# 9 Surgical Approach: Limb Salvage Versus Amputation

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**Abstract**

Major advances have been made in the last 30 years in the treatment of pediatric bone sarcomas. Chemotherapy has been credited with the largest advance in overall survival (from 20–30 % to 60–70 %), but increased expertise in surgical techniques, advanced imaging, and reconstructive options have also had major impact in the area of limb salvage (Weisstein et al. 2005). The surgical decisions in this setting are complex with many intricacies that come in to play. Treatment algorithms should be prioritized by the patient's overall survival first, then the salvage of the limb. Two key principles must always be remembered: the limb salvage procedure should not result in a worse survival for the patient and the function of the limb should be acceptable. Consideration of limb function, appearance, and length must



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be included in the decision of whether to attempt limb salvage versus amputation. Social and financial factors also play a role. The interests and potential future vocation of the patient must be considered, which may not be known in the young patient (Choong and Sim 1997). The goal of this chapter is to outline the approach and surgical considerations when deciding limb salvage and amputation in the setting of pediatric bone sarcoma.

## 9.1 Introduction

Major advances have been made in the last 30 years in the treatment of pediatric bone sarcomas. Chemotherapy has been credited with the largest advance in overall survival (from 20–30 % to 60–70 %), but increased expertise in surgical techniques, advanced imaging, and reconstructive options have also had major impact in the area of limb salvage (Weisstein et al. 2005). The surgical decisions in this setting are complex with many intricacies that come in to play. Treatment algorithms should be prioritized by the patient's overall survival first, then the salvage of the limb. Two key principles must always be remembered: the limb salvage procedure should not result in a worse survival for the patient and the function of the limb should be acceptable. Consideration of limb function, appearance, and length must be included in the decision of whether to attempt limb salvage versus amputation. Social and financial factors also play a role. The interests and potential future vocation of the patient must be considered, which may not be known in the young patient (Choong and Sim 1997). The goal of this chapter is to outline the approach and surgical considerations when deciding limb salvage and amputation in the setting of pediatric bone sarcoma.

General principles of the resection for limb salvage include an extensile longitudinal approach that allows for resection of the biopsy tract and adequate exposure of the adjacent neurovascular bundles. The goal of resection is to perform a "wide resection," which by definition leaves a cuff of normal tissue around the mass. Reconstruction options for large skeletal defects must be available, and adequate soft tissue coverage for closure is of vital importance (DiCaprio and Friedlaender 2003).

### 9.1.1 Timing of Local Control

The timing, when local control in the form of surgical resection is performed, should be individualized based on the patient presentation, diagnosis, and stage of disease. Most centers utilize standard protocols from co-operative groups, such as Children's Oncology Group (COG), which generally call for a period of neoadjuvant chemotherapy prior to surgical resection of the mass. Interestingly, this approach was constructed as the concept of limb salvage was being developed. Before modern modular prosthetic components were available for widespread use, when a patient required a megaprothesis for limb salvage there was often a delay of 6–12 weeks for the device companies to manufacture the implant required. Chemotherapy was initiated during this delay and several advantages of this approach were discovered. First, micrometastatic disease is treated immediately, potentially decreasing early development of drug-resistant clones (Jaffe 2014). Secondly, the period of neoadjuvant treatment allows the surgeon to appropriately plan the procedure and have multiple discussions with the family regarding treatment options. Third, the initial response to chemotherapy may affect the local control approach. Patients may see their tumor progress, shrink, or they may develop metastatic disease, all of which could change options available for surgery. And lastly, systemic treatment up front allows histologic evaluation of the resected tumor, and the percent of tumor necrosis in the case of osteosarcoma correlates with overall survival (Fig. 9.1).

One additional scenario that deserves discussion is the presence of pathological fracture. The occurrence of a pathologic fracture, either at presentation or during induction chemotherapy, was traditionally treated with immediate amputation. However, it has now been established that although overall survival is worse in these patients (55 % compared to almost 80 %), limb salvage can still be performed in select cases in which negative surgical margins can be achieved (Scully et al. 2002).

