9

Overview of Resections around the Shoulder Girdle: Anatomy, Surgical Considerations and Classification

Martin Malawer and James C. Wittig

OVERVIEW

The Tikhoff–Linberg procedure and its modifications are limb-sparing surgical options for selected patients with bone and soft-tissue tumors in and around the shoulder girdle. Today, approximately 95% of patients with tumors of the shoulder girdle can be treated by a limb-sparing procedure. Forequarter amputations are rarely performed, except in cases of tumors that are infected or fungating, tumors that invade the adjacent neurovascular bundle or chest wall, and failed attempts at limb-sparing resections. Function of the forearm, wrist, and hand should be nearly normal following a limb-sparing shoulder girdle resection. A stable shoulder and elbow flexion and extension are achieved without the need for an orthosis.

This chapter describes in detail the specific tumor site and its influence on the surgical management, indications and contraindications of resection, surgical staging and classification, endoprosthetic reconstruction and design features, functional considerations, and rehabilitation. Specific techniques of resection and reconstruction of the proximal humerus and scapula are presented in Chapters 33 and 34.

INTRODUCTION

The upper extremity is involved by bone and soft-tissue neoplasms one-third as often as the lower extremity.[1] The scapula and proximal humerus are common sites of primary sarcoma, including osteosarcoma and Ewing's sarcoma in children and chondrosarcoma in adults.[2] When soft-tissue tumors occur in the upper extremity, they tend to favor the shoulder girdle. Metastatic tumors, in particular hypernephroma, also have a propensity for the proximal humerus.

The shoulder girdle consists of the proximal humerus, the scapula, and the distal third of the clavicle, as well as the surrounding soft tissues (Figure 9.1A). Each bone may be involved by a primary malignant bone tumor or metastases, with or without soft-tissue extension. The bones of the shoulder girdle may also be secondarily involved by a soft-tissue sarcoma and require similar resection and reconstruction techniques (Table 9.1).

Until the mid-twentieth century, forequarter amputation was the treatment for malignant tumors of the shoulder girdle. Today, approximately 95% of patients with sarcomas of the shoulder girdle can be treated safely by limb-sparing resection. The Tikhoff–Linberg resection and its modifications are limb-sparing surgical options for tumors in this location.[3] The relationship of the neurovascular bundle to the tumor and other structures of the shoulder girdle is the most significant anatomic factor in determining resectability and surgical reconstruction.

The resection and reconstruction of tumors of the shoulder girdle consists of three components: (1) surgical resection of the tumor following oncologic principles; (2) reconstruction of the skeletal defect (i.e., endoprosthetic replacement); and (3) soft-tissue reconstruction using multiple muscle transfers to cover the skeletal reconstruction and provide a functional extremity. The goal of all shoulder girdle reconstructions is to provide a stable shoulder and to preserve normal elbow and hand function. The extent of tumor resection and remaining motor groups available for reconstruction dictate the degree of shoulder motion and function.

PATIENT DEMOGRAPHICS AND CLINICAL OUTCOMES

The types of tumors, anatomic locations, and types of shoulder girdle resections performed in 143 patients treated at our institutions from 1980 to 1998 are shown in Figure 9.1B. Our experience with endoprosthetic reconstruction of the proximal humerus and scapula demonstrates that this is a reliable and durable technique of reconstruction. Survival rates based on Kaplan–Meier analysis demonstrate a 9-year survival rate of 98–99% for proximal humeral replacements. There were no mechanical failures or dislocations. Other groups have reported a significant incidence of dislocation following endoprosthetic reconstruction of the shoulder girdle. This has not been our experience. Our results reflect the outcome of our use of "dual suspension" (i.e. static and dynamic) or capsular reconstruction techniques and meticulous attention to soft-tissue reconstruction.

Historical Background

Some of the earliest discussions concerning limb-sparing surgery focused on techniques for resection of tumors about the scapula. Initial reports of shoulder girdle resections were confined to the individual bones or portions of the scapula. The first reported scapular resection was a partial scapulectomy performed by Liston in 1819[4] for an ossified aneurysmal tumor. Between this time and the mid-1960s several other authors discussed limb-sparing resections about the shoulder girdle.[5–11] In 1965 Papioannou and Francis[12] reported 26 scapulectomies and discussed the indications and limitations of the procedure.

The Tikhoff–Linberg interscapulothoracic resection, or triple-bone resection was described by Baumann in 1914 in the Russian literature.[13] He referred to a 1908 report by Pranishkov describing the removal of the scapula, the head of the humerus, the outer one-third of the clavicle, and the surrounding soft tissue for a sarcoma of the scapula. The shoulder was suspended from the remaining clavicle by metal sutures. Tikhoff and Baumann performed three such operations between 1908 and 1913, and Tikhoff was named as the originator of the procedure. The technique became established in the Western surgical community only after Linberg's 1926 English publication.[3]

Classically, most shoulder girdle resections were done for low-grade tumors of the scapula and for periscapular soft-tissue sarcomas. After the 1980s osteosarcoma and Ewing's sarcoma of the proximal humerus became the most common tumors treated with a Tikhoff–Linberg resection. A variety of new techniques and modifications of shoulder girdle resections have been developed. Most have been reported as "Tikhoff–Linberg" or modified "Tikhoff–Linberg" resections. These eponyms do not accurately describe the procedure performed, given that the Tikhoff–Linberg procedure was not intended to refer to sarcomas of the humerus.

Classification: Surgical Resection

Since 1965 several classification systems have been developed to describe shoulder girdle resections.[14] The earlier systems were purely descriptive and related almost exclusively to the bones resected. They did not accommodate or reflect concepts or terminology that have developed in the past two decades in orthopedic oncology.

The present surgical classification system was described by Malawer and associates in 1991 (Figure 9.2).[15] It is based on the current concepts of surgical margins, the relationship of the tumor to anatomic compartments (intracompartmental vs. extracompartmental), the status of the glenohumeral joint, the magnitude of the individual surgical procedure, and precise considerations of the functionally important soft-tissue components. It has six categories, as follows:

Type I : Intra-articular proximal humeral resection
Type II: Partial scapular resection
Type III: Intra-articular total scapulectomy
Type IV: Extra-articular total scapulectomy and humeral head resection (classical Tikhoff–Linberg resection)
Type V: Extra-articular humeral and glenoid resection
Type VI: Extra-articular humeral and total scapular resection

Each type is subdivided according to the status of the abductor mechanism (the deltoid muscle and rotator cuff):

A: Abductors intact
B: Abductors partially or completely resected

In general, Type A (abductors preserved) resections are intracompartmental and Type B (abductors resected) resections are extracompartmental.

This system is based on the anatomic and functional structures removed surgically. The six types are based

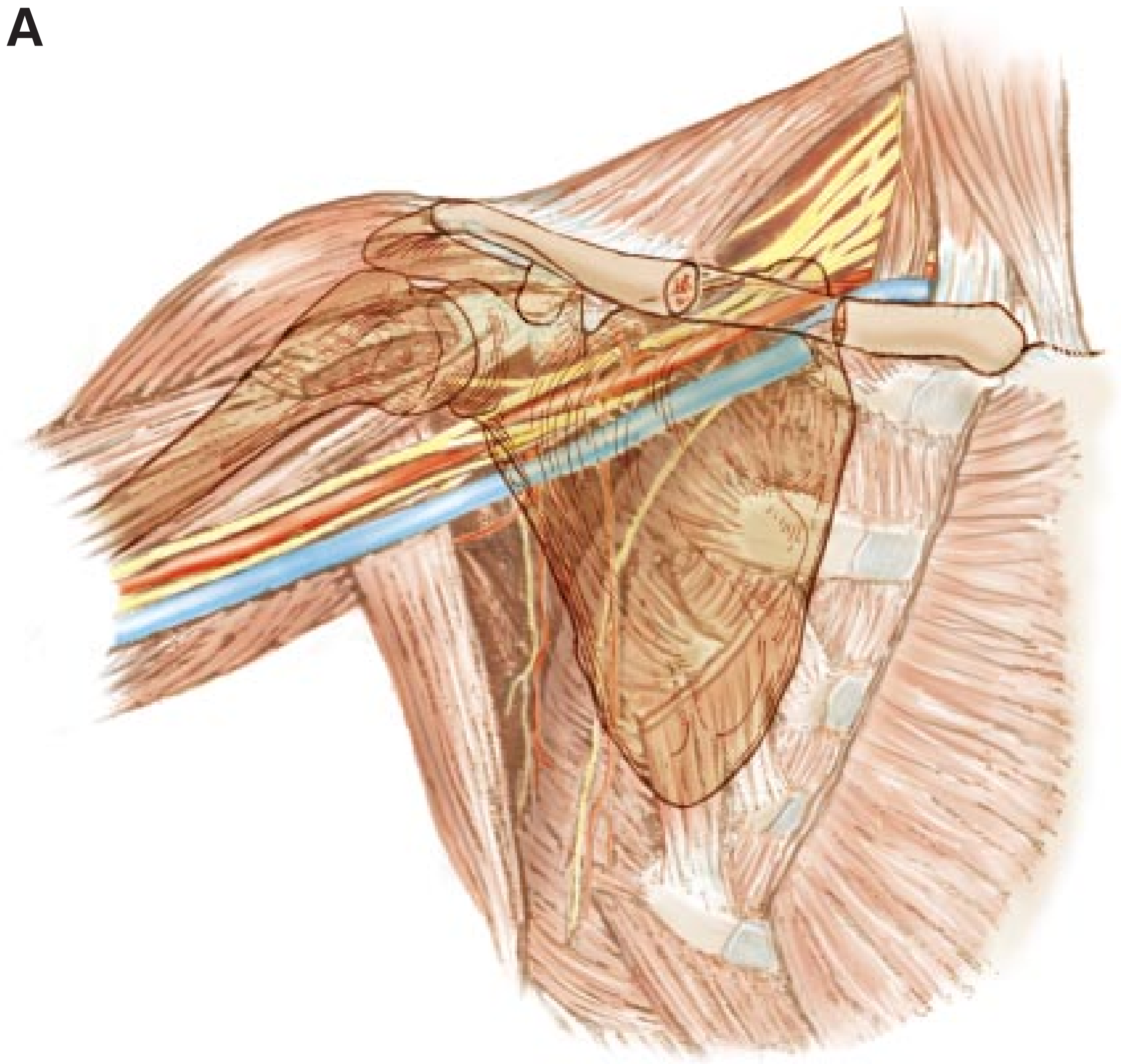


Figure 9.1 *(see above and following page).*

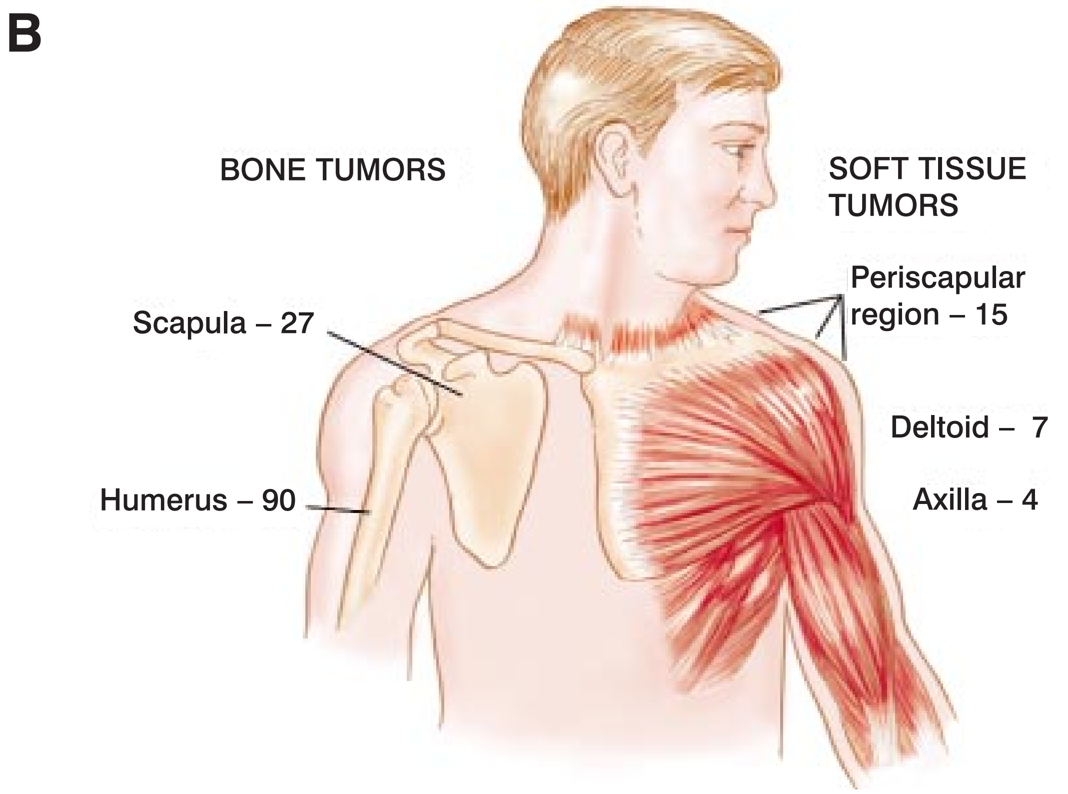


Figure 9.1 (**A**) Anatomy of shoulder girdle. (B) Schematic diagram of our combined* surgical experience in the treatment of shoulder girdle tumors (1980–1998). A total of 143 patients were treated by limb-sparing procedures. There were 117 bone and 15 periscapular soft-tissue tumors. *Combined experience of Martin M. Malawer, M.D., Washington, DC, and Isaac Meller, M.D., Tel-Aviv, Israel.

