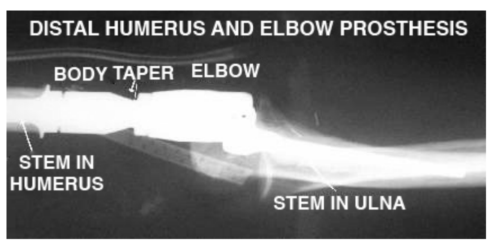

FIG 3 • Postoperative radiograph showing the prosthesis and its components.

activities. Most patients can flex their elbows against 10 pounds of resistance.

COMPLICATIONS

- Transient nerve palsies (over 10%; 1 out of 16 patients); resolved within 6 months
- Skin necrosis and wound infections (over 10%; 1 out of 16 patients); resolved with debridement and closure
- Aseptic loosening (0 out of 16 patients)
- Local recurrence (0 out of 16 patients)
- In one instance the axle broke and was replaced.

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