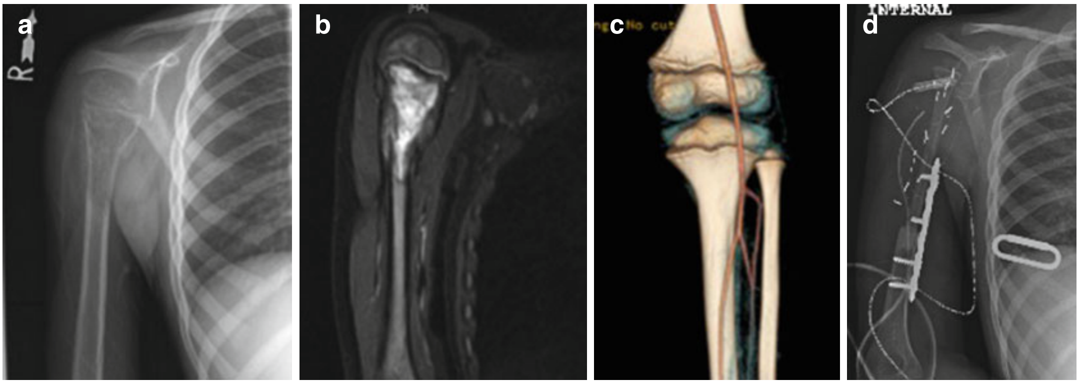


**Fig. 9.1** Pre-operative x-ray (**a**) and MRI (**b**) demonstrating an aggressive sarcoma of the proximal humerus in a 5-year-old boy. A vascularized fibula (**c**) was harvested and used to reconstruct the proximal humerus (**d**)

### 9.1.2 Role of Skeletal Maturity

One of the major differences when considering limb salvage versus amputation in the pediatric population is the growth potential in terms of skeletal maturity. Skeletal maturity (as defined by closure of the growth plates) is gender dependent but is generally not reached until the age of 16–18 years. The most common locations for the development of osteosarcoma include the areas of rapid bone growth (distal femur, proximal tibia, proximal humerus). Therefore, the younger the child is at the time of diagnosis, the more growth that must be accounted for in the surgical decision and reconstruction. In general, the younger (and smaller) the patient, the more difficult limb salvage is to achieve and the worse the morbidity (Guillon et al. 2011). Additional factors that play a role in the decision to perform limb salvage in the skeletally immature patient include size of the resection and tumor, size of available implants, other reconstructive options, size of soft tissue envelope, and potential for lengthening after index procedure.

## 9.2 Indications and Contraindications for Limb Salvage

With current treatment approaches, limb salvage can generally be offered in 90 % of cases (Wilkins et al. 2005). General indications include isolated disease, a good response to chemotherapy, and no involvement of the adjacent neurovascular structure. There are really no absolute contraindications to limb salvage, but the overall function of the limb should always be considered and several relative contraindications have been defined. These contraindications to limb salvage include progression during chemotherapy, encasement of neurovascular structures, the very skeletally immature patient, and sometimes pathologic fracture resulting in a high degree of local tissue contamination. Another consideration should be minimizing the time to resumption of chemotherapy after the local control surgery. Outcome data suggest that systemic therapy should be resumed within 6 weeks of surgery to maximize survival for the patient. Therefore, attempts to minimize infection and wound complications should be paramount. Judicious use of flaps for wound coverage, minimizing operative time, and pre-surgical optimization of blood counts should all be employed to minimize the time the patient will be off systemic treatment.

## 9.3 Reconstructive Options

Once the decision to proceed with limb salvage has been made, there are multiple potential options available for the reconstruction. When the tumor is present in an expendable bone, local control can be achieved with resection without reconstruction. Locations amenable to this