Table 9.1 Histologic classification and anatomic location of bone and soft-tissue tumors around the shoulder girdle of 143 patients treated between 1980–1998

Tumor histologic type	*Anatomic location (no. of patients)*				
	Proximal humerus	*Scapula*	*Proximal arm*	*Periscapula*	*Axilla*
Primary bone sarcomas					
Osteosarcoma	40	6	–	–	–
Chondrosarcoma	29	5	–	–	–
Ewing's sarcoma	3	5	–	–	–
Other primary malignancies of bone	2	5	–	–	–
Metastatic bone disease	11	1	–	–	–
Benign-agressive bone tumors	5	5	–	–	–
Soft-tissue sarcoma	–	–	6	13	4
Benign-agressive soft-tissue tumors	–	–	1	2	–
Totals	90	27	7	15	

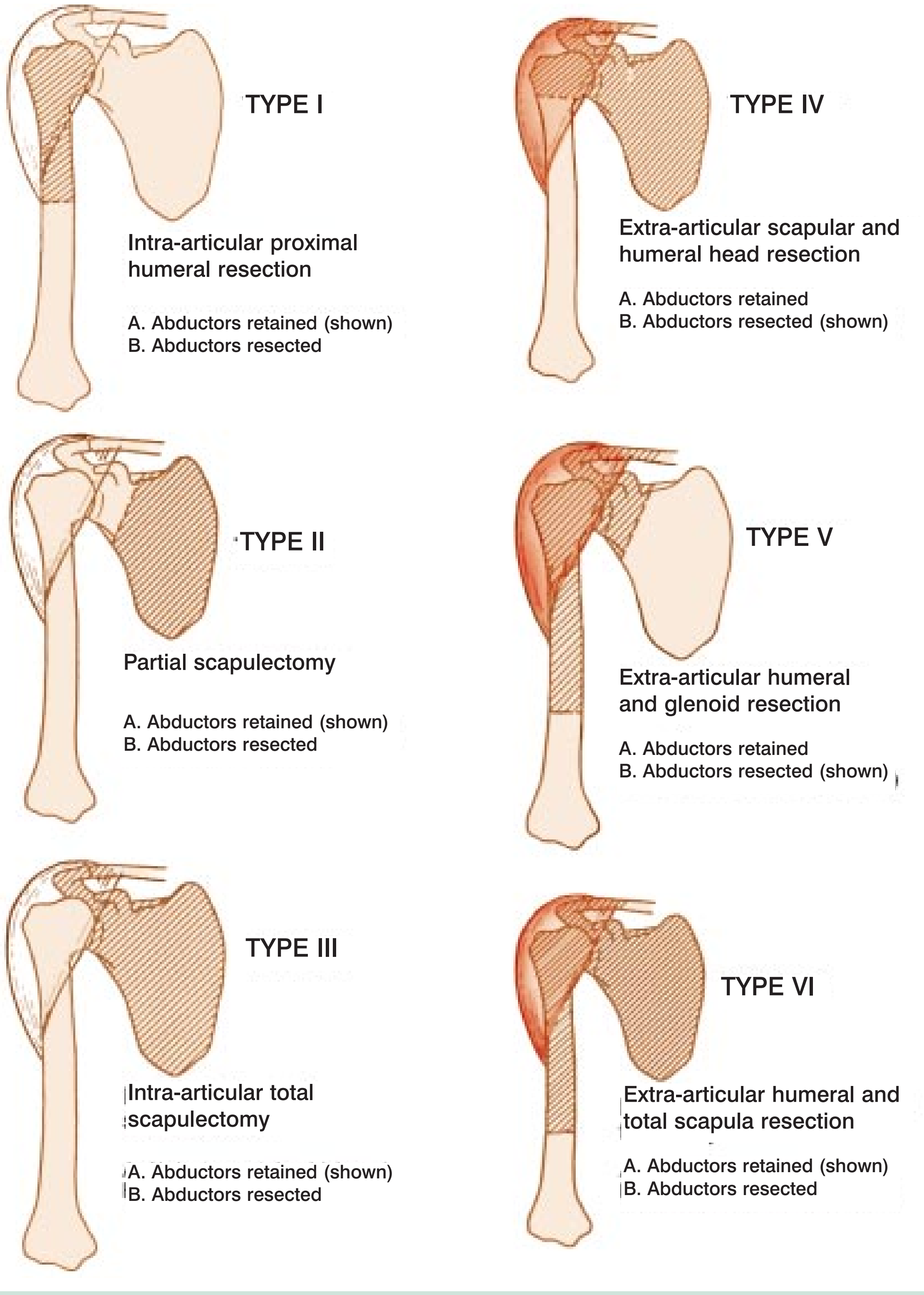


Figure 9.2 Surgical classification of shoulder girdle resections. This system was initially proposed by the senior author in 1991. Types I–III are intra-articular resections, whereas Types IV–VI are extra-artivcular resections. A = abductor muscles retained, B = abductor muscles resected (see text).

on the bony segments involved and their relationship to the glenohumeral joint. The distinguishing variable is the status of the main motor group, the abductor mechanism. The loss of any component of the abductor mechanism (deltoid or rotator cuff muscles) creates a similar functional disability. The abductor mechanism is almost always resected when there is extraosseous extension of a bone tumor in this area.

Type I–VI shoulder girdle resections and their indications are briefly described below. The surgical technique for each resection and reconstruction are described in Chapters 33 and 34.

Type I Resection (Figure 9.3)

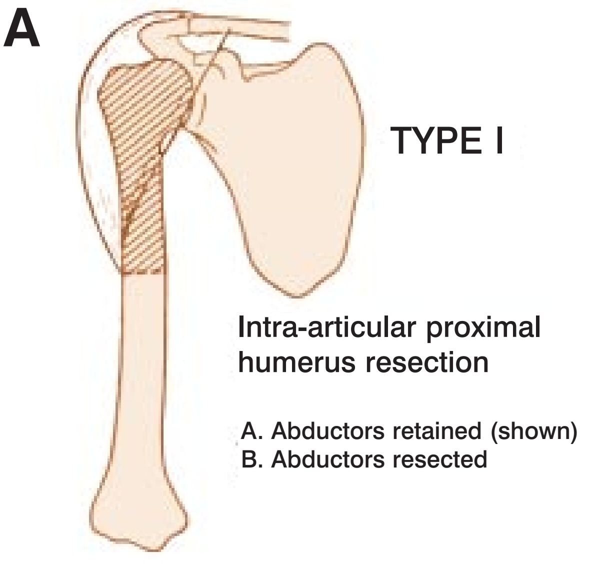
The least frequently performed shoulder girdle resection, this procedure is an intra-articular resection of the proximal humerus. It is performed for some low-grade tumors and, rarely, for high-grade tumors of the proximal humerus that have no extraosseous component (Stage IIA). Metastatic disease of the proximal humerus with extensive destruction of bone or a pathologic fracture can also be treated with a Type I resection. Reconstruction is performed using an endoprosthesis and local muscle transfers. A Gore-Tex graft reconstruction of the glenohumeral joint capsule may be required following a Type I resection, even when normal soft tissues are retained to provide stability (see Chapter 33).

Type II Resection (Figure 9.4)

This procedure is a partial scapulectomy that is extra-articular. It is usually performed for low-grade osseous malignancies of the scapula that involve the medial scapular body. It is rarely indicated for small high-grade malignancies in this location. Soft-tissue sarcomas that secondarily invade the medial scapula may also be treated by this resection. Occasionally, a limited chest wall resection beneath the partial scapulectomy is required to achieve a negative margin of excision. Reconstruction is performed using local muscle transfers and attaching these to the remaining scapula.

Type III Resection (Figure 9.5)

This resection is an intra-articular total scapulectomy. It is most frequently performed for soft-tissue sarcomas that secondarily invade the scapula and for primary osseous malignancies of the scapular body that do not invade the glenohumeral joint. Reconstruction is performed using a total scapular prosthesis if adequate soft tissues remain for reattachment to stabilize the



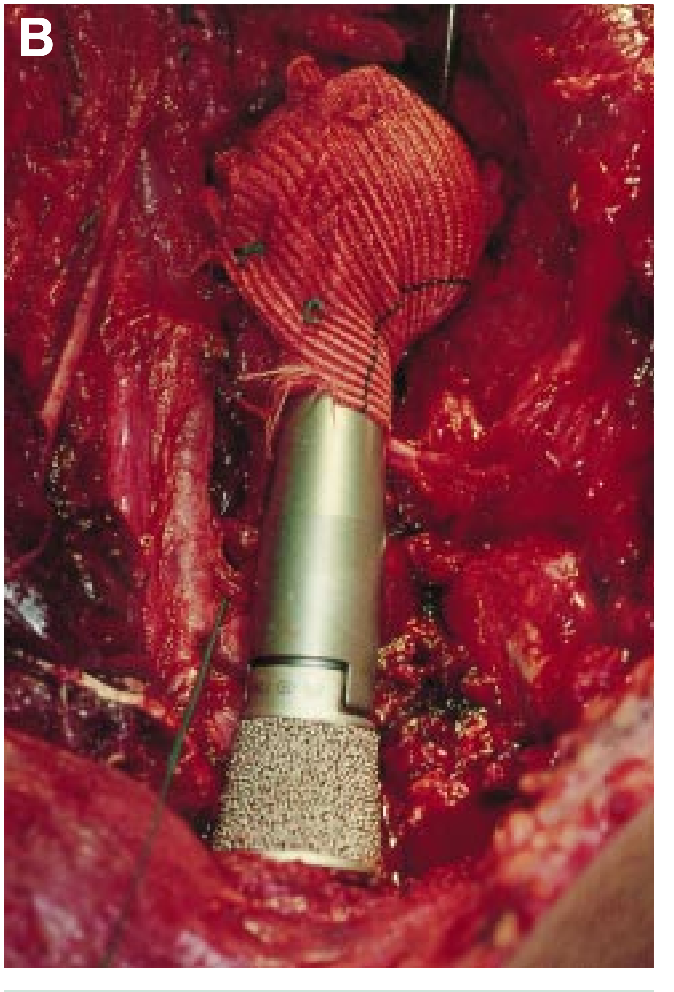


Figure 9.3 (**A**) Type I shoulder girdle resection; (**B**) Intraoperative photograph of a Type I proximal humeral resection.