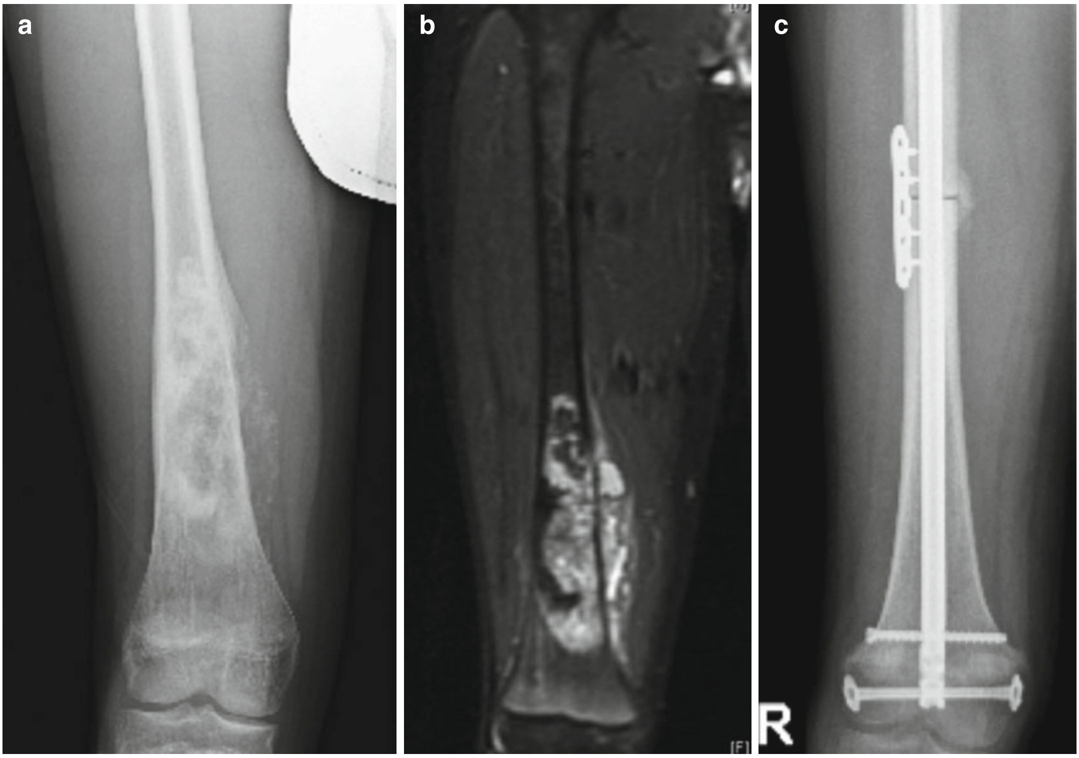


**Fig. 9.2** Pre-operative x-ray (**a**) and MRI (**b**) showing an osteosarcoma of the distal femur. Intercalary physeal sparing allograft was used to reconstruct the defect (**c**)

include the fibula, portions of the pelvis and sacrum, and portions of the ulna. Outside of these select areas reconstruction is usually required.

### 9.3.1 Autograft

The use of autografts in reconstruction for structural defects is fairly limited. The most common indication utilizes the fibula, either in a vascularized or non-vascularized fashion. The mid-portion of the fibula can serve as a structural strut, and has been described in combination with an allograft to promote healing (Li et al. 2011). Vascularized fibular graft has also been described for reconstruction of intercalary resections of long bones (tibia, femur, humerus) (Chen et al. 2007). Another potential indication exists in the very young child (<8 years old) with a malignant proximal humerus tumor. Skeletal growth is an issue, and the proximal fibular epiphysis can be harvested on a vascularized pedicle for reconstruction in an attempt to maintain some growth in the limb (Fig. 9.2).

### 9.3.2 Allografts

Prior to the advent and development of metallic prosthesis in the last 30 years, allograft reconstruction was the mainstay of treatment for pediatric sarcoma patients. Allografts have been used longer than any other reconstruction method. Osteoarticular allografts were used extensively for reconstruction involving the joint and allow a strong repair for ligaments and other soft tissue. Unfortunately, very few of the chondrocytes survive the preservation and sterilization process, so the natural course is for the joint surface to degenerate over time. Osteoarthritis develops in the first 5–10 years in 15 % of patients (Mankin

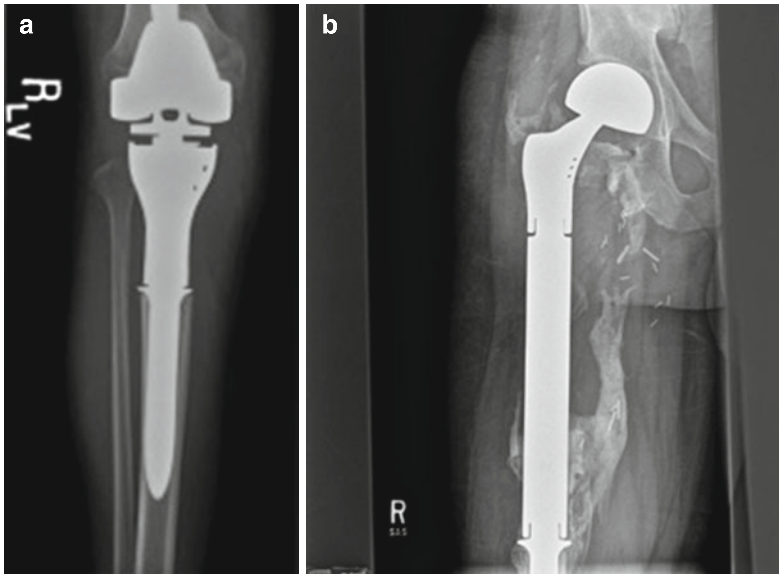


**Fig. 9.3** Examples of modular prosthesis. A proximal tibia (**a**) and proximal femur (**b**) is shown. Heterotopic ossification is commonly seen after the reconstruction, seen particularly well in (**b**)

et al. 1996). Thus, metallic solutions have largely replaced this reconstruction when tumor resection requires the joint to be removed, although it can still be employed in select circumstances (Muscolo et al. 2008).

The major usage of structural allografts occurs in intercalary resections and reconstructions (Fig. 9.3). This technique can be employed in cases where the tumor is limited to the diaphysis and the physis can be spared. The allograft is usually stabilized and protected with either a plate or rod, which minimizes the potential for fracture of the allograft (Miller and Virkus 2010). The ability to spare the joint allows functional outcomes to be maximized for these patients.

The modes of failure associated with allograft reconstruction include infection, fracture, and non-union. Up to 50 % of patients can be expected to experience one of these complications, and the rate of early complication is high (Mankin et al. 1996).

### 9.3.3 Metallic Prosthesis

The advent and development of metallic "mega"-protheses has replaced the utilization of allografts in most circumstances. Modern systems offer tremendous modularity that allows the surgeon to

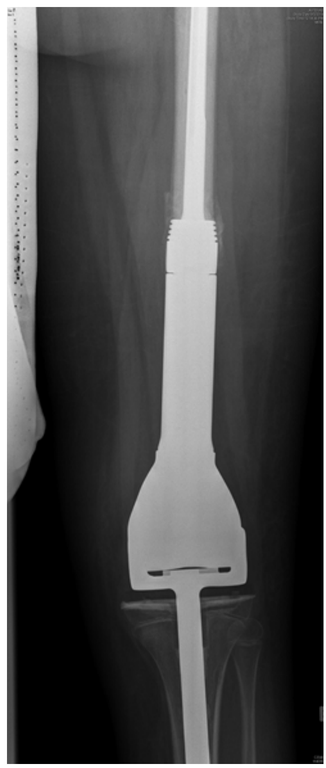

**Fig. 9.4** Plain radiograph showing reconstruction with a non-invasive expandable prosthesis in a 8 years old patient. The prosthesis can be lengthened in the office using an electromagnetic coil

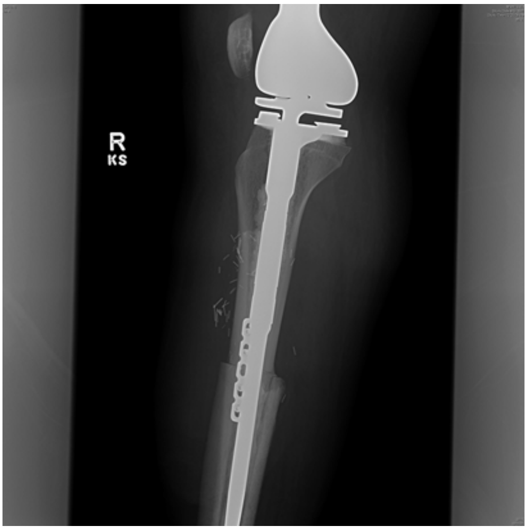


**Fig. 9.5** Lateral radiograph of a knee showing an example of an allograft-prosthestic combination reconstruction that was utilized after resection of the proximal tibia for osteosarcoma. An allograft proximal tibia with extensor mechanism attached is used to reconstruct the bone defect and a metallic prosthetic knee is placed in combination for joint reconstruction

reconstruct almost any length of skeletal defect intra-operatively (Fig. 9.4). Immediate range of motion and weight bearing can often be allowed with these constructs. In addition, there is a lower risk of infection and non-union when compared to allografts, and there is no risk of disease transmission. These devices can also be used for salvage after failure of a prior allograft (Foo et al. 2011). Also available are expandable prostheses, which allow growth of the limb in the child in either an invasive or non-invasive manner (Fig. 9.5). The development of expandable options was a tremendous advance in the realm of limb salvage for young patients (Beebe et al. 2010). The child usually undergoes lengthening every 1 cm or so. Lengthening in larger increments can cause increased pain and neuropraxia. Despite high interest and emotional acceptance with these devices, studies have not shown superiority to limb salvage versus amputation (Henderson et al. 2012).

The main modes of failure for metallic prosthesis include loosening and infection. Either of these can be disastrous for the patient and can lead to extensive revision or even to amputa-

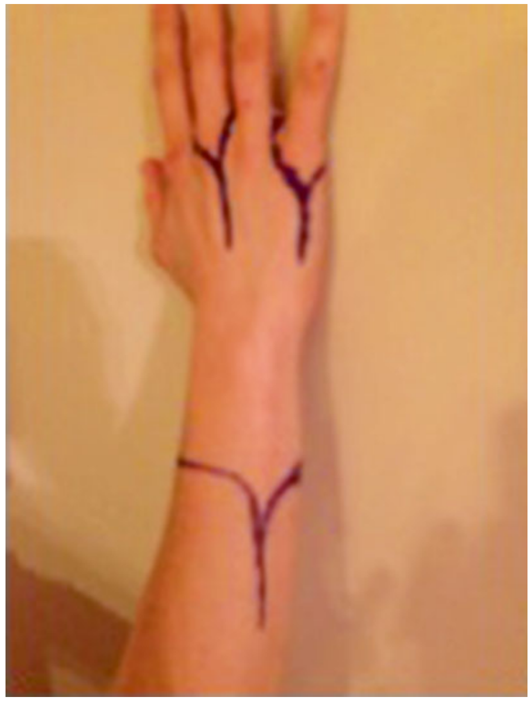

**Fig. 9.6** Incisions for transradial amputation and ray resections

tion. The 10-year survival for these devices is around 60 % (Morgan et al. 2006). Location plays a role in the durability of the reconstruction, with proximal humeral and proximal femur doing the best (77 % at 10 years), distal femur next (65 % at 10 years), and proximal tibia prostheses faring the worst (50 % at 10 years) (Damron 1997).