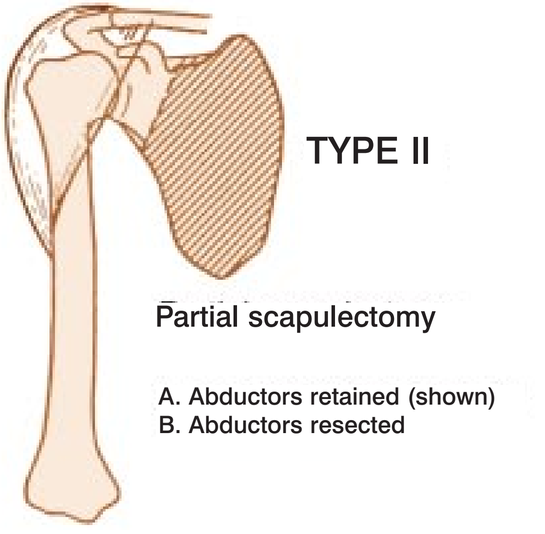


Figure 9.4 Type II shoulder girdle resection.

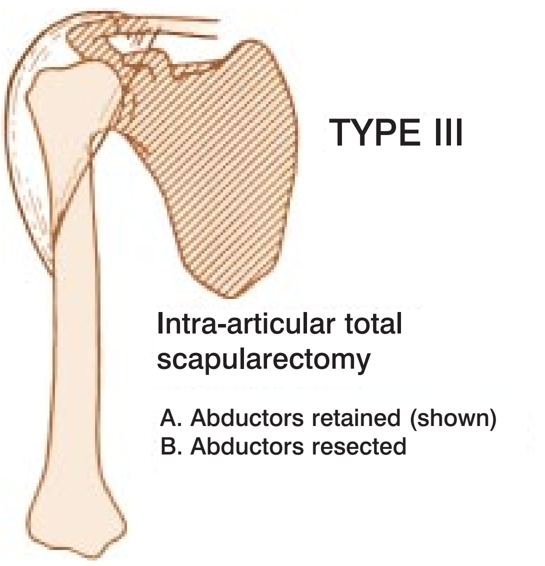


Figure 9.5 Type III shoulder girdle resection.

prosthesis. Otherwise, the proximal humerus is suspended from the distal clavicle and adjacent muscles are transferred to provide stability.

Type IV Resection: The Tikhoff–Linberg Procedure (Figure 9.6)

This procedure is an extra-articular en-bloc resection of the scapula, glenohumeral joint and humeral head, and distal clavicle. It is indicated for high-grade malignancies of the scapula, especially if the tumor extends

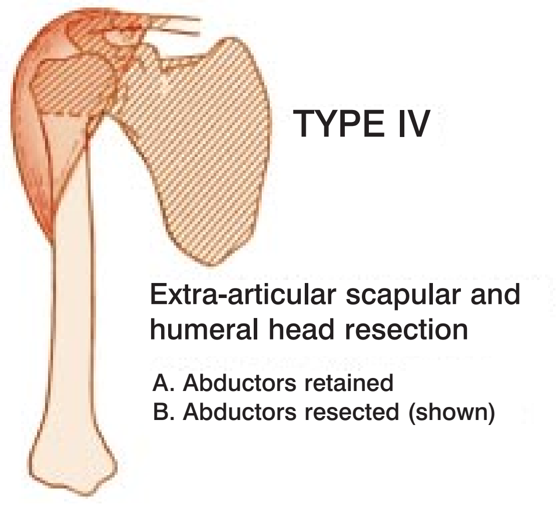


Figure 9.6 Type IV shoulder girdle resection.

anteriorly or laterally and involves the rotator cuff, or there is invasion of the glenohumeral joint. This procedure is also used for some low-grade sarcomas of the scapula and for periscapular soft-tissue sarcomas. Most malignant tumors of the scapular neck or glenoid require this approach.

The extent of proximal humeral resection and the remaining muscle available for reconstruction and coverage dictate the type of reconstruction that is performed. If adequate soft tissue is preserved, a total scapula and shoulder joint prosthesis is used (Figure 9.7). Otherwise, local muscle reconstruction and a dual-suspension technique using Dacron tape to suspend the proximal humerus from the remaining clavicle is performed (see Chapter 33).

Type V Resection (Figure 9.8)

This resection is the most common procedure for high-grade sarcomas of the proximal humerus. It involves an extra-articular, en-bloc resection of the proximal humerus, distal clavicle, and glenohumeral joint. The scapular resection is performed through the scapular neck, just medial to the coracoid. The axillary nerve and shoulder abductors are routinely sacrificed because of the extraosseous extension of tumors in this location (Figures 9.9 and 9.10).

Reconstruction of the osseous defect is performed using the modular proximal humerus endoprosthesis in conjunction with the dual-suspension technique described in Chapters 33 and 34. This is combined with multiple muscle transfers to reconstruct all soft tissues that have been resected.

Figure 9.7 (**A**) Large Ewing's sarcoma of the scapula that involves the glenohumeral joint with a large extraosseous soft-tissue component. This patient was treated with induction chemotherapy followed by resection of the scapula and the humeral head (Type IV resection). This was reconstructed by a scapular prosthesis. A Gore-Tex graft was used to reconstruct the capsule and to restore stability. (**B**) Plain radiograph following reconstruction. The Gore-Tex is outlined in black and the Dacron sutures to repair the scapular prosthesis are marked by the small x.

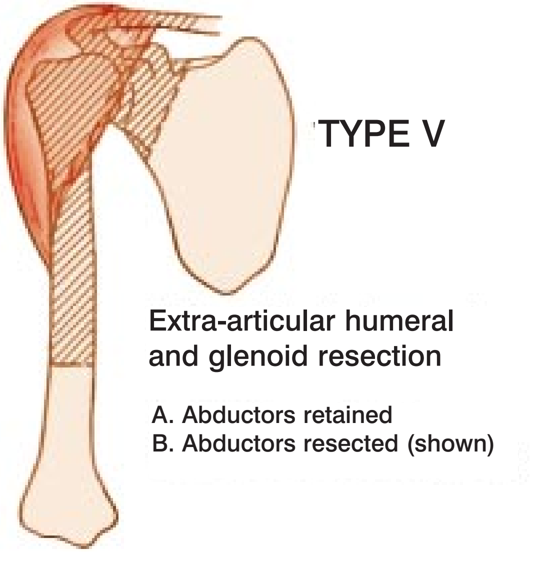


Figure 9.8 Type V shoulder girdle resection.

Type VI Resection (Figure 9.11)

This procedure is performed less frequently than Type V resections and is usually used for large advanced sarcomas of the proximal humerus that cross the shoulder joint and invade the scapula. High-grade soft-tissue tumors located over the glenohumeral joint, with or without osseous extension, may require this type of resection. The procedure involves resection of the proximal humerus and distal clavicle, and an extra-articular en-bloc resection of the glenohumeral joint and entire scapula (Figure 9.12).

UTILITARIAN SHOULDER GIRDLE INCISION (Figure 9.13)

The utilitarian shoulder girdle incision consists of an anterior and posterior component. This incision, or parts of it, permits adequate exploration and resection of the humerus, scapula, or axilla. It provides for safe exposure of the axillary vessels and brachial plexus.

Anteriorly, the incision begins at the junction of the inner and middle thirds of the clavicle, continues over the coracoid process and along the deltopectoral groove, and down the arm over the medial border of the biceps muscle. The posterior incision begins over the mid-clavicular portion of the anterior incision (crossing the suprascapular area) and runs over the lateral aspect of the scapula, and then curves posteriorly. Large fasciocutaneous (axilla) flaps are elevated anteriorly and posteriorly.

Resection of a tumor in the proximal humerus, proximal arm, or axilla utilizes the anterior component.

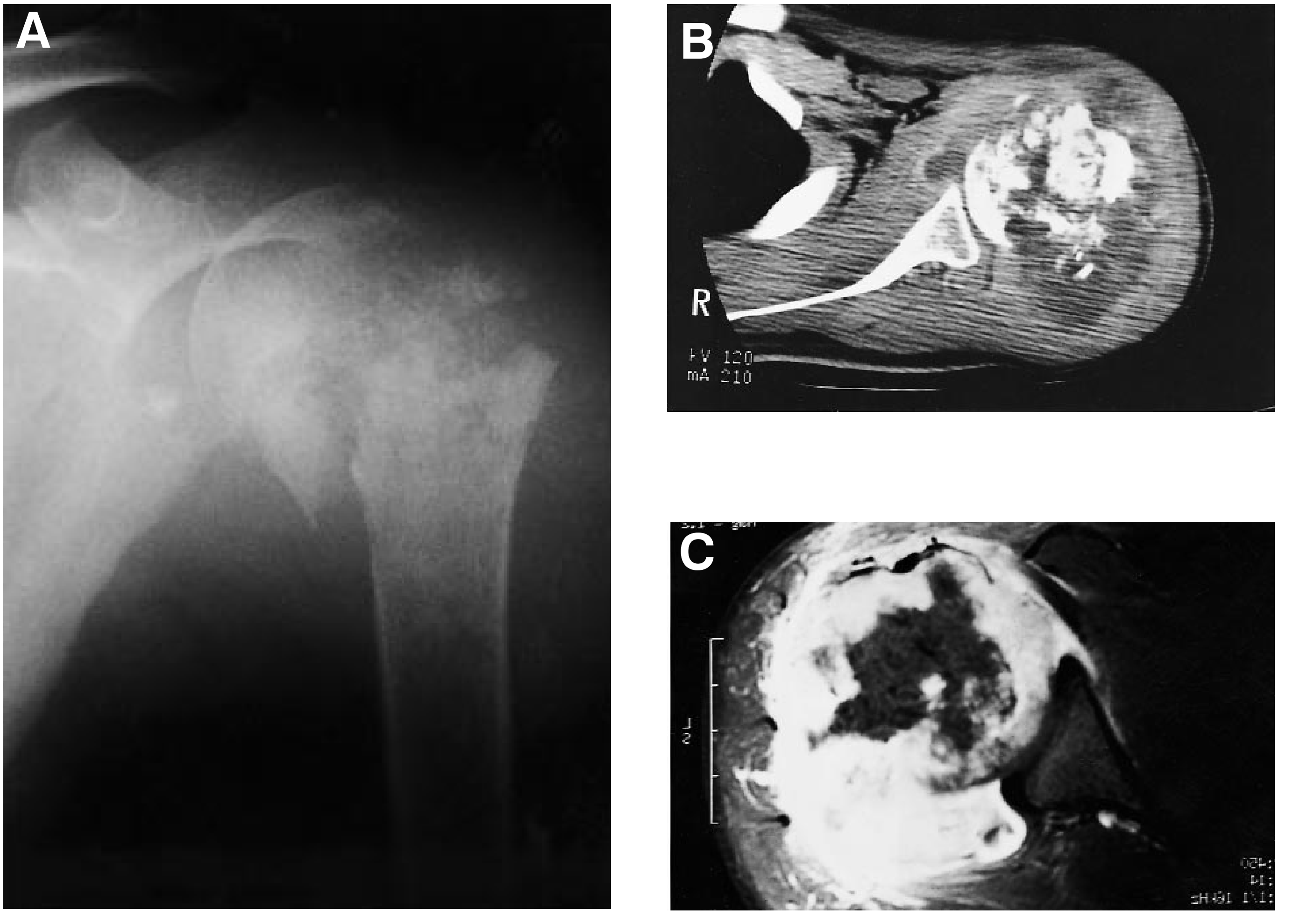


Figure 9.9 (**A**) Plain radiograph of an osteosarcoma of the proximal humerus with a pathologic fracture. In general, osteolytic osteosarcoma is the specific type of osteosarcoma that may develop a pathologic fracture. (**B**) CT scan showing a large soft-tissue component at the fracture site. Note the extension around the glenohumeral joint. Tumors of the proximal humerus may often involve the glenoid and are therefore treated by extra-articular resection (Type V). (**C**) MRI of the same patient showing extensive tumor involvement of the glenohumeral joint and pericapsular mechanisms.