### 9.3.4 Combination (Alloprosthetic Composite)

Combining both an allograft and a prosthetic in a reconstruction is performed in an attempt to capture the benefits and avoid the pitfalls of each of the respective methods. The composite reconstruction can help restore bone stock and provide strong ligamentous attachments with the allograft portion, while the prosthetic portion avoids the cartilage degradation associated with osteoarticular allografts (Fig. 9.6).

## 9.4 Amputation

Amputation is one of the oldest surgical procedures known to man. The most common indications for amputation are: infection, ischemia, trauma, and malignancy. With improved antibiotics, revascularization procedures, soft tissue reconstruction, and limb-salvage techniques, fewer patients require amputation today than ever before. Nevertheless, sometimes amputation is the more prudent option in terms of either time for recovery or risk of complications. In these instances, it is important for surgeons to emphasize to patients that amputation represents the beginning of a new life rather than the culmination of previous treatment failures (Figs. 9.7 and 9.8).

**Fig. 9.7** Incisions for above- and below-knee amputations

### 9.4.1 Indications

Approximately 13,000 Americans live with lower extremity amputations due to malignancy (Ziegler-Graham et al. 2008). With the advent of modern chemotherapy, survival rates have

**Table 9.1** Considerations impacting surgical choice for malignant bone tumors

| Patient factors | Oncologic factors |
|---|---|
| Risk tolerance for recurrence | Responsiveness to adjuvant treatment |
| Occupation | Local aggressiveness |
| Ability to undergo rehabilitation | Stage of disease |
| Age | Single lesion or multifocal lesion |
| Cosmesis | |
| **Treatment factors** | **Anatomic factors** |
| Prior treatment sequellae | Size of lesion |
| Chemoresponsiveness | Proximity to critical structures |
| Radiation responsiveness | Extent of contamination |
| | Ability to achieve negative or wide margins |

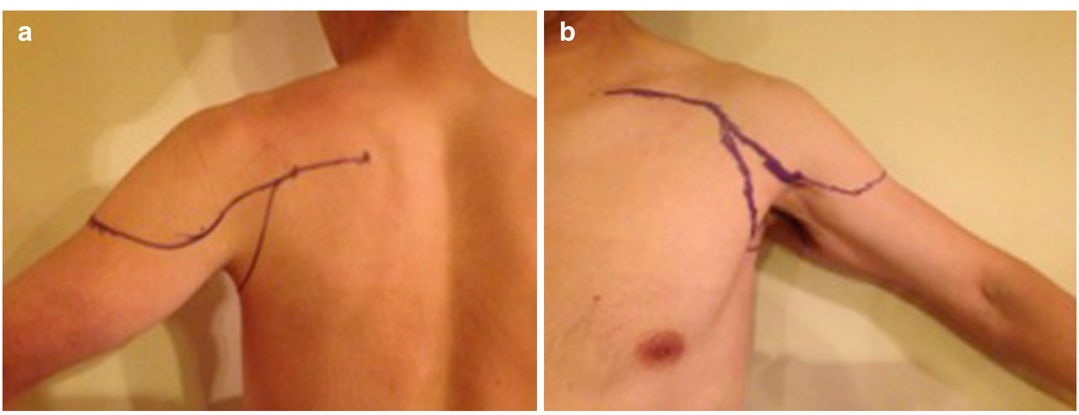


**Fig. 9.8** Incision for shoulder disarticulation or forequarter amputation. (**a**) Posterior incision (**b**) Anterior incision

improved from approximately 20 % prior to the 1970s to nearly 70 % for primary bone sarcomas (Ng et al. 2013). Effective imaging technology and radiation techniques have allowed most patients with soft tissue sarcomas to preserve their limb without significant increases in local recurrence rates or overall mortality.

The threshold to perform an amputation for tumor varies widely amongst institutions. Every situation is unique and should be evaluated on a case-by-case basis. There are numerous important factors to consider (Table 9.1).