It starts with the exposure of the main neurovascular bundle of the upper extremity. It is performed by a deltopectoral incision, detachment, medial reflection of the humeral insertion of the pectoralis major muscle, and detachment and reflection of the coracoid origins of the pectoralis major, coracobrachialis, and short head of the biceps muscle. The posterior component of the utilitarian incision is first used for resections around the scapula and glenoid: if the resection is performed close to the neurovascular bundle as in the case of an extra-articular resection of the scapula, the anterior incision is required to expose the neurovascular structure. The posterior incision permits wide exposure of the scapula, rhomboids, latissimus dorsi, and trapezius muscles.

We have found this incision permits safe exposure for resection and reconstruction of most shoulder girdle tumors.

INDICATIONS AND CONTRAINDICATIONS TO LIMB SPARING SURGERY

Indications for limb-sparing procedures include high-grade and some low-grade bone and soft-tissue sarcomas of the shoulder girdle. Occasionally, benign-aggressive tumors may also require these treatment techniques. Selection of patients for this procedure is based on the anatomic location of the tumor and a thorough understanding of the natural history of sarcomas and other malignancies.

Absolute contraindications for limb-sparing procedures include tumor involvement of the neurovascular bundle, or a patient's inability or unwillingness to tolerate a limb-sparing operation. Relative contraindications may include chest wall extension, pathologic fracture, previous infection, lymph node involvement

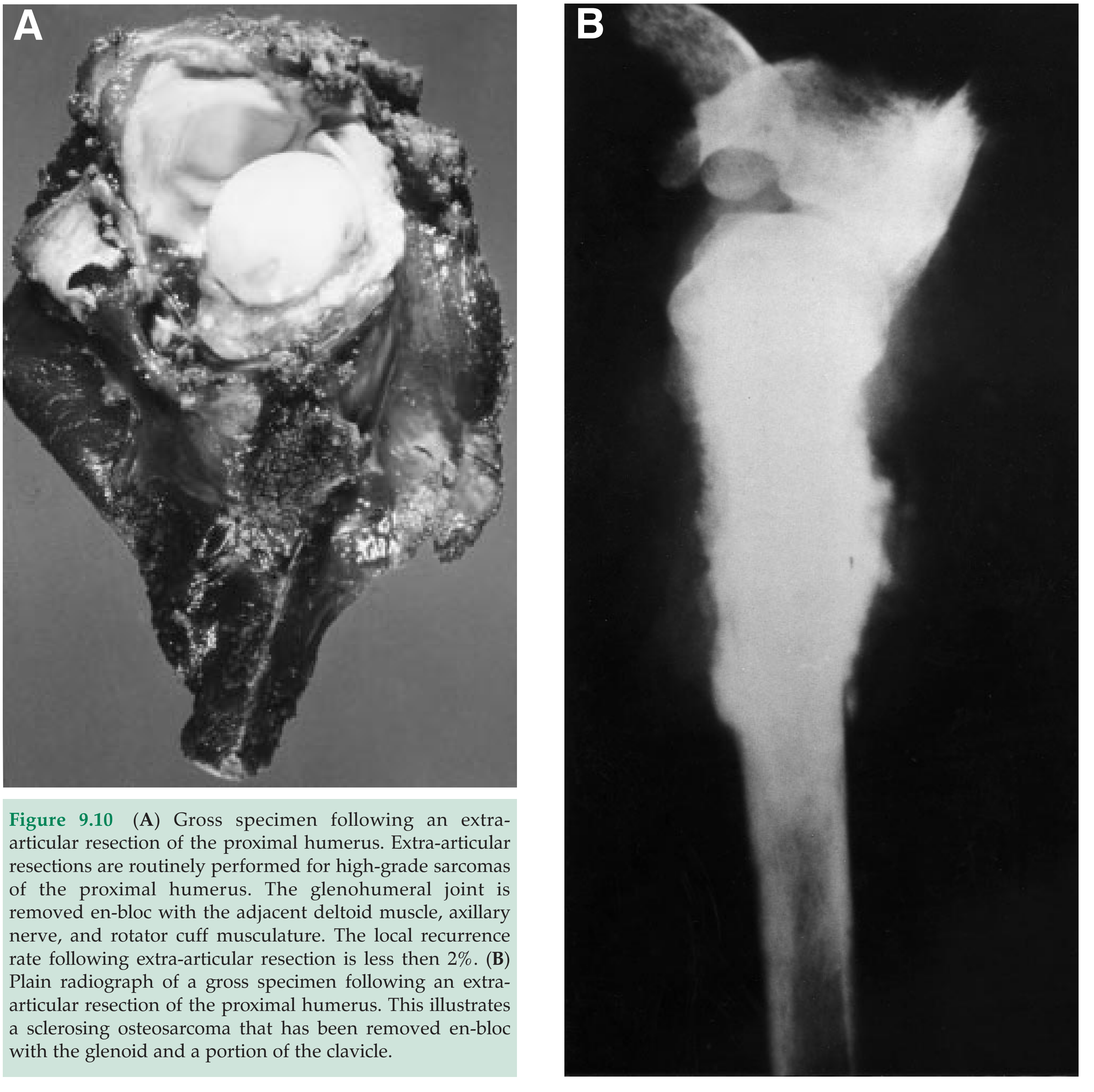


Figure 9.10 (**A**) Gross specimen following an extra-articular resection of the proximal humerus. Extra-articular resections are routinely performed for high-grade sarcomas of the proximal humerus. The glenohumeral joint is removed en-bloc with the adjacent deltoid muscle, axillary nerve, and rotator cuff musculature. The local recurrence rate following extra-articular resection is less then 2%. (**B**) Plain radiograph of a gross specimen following an extra-articular resection of the proximal humerus. This illustrates a sclerosing osteosarcoma that has been removed en-bloc with the glenoid and a portion of the clavicle.

or a complicated, inappropriately placed biopsy that has resulted in extensive hematoma that has resulted in tissue contamination.

Biopsy Site

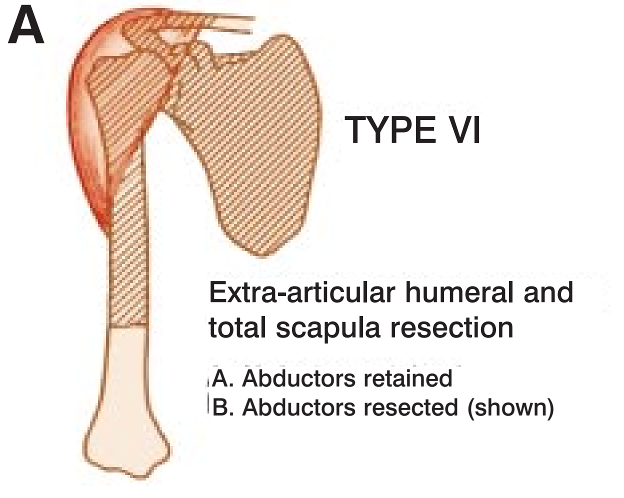
One of the most common causes for forequarter amputation is an inappropriately placed biopsy that has resulted in contamination of the pectoralis muscles, neurovascular structures, and chest wall. Extreme care must be taken with the biopsy placement and technique (see Biopsy Technique section).

Vascular Involvement

Fortunately, most tumors of the proximal humerus are separated from the anterior vessels by the subscapularis muscle and short head of the biceps. It is rare for the axillary or brachial artery to be involved with tumor, although a large soft-tissue component may cause displacement and compression. In general, if the vessels appear to be involved with tumor, the adjacent brachial plexus is also involved, and a limb-sparing procedure may be contraindicated.

Nerve Involvement

The three major cords of the brachial plexus follow the artery and vein and are rarely involved with tumor. Two of its major branches, the axillary and musculocutaneous nerves, may be involved. Resection of the axillary nerve is usually required for Stage IIB tumors of the proximal humerus. The musculocutaneous and radial nerves are rarely involved. The deficit created by resecting the radial nerve is greater than that for the musculocutaneous nerve, but this should not be an indication for amputation. If the resection will lead to a major functional loss and a close margin (increasing the risk of local recurrence), amputation should be considered. Direct tumor extension into the brachial plexus necessitates a forequarter amputation.



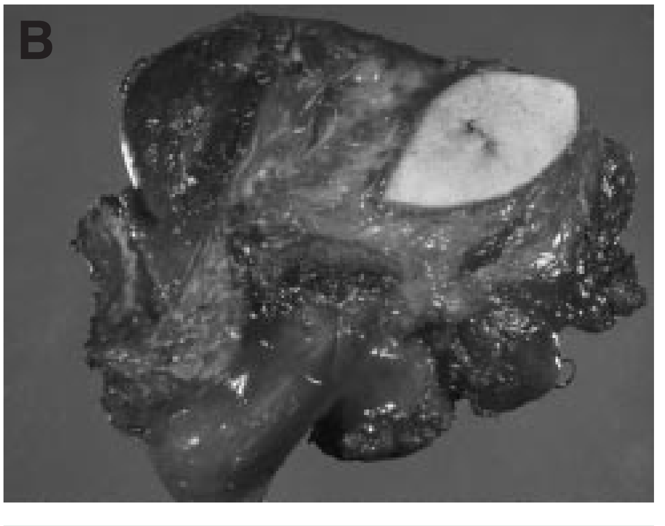


Figure 9.11 (**A**) Type VI shoulder girdle resection. (**B**) Gross specimen of a total scapula and total humerus resection.

Lymph Nodes

Bone sarcomas rarely involve adjacent lymph nodes; nevertheless, axillary nodes should be evaluated and may require biopsy. In the rare incidence of lymph node involvement documented by biopsy, a forequarter amputation may be the best method for removing all gross disease. Alternatively, a lymph node dissection in conjunction with a limb-sparing procedure may be considered. It is the author's experience (Malawer), based on two cases, that local control and long-term survival can be obtained by this method.

Chest Wall Involvement

Tumors of the shoulder girdle with large extraosseous components may occasionally involve the chest wall, ribs, and intercostal muscles. This should be evaluated preoperatively with physical examination and imaging studies; however, such involvement is often not determined until the time of surgery. This is not an absolute indication for forequarter amputation; a limb-sparing procedure combined with a chest wall resection may be performed, depending on the involvement of adjacent soft tissues and neurovascular structures.

Previous Resection

The local recurrence rate is increased if a wide resection is attempted following a previous resection around the shoulder girdle. This is especially true of tumors of the scapula and clavicle and of soft-tissue tumors that involve the proximal humerus.

Infection

In patients with high-grade sarcomas, limb-sparing procedures performed in an area of infection are extremely risky, because these patients must receive postoperative adjuvant chemotherapy. If an infection cannot be eradicated with the primary resection, amputation is advisable.

Preoperative Evaluation and Imaging

Physical examination, plain radiographs, computerized tomography and magnetic resonance imaging, arteriography and bone scan (total-body and three-phase) are important means of evaluating a patient with a tumor

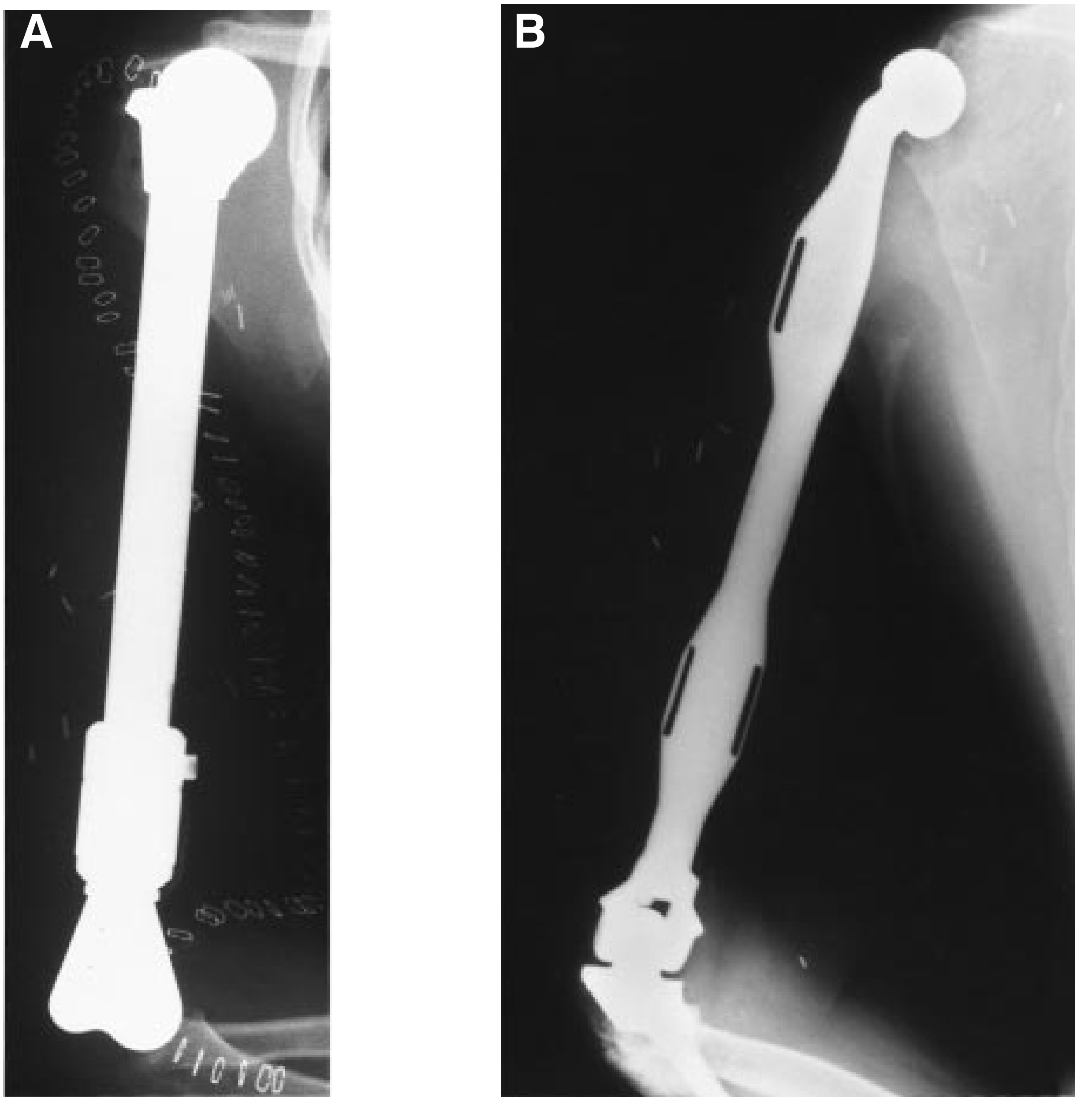


Figure 9.12 Total humeral prosthesis. (**A**) An expandable total prosthesis utilized in a 6-year-old child for a diaphyseal osteosarcoma. (**B**) A solitary total humerus with an elbow joint utilized in a skeletally mature adolescent.

of the shoulder girdle. For large tumors of the proximal humerus a venogram may also be a useful study if there is evidence of distal obstruction suggesting intravascular tumor thrombus (analogous to tumor thrombi seen in the iliac vessels from large pelvic sarcomas).

Physical Examination

The physical examination is important in determining tumor extension into the glenohumeral joint, neurovascular involvement, or tumor invasion of the chest wall. If tumor has invaded the joint, shoulder range of motion is generally reduced and the patient may complain about discomfort and pain. Neurovascular involvement or compression may be suggested by an abnormal neurovascular exam or by decreased or absent pulses. Tumors that move freely with respect to the chest wall are usually separated from it by at least a thin tissue plane through which it is safe to dissect (Figures 9.14 and 9.15A).

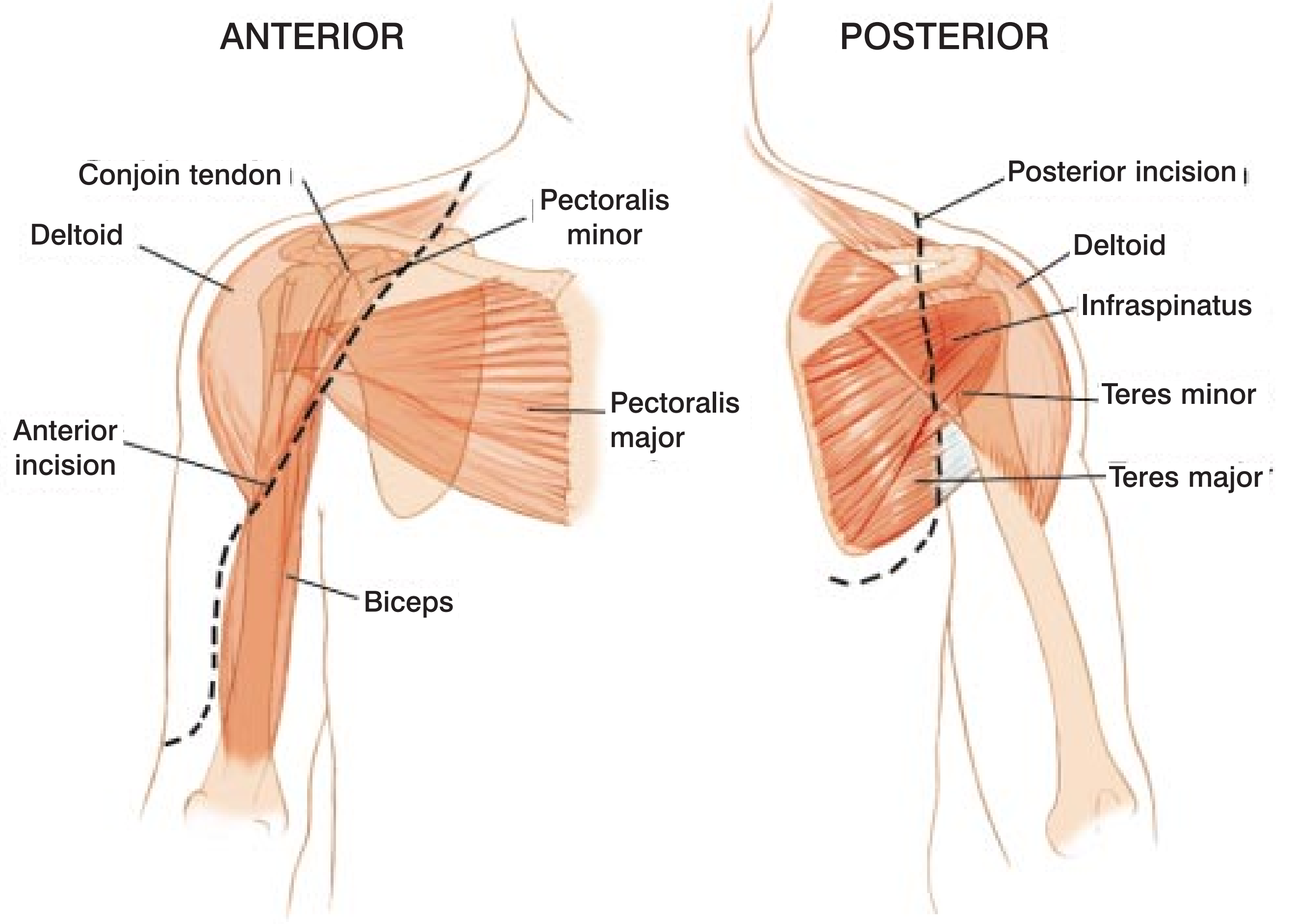


Figure 9.13 Utilitarian shoulder incision used by the authors for exposure of the proximal humerus, scapula, and/or shoulder girdle.

Imaging Studies

These are extremely important in determining the exact anatomic location and extent of tumor involvement. The specific information gained from each modality is as follows:

Bone scan

This study helps determine intraosseous tumor extent and detects metastases. It may also indicate rib involvement or extension of the tumor across the joint with further invasion of the adjacent bone. The blood flow portion (three-phase study) helps determine tumor vascularity.

MRI

This scan is useful to determine the extent of soft-tissue involvement and tumor extension into the joint or chest wall. It is especially useful in evaluating tumors of the suprascapular region that may extend below the subscapularis muscle and exit near the coracoid. The location of vessels, which directly correlates to the position of the nerves, can also be visualized. The intraosseous tumor extent can also be evaluated, and this is necessary for determining the location of required bone resection. All three planes should be examined. MRI has not been reliable in determining tumor response to induction chemotherapy (Figure 9.15).

CT

CT is considered complementary to MRI in evaluating the chest wall, clavicle, and axilla. Compared with MRI it is more useful in determining cortical bone changes or destruction, and is more reliable in determining the bone response and effects of induction chemotherapy (Figure 9.9).

Figure 9.14 Macrospecimen following resection of osteosarcoma of the proximal humerus. Note that the tumor is filling up the intramedullary canal as well as a small soft-tissue component projecting laterally. Ninety-five percent of osteosarcomas have extraosseous components.

Angiography

Although vessels can be visualized using MRI, arteriography remains the most useful study for determining the relationship of the tumor to the brachial plexus and vessels, as well as depicting the exact level of the circumflex vessels and any anatomic variants or anomalies. This is also the most useful study in predicting the tumor response to induction chemotherapy. Tumor necrosis is directly related to the decrease or absence of tumor vascularity.

DETERMINING RESECTABILITY OF SHOULDER GIRDLE TUMORS

High-grade tumors arising from the shoulder girdle region are frequently large and encroach upon the neurovascular bundle. Tumors that encase or invade the brachial plexus are considered unresectable. It is difficult to clinically determine which tumors are unresectable. Based on our experience we have found the clinical triad of intractable pain, motor deficit, and venogram showing obliteration of the axillary vein to be very reliable in predicting brachial plexus invasion. There is no single imaging study that accurately visualizes the brachial plexus. MRI and CT scans typically show a large tumor juxtaposed to the neurovascular bundle. Venography, however, is extremely accurate in predicting brachial plexus invasion. The axillary vein, axillary artery and brachial plexus travel in intimate association within a single fascial sheath (axillary sheath). The major nerves and cords form the periphery of the sheath; therefore only obliteration (not just compression) of the brachial or axillary vein denotes direct tumor extension in and around the nerves. This indicates secondary involvement of the venous wall. This progression also explains the clinical triad of pain, motor loss, and venous obstruction. Tumors that invade or encase the brachial plexus obliterate the axillary vein because of its thin walls and low intraluminal pressure. In these instances arteriography demonstrates displacement of the axillary artery; however, the axillary artery remains patent because of its thick walls and high intraluminal pressures. The final decision, however, regarding the need for a forequarter amputation should be reserved until surgical exploration of the brachial plexus has been performed.

Biopsy Technique

The biopsy site should be carefully selected. It should be located away from the major vessels and nerves and placed so that it can be widely excised by the definitive resection. Inadvertent contamination of the neurovascular structures or the chest wall must be avoided. Sarcomas of the shoulder girdle rarely require an open biopsy. The majority of sarcomas in this location have an extraosseous (soft-tissue) component; therefore, a small-needle or core biopsy should be performed (Figure 9.16).

All fine-needle or core biopsies should be performed under fluoroscopic or CT guidance unless a mass is easily palpable and located away from the neurovascular bundle. Only one puncture site is required. The needle is then reintroduced through the same puncture site, but the angle is varied so that cores can be obtained from several different regions of the tumor. Touchpreps and frozen sections are performed at the time of biopsy to confirm that adequate intralesional tissue has been obtained for diagnosis. Cultures are routinely obtained, irrespective of the suspected diagnosis, because an infection may simulate any malignancy.

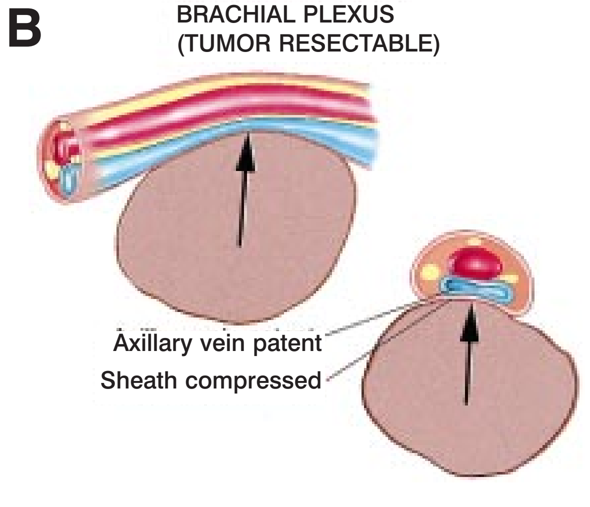
Proximal Humerus

Needle or incisional biopsies of tumors of the proximal humerus should be performed through the anterior one-third of the deltoid muscle, not through the deltopectoral interval. 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 biopsy hematoma are easily removed at the definitive resection. A biopsy through the deltopectoral interval will contaminate the pectoralis muscle which is necessary for reconstruction and increase the risk that a hematoma may spread along the brachial vessels to the chest wall, making 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.