On a fundamental level, it is important to note that the oncologic role of surgical resection or amputation for an extremity-based primary lesion is local control. If metastases are already present, eradicating local sites of tumor is less essential, particularly if they are minimally symptomatic and if there is not a reasonable chance of long-term survival with systemic therapy. For non-metastatic cases, achieving local control is necessary for long-term survival. However, it is unclear what additional risk of metastasis is incurred with local recurrence of tumor followed by timely re-resection or amputation. If the surgeon and patient are relatively risk-tolerant and there are effective adjuvant modalities, limb-salvage may be attempted in even high-risk cases, with the philosophy that amputation can always be performed later in the event of local recurrence.

### 9.4.2 Risks/Benefits/Alternatives

With loss of a limb, patients lose function and cosmesis. The impact upon the patient depends on the availability of an effective prosthesis, the patient's occupation and lifestyle, and the specific body part lost. Approximately 90–100 % of patients experience phantom-limb sensations and more than 50 % experience some degree of phantom-limb pain (Krane and Heller 1995). Phantom pain is most prevalent at 6–18 months following surgery and decrease with time (Bosmans et al. 2010).

Amputation has several advantages over limb-salvage. Typically, it has a lower rate of complications such as fracture, infection, wound healing issues, and neurovascular injury. Amputations can usually be performed more rapidly than limb-salvage surgery and may be preferable in medically comorbid patients. In theory one might think the local recurrence rate would be lower due to wider margins, but the data suggest that limb-salvage is equally effective at local control.

Surgical limb-salvage options include Van Nes rotationplasty for distal femoral or proximal tibial malignancies (Cammisa et al. 1990) and vascular bypass for tumors encasing critical vessels. Sacrifice of either the femoral or sciatic nerve in the lower extremity is acceptable and can be compensated with bracing. Loss of both major nerves, however, renders the limb functionally incapacitated. In the upper extremity, tendon transfers, nerve transplants, and specialized procedures such as opponensplasty can reduce the morbidity of major tumor resections.

### 9.4.3 Rehabilitation and Prosthetics

The rehabilitation process for amputees begins pre-operatively rather than post-operatively. Prosthetic education and psychosocial support play a large role in patient satisfaction. Many young patients seek and ultimately utilize the latest technology in prosthetics, but for the first 9–12 months of recovery, a more basic prosthesis is often used. Numerous prosthetic adjustments are necessary to optimize fitting and comfort while the stump is healing and attaining a steady state. Although a full discussion of the available prosthetics for all amputation levels is beyond the scope of this chapter, it is important that the surgeon be familiar with the basic principles of prosthetic compatibility and have a close working relationship with a reliable prosthetist.

## 9.5 Surgical Techniques

### 9.5.1 Ray Resection and Partial Hand Amputation

The extent of the amputation is largely dependent on the extent of the malignant process. For amputations involving border digits, a teardrop-shaped incision is performed with the apex proximally and along the ulnar or radial side of the hand. The incision is carried through the webspace and the proper digital neurovascular bundle to the adjacent finger is preserved if possible. For a complete ray resection, the metacarpal is disarticulated at the carpometacarpal joint. If more than one border ray is resected, one side of the palmar vascular arches will likely need to be ligated. The vascularity to the hand is not jeopardized because there are two arches (deep and superficial) and each have dual blood supplies (radial and ulnar arteries). Oftentimes with border ray resections, a flap such as a reverse radial forearm flap is needed for soft tissue coverage.

For amputations involving central digits only, a dorsally-based racquet-shaped incision is used. The adjacent proper digital neurovascular bundles are preserved if possible. The intermetacarpal ligament from adjacent digits should be repaired to improve stability of the hand. A closing wedge osteotomy of the distal row of carpal bones at the base of the resected rays can be performed in order to close down the space between the adjacent digits and prevent dropping of small objects.

### 9.5.2 Transradial and Transhumeral Amputation

The transradial and transhumeral amputations are relatively straightforward procedures. In all instances, maximal length of the stump should be preserved. A fishmouth incision is used. The fascia and muscles are transected as distally as possible to provide ample bony coverage. All neurovascular structures are transected separately. Nerves should be transected under tension and allowed to retract. Using drillholes, the anterior and posterior compartment musculature are myodesed to the end of the bone. A tension-free fascial closure should be endeavored in all cases. Because the skin is highly mobile and well-vascularized in the upper extremity, elevating large subcutaneous flaps to achieve skin coverage is rarely an issue.

### 9.5.3 Shoulder Disarticulations and Forequarter Amputations

The patient is positioned lateral. An incision is performed in line with the clavicle and carried down into a deltopectoral approach. This incision is carried laterally and posteriorly following the distal border of the deltoid muscle. Posteriorly, this incision is carried in line along the spine of the scapula. To create a fishmouth incision, a second limb of the incision is carried down the lateral chest wall and curved posteriorly to join the first incision.