Scapula

Biopsies of the scapular body are more difficult to perform than biopsoes of the proximal humerus; however, they are crucial in determining the final operative procedure. The biopsy site should be along the intended incision site of the resection. A posterior needle biopsy is recommended for tumors arising within the body of the scapula; the anterior approach should be avoided.



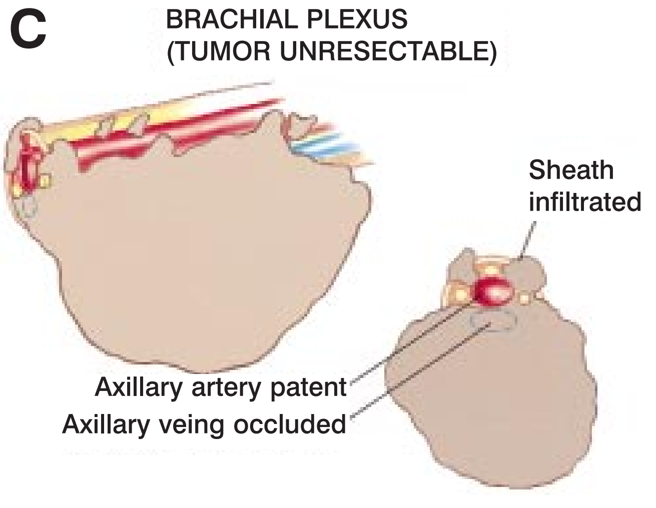


Figure 9.15 (**A**) MRI of a typical osteosarcoma of the proximal humerus. Note the involvement of one-third of the proximal humerus with a large extraosseous component below the deltoid muscle. CT and MRI are used concurrently to determine the bony and soft-tissue details when evaluating sarcomas. The deltoid muscle and the axillary nerve are often resected when performing a limb-sparing procedure. (**B**) Schematic demonstrating a resectable tumor. The tumor is compressing and displacing the neurovascular bundle; however, there is no invasion or encasement. This situation most commonly arises in the treatment of a sarcoma. An arteriogram and venogram would show patency of the axillary artery and vein. (**C**) Schematic demonstrating an unresectable tumor. The tumor is infiltrating the neurovascular structures and obliterating the axillary vein. Venography would show an obliterated axillary vein. Arteriography would show a displaced but patent axillary artery.

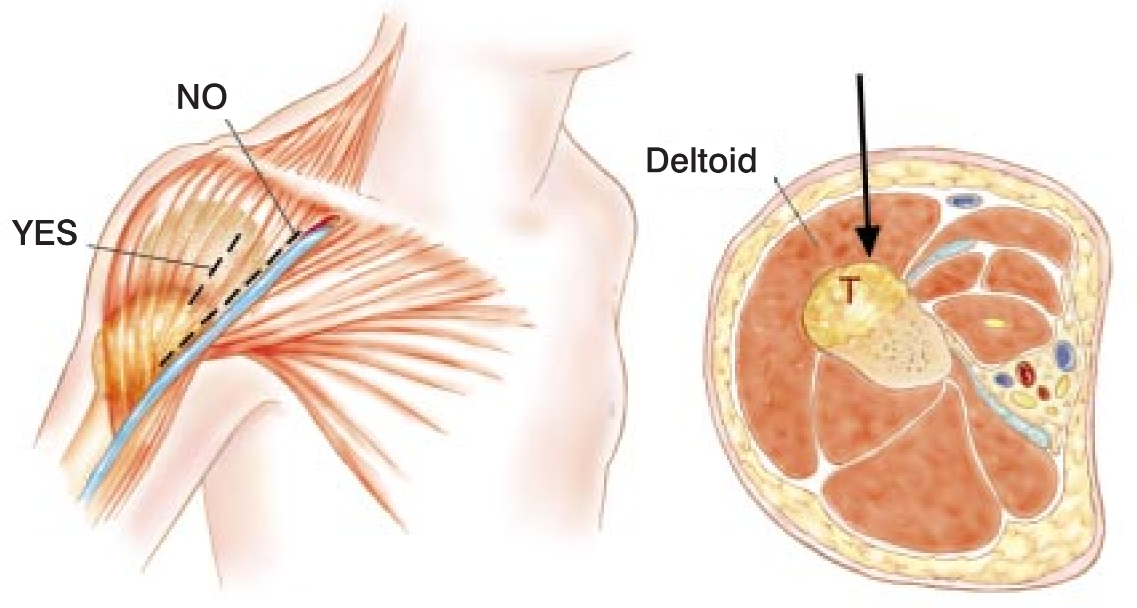


Figure 9.16 Schematic diagram of biopsy technique for tumors of the proximal humerus. The biopsy should be performed through the anterior one-third of the deltoid. The deltopectoral groove must be avoided. A core biopsy is recommended. An open biopsy should be performed only if a core needle biopsy is nondiagnostic.

Biopsies of tumors in the lateral aspect of the scapula or glenoid region should be performed along the lateral or axillary aspect of the scapula, directly through the posterior deltoid and teres minor.

Clavicle

Unless a soft-tissue component is present, a small open biopsy of the clavicle is advisable. A needle may injure the underlying neurovascular structures. Biopsies of the clavicle are done through an incision that is parallel to the long axis of the clavicle. Care should be taken not to dissect circumferentially around the clavicle. As with all incisional biopsies, hemostasis needs to be obtained before closing the biopsy incision.

SURGICAL AND ANATOMIC CONSIDERATIONS

A limb-sparing procedure involving the shoulder girdle is more difficult than a forequarter amputation. The surgical options are technically demanding and are fraught with potential complications. The local anatomy of the tumor often determines the extent of the required resection. One should be experienced with all aspects of shoulder girdle anatomy and familiar with several unique anatomic considerations.

"FUNCTIONAL COMPARTMENT" OF THE SHOULDER (Figure 9.17A–C)

Sarcomas grow locally in a centripetal manner and compress surrounding tissues (muscles) into a pseudocapsular layer. The pseudocapsular layer contains microscopic finger-like projections of tumor referred to as satellite nodules. Sarcomas spread locally along the path of least resistance. Surrounding fascial layers resist tumor penetration and therefore provide boundaries to local sarcoma growth. These boundaries form a compartment around the tumor. A sarcoma will grow to fill the compartment in which it arises, and only rarely will an extremely large sarcoma extend beyond its compartmental borders. In discussing bony sarcomas that extend beyond the cortices into the surrounding soft tissues, a functional anatomic compartment refers to the investing muscles that are compressed into a pseudocapsular layer. These muscles provide the fascial borders of the compartment that has important surgical implications. A wide resection of a bone sarcoma removes the entire tumor and pseudocapsular layer and must therefore encompass the investing muscle layers (compartmental resection).

The functional compartment surrounding the proximal humerus consists of the deltoid, subscapularis and remaining rotator cuff, latissimus dorsi (more distally), brachialis, and portions of the triceps muscles. The

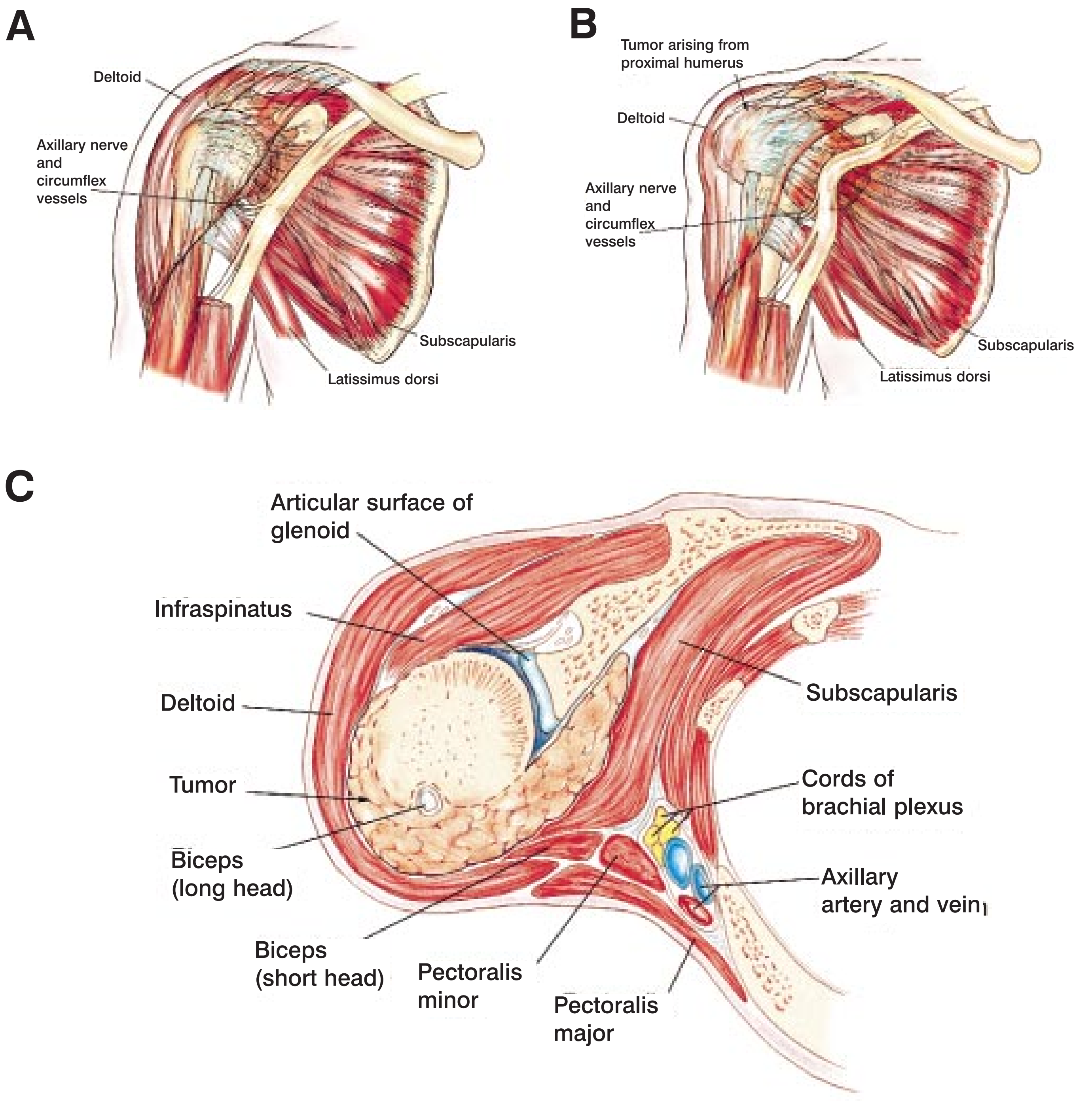


Figure 9.17 *(see above and following page).*

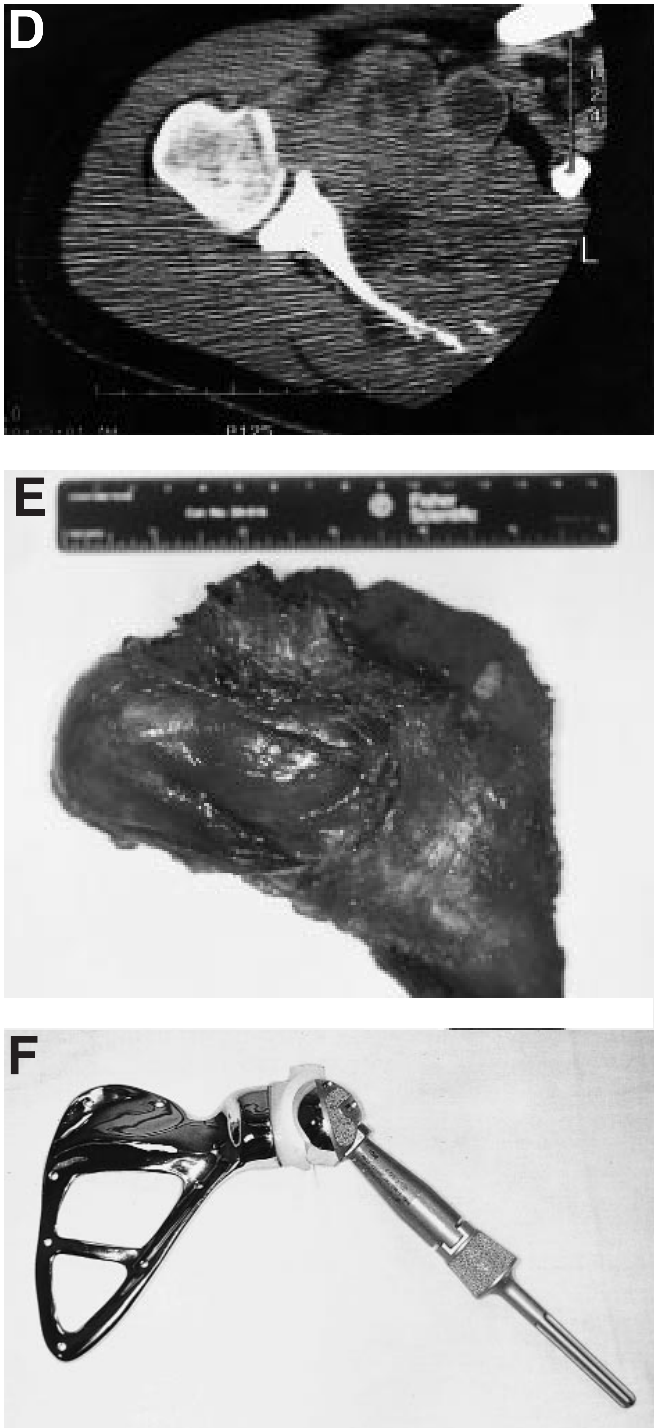


Figure 9.17 Functional anatomic compartment of the proximal humerus. (**A**) The proximal humerus is surrounded by the subscapularis and latissimus dorsi anteromedially, the deltoid laterally, and the remaining rotator cuff superiorly and posteriorly. These muscles form a functional anatomic compartment surrounding the proximal humerus. The only neurovascular structures that enter this compartment are the humeral circumflex vessels and the axillary nerve. (**B**) Schematic showing the local growth of a high-grade spindle cell sarcoma arising from the proximal humerus. High-grade sarcomas most commonly penetrate the bony cortices of the proximal humerus and compress the surrounding muscles into a pseudocapsular layer. The surrounding muscle fascia poses a barrier to tumor extension and contains the tumor within the functional anatomic compartment surrounding the shoulder. The deltoid, subscapularis, and infraspinatus muscles are compressed into a pseudocapsular layer. The glenoid and lateral scapula are also contained within this compartment. High-grade sarcomas grow centripetally and will follow the fascial borders of the compartment to the opposing glenoid surface. (**C**) Cross-section of the glenohumeral joint demonstrating a high-grade sarcoma arising from the metaphyseal region of the proximal humerus. The deltoid, subscapularis, and infraspinatus muscles contain the tumor. The subscapularis muscle protects the neurovascular structures (i.e. axillary vessels and brachial plexus) from tumor involvement, thus permitting limb-sparing resection in most cases (arrow). Tumors that protrude beyond the bony cortices extend along the capsule and rotator cuff muscles to the opposing glenoid and scapula. (**D**) CT scan demonstrating marked destruction of a scapula secondary to a Ewing's sarcoma. There is tumor involvement of the glenohumeral joint. A Type IV (Tikhoff–Linberg) resection was performed following induction chemotherapy. (**E**) Gross specimen showing the scapula covered by its adjacent musculature. (**F**) A modern scapula prosthesis that can be mated to a proximal humeral component (Howmedica, Inc.) This is a newer design of the scapular prosthesis that has holes along the glenoid as well as the vertebral and axillary borders for reattachment of the shoulder girdle musculature with 3-mm Dacron tape. The capsular mechanism is reconstructed with a Gore-tex® graft.

glenoid and scapular neck also reside within the functional compartment of the proximal humerus since they are contained by the rotator cuff and capsule and the subscapularis muscle. Sarcomas that arise from the proximal humerus and extend beyond the cortices compress these muscles into a pseudocapsular layer. The fasical layers surrounding these muscles resist tumor penetration. The only neurovascular structures that enter this compartment are the axillary nerve and humeral circumflex vessels. The main neurovascular bundle (brachial plexus and axillary vessels) to the upper extremity passes anterior to the subscapularis and latissimus dorsi muscles. These muscles and their investing fascial layers are therefore particularly important for protecting the neurovascular bundle from tumor involvement. They also protect the pectoralis major muscle that must be preserved during surgical resection for soft tissue coverage.

High-grade sarcomas that extend beyond the bony cortices of the proximal humerus expand the investing muscles that form the compartmental borders and pseudocapsular layer. They grow along the path of least resistance and therefore are directed toward the glenoid and scapular neck by the rotator cuff and glenohumeral joint capsule. Anteriorly, the tumor is covered by the subscapularis that bulges into and displaces the neurovascular bundle. Only rarely will a very large proximal humerus sarcoma extend beyond the compartmental borders. In these instances the tumor usually protrudes through the rotator interval. A wide (compartmental) resection for a high-grade sarcoma must therefore include the surrounding muscles that form the pseudocapsular layer (deltoid, lateral portions of the rotator cuff), the axillary nerve, humeral circumflex vessels and the glenoid (extra-articular resection of the proximal humerus).

Most high-grade scapular sarcomas arise from the region of the scapular neck. The compartmental borders surrounding the scapula neck consist of the rotator cuff muscles and portions of the teres major and latissimus dorsi muscle. The compartment consists of all of the muscles that originate on the anterior and posterior surfaces of the scapula; the subscapularis, infraspinatus, and teres muscles. The deltoid, although not one of the compartmental borders, since it attaches to a narrow region of the scapular spine and acromion, may be involved secondarily by a large soft-tissue extension. In most instances the deltoid is protected by the rotator cuff muscles because of the anatomic origin of most tumors from the neck region. Similar to the proximal humerus, the rotator cuff muscles are compressed into a pseudocapsular layer by sarcomas that arise from the scapula. The subscapularis also protects the neurovascular bundle from tumor involvement. The head of the proximal humerus is contained within the compartment surrounding the scapula by the rotator cuff muscles. Wide resection of a high-grade scapular sarcoma must therefore include the rotator cuff and, in most instances, the humeral head. The axillary nerve is not contained within the compartment and therefore can be spared from resection. Additionally, because the deltoid is not compressed into a pseudocapsular layer, it can usually be preserved.

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.[16,17] Pericapsular and rotator cuff involvement occurs early and must be evaluated.

Glenohumeral Joint

The shoulder joint appears to be more prone to intra-articular or pericapsular involvement by high-grade bone sarcomas than are other joints. There are several mechanisms for tumor spread: direct capsular extension, tumor extension along the long head of the biceps tendon, fracture hematoma from a pathologic fracture, or poorly planned biopsy. These mechanisms make patients who undergo intra-articular resections for high-grade sarcomas at greater risk for local recurrence than those undergoing extra-articular resections. Therefore, it is often necessary to perform an extra-articular resection for high-grade bone sarcomas of the proximal humerus or scapula.

Neurovascular Bundle

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 (i.e. the neurovascular bundle). Large tumors involving the upper scapula, clavicle, and proximal humerus may displace the infraclavicular components of the plexus, which may necessitate sacrifice of some of the major nerves.

Musculocutaneous and Axillary Nerves

These two nerves are often in close proximity to or in contact with tumors around the proximal humerus. The musculocutaneous nerve is the first nerve to leave the brachial plexus. It typically leaves the lateral cord just distal to the coracoid process, passes through the coracobrachialis, and runs between the brachialis and biceps. It should be preserved, if possible, to maintain normal elbow function. The path of this nerve may vary extensively (within 6–8 cm of the coracoid). It should be identified prior to any resections because it can be easily injured at any of these locations.

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 passes between the teres major and minor to innervate the deltoid muscle posteriorly. Tumors of the proximal humerus are most 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 are almost always sacrificed when the proximal humerus is resected.

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 once it passes the inferior border of the axilla. It is surrounded by the three cords of the brachial plexus and 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 distal brachial artery and vein to fall away from the tumor mass. Occasionally, there is anatomic variability in the location of its branches that would lead to difficulty in identification and exploration if not previously recognized. A preoperative angiogram can help determine vascular displacement and anatomic variability.

Scapula (Figure 9.17D–F)

Tumors of the scapula often become quite large before being diagnosed. In their early stages, tumors arising in the body of the scapula are surrounded by a cuff of muscle in all dimensions. Important areas to evaluate are the chest wall, axillary vessels, proximal humerus and rotator cuff, and periscapular tissue.

Glenohumeral Joint

Sarcomas arising from the glenoid or scapular neck usually involve the joint and adjacent capsule. Therefore, an extra-articular resection through both anterior and posterior approaches (see Surgical Techniques section) should be performed for tumors in this location.

Neurovascular Involvement

As sarcomas of the scapula enlarge, they may produce a large axillary component and involve the axillary vessels and brachial plexus. When there is a large anterior extraosseous mass, anterior exploration of the neurovascular bundle should be performed to determine resectability or facilitate an extra-articular resection.

Lymph Nodes

The axillary and supraclavicular lymph nodes should be carefully examined preoperatively. Lymph node biopsy may be necessary to determine resectability.

Suprascapular Tumors (Figure 9.20)

This is a difficult area to evaluate by physical exam and even with modern imaging techniques. Large tumors in this location often extend into the anterior and posterior triangles of the neck, making resection difficult or contraindicated, except for purposes of palliation.

SURGICAL TECHNIQUES

See Chapters 33 and 34 .

ENDOPROSTHETIC RECONSTRUCTION

Endoprosthetic reconstruction was developed in the 1940s (Figure 9.18). Initially, attention focused on reconstruction of skeletal defects of the lower extremity. Use of the technique was gradually broadened to include defects of the upper extremity and shoulder girdle. Marcove[18] and Francis[19] performed some of the first resections for high-grade sarcomas in this location in the late 1960s and 1970s. During the early 1980s all prosthetic replacements were custom-made for each patient. In 1988 a modular replacement system (MRS), that obviates the need for custom devices, was developed by Howmedica, Inc. (Rutherford, NJ) (Figure 9.19).

The MRS has undergone several design changes and improvements since that time. The present components for proximal humerus and scapular replacement are shown in. The MRS is used in conjunction with both intra- and extra-articular resections, and results are highly predictable and successful. Reported rates of fracture, infection, nonunion, reoperation, and tumor recurrence are lower, and time of immobilization is shorter with endoprosthetic reconstruction than with allograft, composite reconstruction, or arthrodesis. Survival of the MRS proximal humeral prosthesis is reported to be 95–100% at 10 years (Figure 9.20).[20]

Design Features: Proximal Humeral Endoprosthesis

1. Modular components, including stem, body, and humeral head.
2. Polished intramedullary stems for cement fixation available in multiple diameters and lengths.
3. Facing reamer to create a perfect "seat" for the stem–bone interface that protects the stem from bending stresses.

4. Porous coating (circumferential) at the prosthesis–bone junction for ingrowth of extracortical bone graft and soft tissue to seal the bone–cement–stem interface. Incorporation of extracortical bone graft also protects the prosthetic stem by sharing bending and loading stresses.
5. Humeral heads (available in two sizes) with porous coating and metal loops or holes to facilitate muscle and tendon attachment and soft-tissue ingrowth.