A standard deltopectoral approach is performed and the deltoid insertion is subperiosteally elevated off the humerus. The pectoralis major, latissimus dorsi and teres major insertions are released off the humerus. The conjoint tendon origin and pectoralis minor insertion on the coracoid process are released. This muscular exposure should reveal the brachial plexus and axillary artery clearly. If more proximal control of the vessels is necessary, these structures should be identified deep to the clavicle. The lateral two-thirds of the clavicle is subperiosteally skeletonized. The clavicle is carefully transected and the lateral two-thirds is removed. The neurovascular bundle is seen clearly emerging from the chest cavity and running over the first rib into the arm.

If the scapula is to be removed, it can be easily dissected posteriorly by raising large subcutaneous flaps and releasing its muscular attachments off the chest wall. If the scapula is to be maintained, the shoulder can be disarticulated at the glenoid, maintaining the acromion for better cosmesis. The deltoid flap is very well-perfused and can simply be folded over the soft tissue defect for closure.

### 9.5.4 Below Knee Amputation

In an ideal situation, the tibial osteotomy is planned at approximately 15 cm distal to the knee joint line. A long posterior flap approximately 15 cm long is utilized in which the medial edge of the flap is along the posteromedial border of the tibia and the lateral edge of the flap is in line with the fibula. The anterior soft tissue flap is angled 90° from the posterior flap rather than a fishmouth to reduce dog-ears and redundant skin during closure.

After incising the skin, the fascia is incised slightly distally to ensure a tension-free fascial closure. The muscles of the anterior compartment are transected at the same level as the planned tibial osteotomy. The anterior neurovascular bundle is identified. The nerve is transected sharply under tension to allow it to retract, and the artery and vein are ligated separately. Next, the peroneal muscles are transected at the same level.

If a standard below the knee amputation is being performed, the tibia is then osteotomized at the planned level and the fibula osteotomized slightly proximally. If an Ertl or transosseous bone bridge is planned, a sleeve of periosteum should be raised off the tibia distal to the planned resection level and the fibula should be transected about 6–8 cm distal to the tibial level.

The proximal end of the osteotomized distal tibia should be lifted anteriorly, and the deep posterior compartment muscles subperiosteally elevated off the amputated tibia and fibula to the level of the long posterior flap at which point they should be transected. The posterior tibial and fibular vessels can be clamped at this level for temporary control. The deep posterior compartment and soleus muscles are resected, leaving only the gastrocnemius muscles on the posterior flap. The neurovascular structures are transected and ligated at the level of the tibial osteotomy.

If no bone-bridge is planned, the edges of the cut bone should be smoothed down and drill holes placed in the anterior and medial aspects of the tibia. If the patient is skeletally immature, an uncontaminated metatarsal or phalangeal head and neck harvested from the amputated foot can be pressfit into the open canal of the osteotomized tibia to reduce the risk of overgrowth. If a bone-bridge is intended, a high-speed burr should be used to create a slot in the tibia to accept a segment of fibula to be placed between the remaining fibula and the tibia. This segment can be secured with heavy non-absorbable suture through drill holes, an Endobutton®, or screws (Ng and Berlet 2010). A flap of periosteum can be sutured over the fibular segment to improve osseous union.

For closure, non-absorbable suture is run through the gastrocnemius muscle and used to secure it over the front of the tibia through drillholes. The posterior and anterior fascia are sutured together for a tension-free closure. Nylon sutures are used for skin closure. To remove redundant skin and eliminate dog-ears, triangles of skin are removed from each side at the ends of the incision as the wound is progressively closed. A well-padded posterior splint is applied to keep the knee in extension and prevent flexion contractures.

### 9.5.5 Above Knee Amputation (AKA)

The level of an AKA is largely determined by the location of the pathology, but as a general rule, as much length as possible should be preserved. A fishmouth incision is planned with equal sized anterior or posterior flaps. Depending on the skin available, medial-lateral flaps can be successful as well. The “angle” at the corners of the fishmouth should be very acute to allow preservation of maximal skin. In fact, a guillotine amputation may be performed initially, and once the rest of the limb has been removed, the skin flaps can be fashioned from the guillotined stump by essentially removing dog-ears.

The quadriceps musculature is transected at the level of the anterior flap. The periosteum is subperiosteally elevated back to the level of the bone resection. In order to have enough soft tissues for closure, the femoral osteotomy should be at least 10–12 cm proximal to the extent of the flaps. Approximately 8–10 cm proximal to the superior pole of the patella, the femoral vessels may be found directly posterior to the medial intermuscular septum, diving into the adductor hiatus. These vessels should be carefully dissected and ligated.

After performing the femoral osteotomy, as much length as possible for the adductor musculature should be preserved. The hamstrings are transected at the level of the posterior flap and the sciatic nerve sharply transected under tension. Drillholes should be placed anteriorly and laterally. Large non-absorbable suture should be used to affix the adductors and hamstrings to the femur. The quadriceps are folded over the top and sutured to the hamstrings. If the patient is skeletally immature, a harvested uncontaminated metatarsal or phalangeal head and neck can be pressfit into the end of the femur to reduce overgrowth. The skin is closed with nylons and the stump is wrapped in a well-padded dressing.

### 9.5.6 Hip Disarticulation

Achieving soft tissue coverage for hip disarticulations and hemipelvectomies can be challenging depending on the location and size of the tumor. The main two workhorse flaps for coverage are anterior and posterior.

For a standard posterior flap hip disarticulation, the patient is positioned supine with a bump under the ipsilateral trunk and a teardrop shaped incision is made with the apex or corner starting near the anterior superior iliac spine. The posterior aspect of the incision wraps around distal to the gluteal musculature. The femoral triangle is explored and the main vessels are ligated separately. All of the anterior and medial compartment muscles are transected near their origin. A circumferential hip capsulotomy is performed and the femur is disarticulated. The gluteal muscles are released at their insertions and are separated from the hamstrings and vastus lateralis. The sciatic nerve is transected proximally under tension. The superior and inferior gluteal vessels are preserved as they are the blood supply for the posterior flap. The posterior flap is folded anteriorly and used to cover the resultant soft tissue defect.

For a standard anterior flap hip disarticulation, the patient is positioned lateral, but held in place loosely by a beanbag such that he or she can be rolled posteriorly to a more supine position for the anterior dissection. The medial incision starts just medial to the femoral vessels proximally and is extended to the medial knee. The greater saphenous vein is ligated and the spermatic cord is protected in males. The femoral vessels are identified, but the integrity of the femoral sheath is maintained. The quadriceps muscles are transected just proximal to the knee and subperiosteally elevated off the anterior femur. The superficial femoral artery is identified and ligated at the level of the adductor hiatus. The lateral incision is performed slightly posterior to the lateral intermuscular septum. As the anterior flap is elevated, the medial plane of dissection is carried out between the vastus medialis and femoral vessels anteriorly and the adductor musculature posteriorly. The sartorius muscle may be sutured over the femoral sheath to help provide coverage posteriorly. The deep femoral artery is ligated as it travels directly posterior to the femur and the multiple perforator vessels are cauterized as they travel laterally. As the flap is elevated proximally and anteriorly, the lateral circumflex vessels and its branches are protected because they are a main blood supply to the anterior flap.

The proximal lateral portion of the incision is angled posteromedially towards the posterior sacral iliac spine at the tip of the greater trochanter, similar to a posterolateral approach to the hip. The muscular insertions are subperiosteally elevated off the proximal femur and a circumferential capsulotomy is performed. The ligamentum teres is transected and the femur is disarticulated. The anterior flap is brought posteriorly to cover the resultant soft tissue defect.

### 9.5.7 Pediatric Amputations

Special considerations are required for amputations in patients less than 10 years old compared to adolescents and adults (Rab 2001; Cummings and Kapp 1992). First, all physes should be preserved if possible to allow for continued longitudinal growth of the stump. An acceptable length femoral stump in an 8-year old child may not be adequate to support a prosthesis once the patient grows into a full-grown adult due to the loss of the distal physis which provides the majority of femoral length. Second, disarticulations are advantageous in pediatric amputations because it prevents terminal overgrowth, allows for an end-bearing stump, and retains adequate shape to the stump as the child grows. In adults, disarticulations are bulbous and difficult to fit for prostheses. In children, transosseous amputations tend to become conical and rotationally unstable for prostheses while disarticulations develop into well-shaped stumps. Third, preservation of the proximal fibula, even if very short, is advantageous for below-knee amputations. The additional width of the stump allows for more effective prosthetic fitting. Fourth, parents should be forewarned that terminal overgrowth is very common, particularly in transhumeral and below-knee amputations, and that multiple revisions of bony prominences may be necessary. The exact mechanism is unclear and there is no highly reliable method to prevent it. Fifth, superior healing capacity in children allow for success in using creative wound closure techniques that would likely not work in adults. Retaining maximal bone length is recommended despite tenuous soft tissue coverage is recommended, even if the use of split-thickness skin grafts is necessary.

## 9.6 Summary

The surgical management of pediatric bone sarcomas remains a challenge. Limb-sparing surgery can be achieved in 90 % of cases, but only in cases where survival of the patient is not diminished compared to amputation and where the reconstructed limb affords a good functional outcome. Many options exist for the reconstruction and are tailored to the individual patient. Amputation is still the best option for some patients and with the progress made in prosthesis design and durable and functional outcome can be achieved in many patients.

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