Design Features: Scapular Replacement Prosthesis

1. Nonconstrained or semiconstrained design.
2. Holes along the periphery of the prosthetic scapular body for reattachment of the scapular stabilizing muscles (levator scapulae, rhomboids, and trapezius muscles).
3. Holes along the base of the prosthetic scapular neck for capsular reconstruction with native capsule or Gore-Tex aortic graft.

Figure 9.18 (**A**) The original custom prosthesis utilized during the 1960s as developed by Howmedica, Inc. (**B**) Plain radiograph of the proximal humerus modular replacement system that has been in use in the United States since 1988. A modular system consists of three components: the head, body, and stem.

FUNCTIONAL AND REHABILITATION CONSIDERATIONS

Patients undergoing shoulder girdle resections retain hand and elbow function, but lose shoulder motion. The goal of shoulder girdle reconstructions is to provide a stable shoulder that allows positioning of the arm and hand in space, thereby preserving function. The functional and cosmetic outcome is superior to that of a forequarter amputation.

Proximal Humeral Resections

Function

The goal is to obtain a stable shoulder girdle with preservation of full elbow, wrist, and hand function. Shoulder stability is obtained by multiple muscle transfers and reconstruction. Shoulder motion is dependent upon the type of resection required (Type I or V) and the preserved soft tissues. Some shoulder motion is expected, but shoulder abduction is usually extremely limited unless the axillary nerve and deltoid muscle have been preserved. Most patients regain full

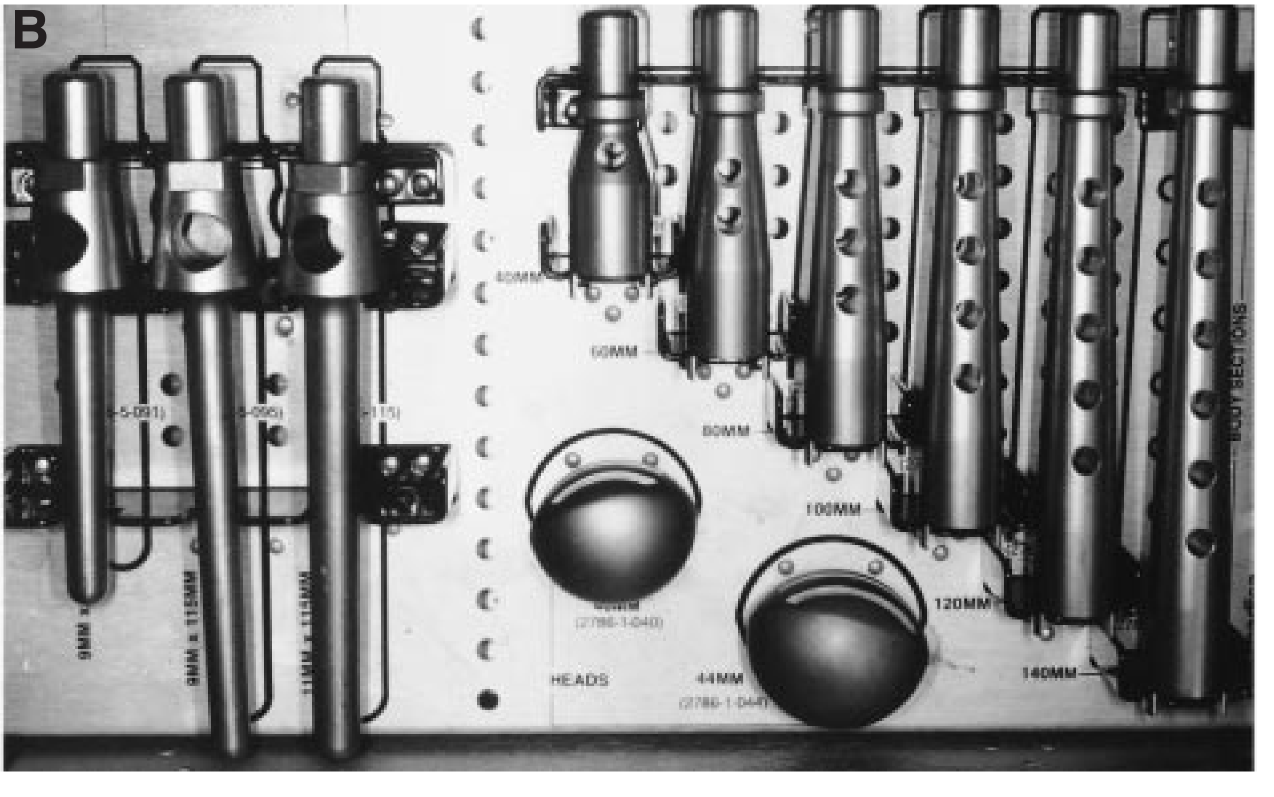


Figure 9.19 (**A**) Modular replacement system showing the various sizes for the proximal humerus. (**B**) The large holes within the body and the stems indicate these components are trial components.

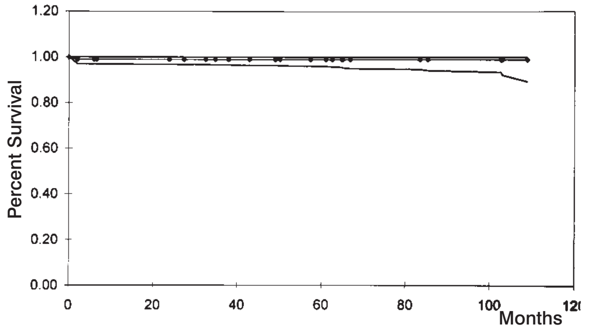


Figure 9.20 Kaplan–Meier curve of 23 proximal humeral prostheses performed for reconstruction following extra-articular resection (Type V) for high-grade osteosarcomas. There has been no prosthetic loosening and the actuarial prosthetic survival rate is 100% at 100 months.

internal and external rotation, flexion and extension of 30–50 degrees, and 10–30 degrees of active abduction.

Patients who undergo proximal humeral resections generally regain normal elbow and hand function.

Rehabilitation

The rehabilitation process begins with a preoperative patient orientation program that often gives the patient the opportunity to meet someone who has undergone a similar procedure, to discuss the perioperative course and demonstrate the expected functional and cosmetic outcome.

A sling is applied in the operating room to provide shoulder and arm support and restrict motion. Edema is controlled with elevation and a compression wrap or stocking. In the immediate postoperative period the patient is instructed on motion exercises for the wrist and hand, and elbow flexion is encouraged within the confines of the sling. Neck motion and shoulder elevation exercises are instituted within 1–2 days following surgery.

Once the incision has healed and the sutures are removed, at 2–4 weeks after surgery, shoulder exercises and elbow extension are begun. Pendulum exercises and gentle shoulder motion (flexion, extension, internal and external rotation) are done with the help of a family member or physical therapist. Elbow flexion, extension, supination and pronation are also performed. The sling is removed for therapy but is subsequently reapplied to provide support until shoulder girdle stability and arm strength are improved. Gentle strengthening is instituted once motion has returned, with the use of active motion and isometric exercises and light weights (2–10 pounds).

Normal daily activities are encouraged, but weights in excess of 20 pounds should not be lifted with the reconstructed extremity.

Total Humeral Resections

The unique postoperative considerations following total humeral replacement are the potential for arterial occlusion or thrombus and nerve compression or neuropraxia. Postoperative edema may be more severe and may require a compressive stocking for control. A sling is required for a longer period of time than following proximal humeral resections to allow for healing of the soft tissue of the shoulder girdle and elbow joint. Fortunately, for true diaphyseal tumors, most of the musculature about the shoulder girdle and elbow can be preserved, thereby allowing shoulder stability and normal elbow function.

Scapular Resections

Function

There is minimal functional loss following partial scapular resections (Type II), shoulder motion and strength are almost normal. Total scapular resections (Types III and IV) result in significant loss of shoulder motion, predominantly shoulder abduction. If a prosthesis is utilized, abduction to 60–90° can be obtained. Elbow and hand function should be normal, again depending on the extent of the resection and remaining nerves. Soft-tissue reconstruction is the key to establishing shoulder stability and obviating the need for an external orthosis.

Rehabilitation

A sling is required for approximately 2–4 weeks to allow healing of the transferred muscles, which provide the stabilizing force to the upper extremity. A compression arm stocking may be required to prevent swelling in the immediate postoperative period. Motion of the hand and wrist, and elbow flexion, are encouraged in the immediate postoperative period. Elbow extension and shoulder motion are initiated after the incision has healed, approximately 2–4 weeks after surgery. Gentle motor strengthening is begun approximately 6 weeks after surgery, with the goal of strengthening the pectoralis major, latissimus dorsi, trapezius, and other scapular stabilizers. Cosmetic appearance is markedly improved following prosthetic replacement of the scapula compared to those patients left without a scapula reconstruction. In addition, abduction and external rotation is partially restored.

References

1. Rosenberg SA, Suit FD, Baker LH. Sarcomas of soft tissue. In: Devita VT, Hellman S, Rosenberg SA, editors. Cancer: Principles and Practice of Oncology, 2nd edn. Philadelphia: JB Lippincott; 1985:1243–93.
2. Dahlin DC. Bone Tumors: General Aspects and Data on 6,221 Cases, 3rd edn. Springfield: Charles C Thomas; 1978.
3. Linberg BE. Interscapulo-thoracic resection for malignant tumors of the shoulder girdle region. J Bone Joint Surg. 1928;10:344.
4. Liston R. Ossified aneurysmal tumor of the subscapular artery. Eduil Med J. 1820;16:66–70.
5. Mussey RD. Removal by dissection of the entire shoulder blade and collar bone. Am J Med Sci. 1837;21:390–4.
6. Syme J. Excision of the Scapula. Edinburgh: Edmonston and Douglas; 1864.
7. Pack GT, Baldwin JC. The Tikhoff–Linberg resection of the shoulder girdle. Case report. Surgery. 1955;38:755–7.
8. Pack GT, Crampton RS. The Tikhoff–Linberg resection of the shoulder girdle. Clin Orthop. 1961;19:148–61.
9. Guerra A, Capanna R, Biagini R *et al*. Extra-articular resection of the shoulder (Tikhoff–Linberg). Ital J Orthop Traumatol. 1985;11:151–7.
10. Marcove RC. Neoplasms of the shoulder girdle. Orthop Clin N Am. 1975;6: 541–52.
11. Marcove RC, Lewis MM, Huvos AG. En-bloc upper humeral interscapulothoracic resection. The Tikhoff–Linberg procedure. Clin Orthop. 1977;124:219–28.
12. Papioannou AN, Francis KC. Scapulectomy for the treatment of primary malignant tumors of the scapula. Clin Orthop. 1965;41:125.
13. Baumann PK. Resection of the upper extremity in the region of the shoulder joint. Khirurgh Arkh Velyaminova. 1914;30:145.
14. Samilson RL, Morris JM, Thompson RW. Tumors of the scapula. A review of the literature and an analysis of 31 cases. Clin Orthop. 1968;58:105–15.
15. Malawer MM. Tumors of the shoulder girdle: technique of resection and description of a surgical classification. Orthop Clin N Am. 1991;22:7–35.
16. Malawer MM, Link M, Donaldson S. Sarcomas of Bone. In: Devita VT, Hellman S, Rosenberg SA, editors. Cancer: Principles and Practice of Oncology, 3rd edn. Philadelphia: JB Lippincott; 1984:1418–68.
17. Malawer MM, Sugarbaker PH, Lambert MH *et al*. The Tikhoff–Linberg procedure and its modifications. In: Sugarbaker PH, editor. Atlas of Sarcoma Surgery. Philadelphia: JB Lippincott; 1984:000–00.
18. Marcove RC. Neoplasms of the shoulder girdle. Orthop Clin N Am. 1975;6:541–52.
19. Francis KC, Worcester JN. Radical resection for tumors of the shoulder with preservation of a functional extremity. J Bone Joint Surg (Am). 1962;44;1423–30.
20. Henshaw RM, Jones V, Malawer MM. Endoprosthetic replacement with the modular replacement system: survival analysis of the first 100 implants with a minimum 2-year follow-up. Presented at the Combined Meeting of the American and European Musculoskeletal Tumor Societies, 6–10 May, 1998; Washington, DC.