Complex reconstruction in the management of extremity sarcomas

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The concept of limb-sparing surgery for bony sarcomas has evolved over the past 25 years. Today, more than 90% of patients treated by surgeons with expertise in musculoskeletal oncology undergo successful limb-sparing procedures. Many large centers have abandoned osteochondral allografts and resection arthrodesis for the reconstruction of segmental bone and joint defects in favor of metallic endoprostheses. Endoprosthesis survival rates now exceed 85% at 5 years for reconstructions about the knee, which is the most common site for primary bone sarcomas. In the shoulder girdle, the type of resection and soft-tissue reconstruction is probably more important than the type of implant. Extra-articular resection is recommended for most large stage IIB tumors. New expandable prostheses able to be lengthened nonoperatively hold promise for very young children with lower extremity sarcomas. Allograft-prosthetic composites and proximal femoral prostheses provide reliable and stable hip reconstructions. Acetabular components are not required, but attention to capsular reconstruction is necessary to prevent hip dislocation. Techniques of scapula replacement have advanced and provide better upper extremity function after scapula resection than resection alone.

Keywords
allograft bone sarcoma, endoprosthesis reconstruction, survival knee, shoulder

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Abbreviations

APC	allograft prosthetic composite
MSTS	Musculoskeletal Tumor Society

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The concept of limb-sparing surgery for bone sarcomas has gradually evolved over the past 25 years. Prior to this, all high-grade bone sarcomas were treated by amputation one joint above the involved bone. With the introduction of adriamycin- and methotrexate-based chemotherapy protocols in the early 1970s at Memorial Sloan-Kettering Cancer Center, New York University Hospital, and the Children's Hospital of Philadelphia, surgeons such as Ralph Marcove, Kenneth Francis, and Hugh Watts developed techniques of limb-sparing surgery using custom endoprostheses. Today, 90 to 95% of patients with extremity sarcomas, who are treated at major cancer centers by surgeons with expertise in musculoskeletal oncology undergo successful limb-sparing procedures. Functional outcomes are good, and local recurrence rates are low.

These dramatic improvements in patient care are the result of significant advances along many fronts, including improved understanding of tumor biology, effective induction (neoadjuvant) chemotherapy, advances in accurate preoperative imaging, improved surgical techniques, and technological advances in reconstructive hardware.

Various techniques of segmental reconstruction have been used over the past two to three decades at different centers in the United States and Europe. Long-term results are now available. The purpose of this paper is to discuss the various techniques of reconstructing surgical defects at the common anatomic sites and to review recent literature on this topic.

Types of reconstructive techniques

There are three components to limb-sparing surgery for bony sarcomas. The first is the resection of the bony tumor. The second is the reconstruction of the large (15–20 cm) bone defect. In general, this defect includes a segment of the affected bone and adjacent joint. The third component is the use of adequate soft tissue or muscle flaps, or both, to provide good soft-tissue coverage and to re-establish motor function and stability.

The original technique for skeletal reconstruction, used by William Enneking [1], a pioneer in orthopedic oncology, was resection arthrodesis, in which a segment of bone containing sarcoma and the adjacent articulation are removed en bloc and an arthrodesis that spans the

missing segment as well as the joint is performed. The absence of motion at the joint is an obvious limitation of function, and this method is only rarely used today.

During the early and late 1970s, surgeons at the Massachusetts General Hospital [2,3] and other centers popularized the use of osteochondral allografts to reconstruct segments of bones and adjacent articulations. In this method, matched cadaveric bone is attached to the remaining host bone using metallic fixation, and the periarticular ligaments and tendons are attached to the allograft itself. Unfortunately, many surgical difficulties were encountered with this approach; they included failure to achieve union between the host bone and allograft, fracture of the allograft, and a relatively high infection rate of the essentially necrotic graft material that sometimes necessitated late amputation of the limb. Long-term studies of these patients showed that less than half of the allografts of the lower extremity lasted more than 10 years, and that a significant number of early and late amputations were needed [4•]. Most large centers have now abandoned allograft reconstruction except for specific indications.

An analogous technique uses a combination of allograft (for segmental reconstruction) and metallic prosthesis (for articular reconstruction) as an allograft prosthetic composite (APC). The advantage of this method is that it allows for reattachment of the periarticular ligaments and tendons to the allograft while the high surface stresses at the joint surface are borne by metallic components, in the hope of avoiding some of the failures often seen in pure allograft reconstruction.

Some centers, particularly those in Europe and Japan, use the patient's own bone, that is, autograft, to reconstruct segmental bone loss. The most commonly used bone is the fibula, which is harvested along with its nutrient vessel to allow for revascularization. Although this technique has been used in the lower extremity, it is more effective for the arm, because the small size of the fibula lends itself better to upper-extremity reconstructions. Recently, the use of Ilizarov distraction-osteogenesis to gradually lengthen nearby bones and fill the defect created by tumor resection has been reported [5].

Most large centers have now adopted the use of metallic endoprostheses for skeletal reconstruction after segmental bone resection. The advantages of metallic endoprostheses include durability of the implant, the ability to match the implant to the defect at the time of surgery, and the predictable good functional results, over both the short and the long term. Importantly, the incidence of infection and implant complications is typically lower than it is following reconstructions involving allografts. Endoprosthetic reconstruction is extremely reliable for the distal femur (the most common site for osteosarcoma), the proximal femur (a common site for osteosarcoma, chondrosarcoma, and Ewing sarcoma), the proximal humerus, and the scapula. The most difficult areas for reconstruction, regardless of technique, are the proximal tibia and the acetabulum.

Knee

Surgical challenges

The knee is the most commonly reconstructed articulation, and more experience has been gained at this site than at any other. Osteosarcoma most commonly occurs about the knee and favors the distal femur over the proximal tibial metaphysis by a ratio of 2:1. Early on, the challenge for surgeons attempting limb-sparing surgery was to preserve the critical neurovascular structures about the knee. Routine use of neoadjuvant chemotherapy now permits preservation of the popliteal vessels and sciatic nerve in almost all cases and decreases the amount of soft tissue resected. Current challenges for reconstruction include preventing complications, both short and long term (i.e., early postoperative flap necrosis, late "loosening" at the metallic stem-bone interface, and deep infection).

Tumors arising from the proximal tibia pose special challenges because of the subcutaneous location of the tibia, which can result in tenuous soft-tissue coverage for the implant or APC, as well as the necessity for reconstructing the extensor mechanism after division of the patellar ligament at its tibial attachment. The authors routinely use a medial gastrocnemius rotational flap to cover the prosthetic reconstruction and augment the extensor mechanism reconstruction.

Endoprosthesis

Most reports on knee reconstruction in 2002 focused on the use of metallic endoprostheses. Bickels *et al.* [6••] presented the results of 110 consecutive patients with distal femur endoprostheses with 2 years' minimal follow-up. Of these 110 procedures, 73 entailed the use of modern "modular" components. All prostheses were implanted with bone cement and used a rotating-hinge knee component. The authors reported low rates of major complications: six patients (5.4%) developed deep wound infections, and an equal number developed aseptic loosening. The 5- and 10-year Kaplan-Meier survival rates of the prostheses (defined as no component having to be removed or revised) were 93% and 88%, respectively. The overall limb-salvage rate was 96%, and function was good-to-excellent in 85% of the patients.

Yasko *et al.* [7] reported on the long-term results in 54 patients who underwent reconstruction at their institution with the use of the "Finn" rotating-hinge knee prosthesis The procedures were performed between 1991 and 1999. All implants were cemented. There were

seven broken implants, two infections, and one instance of aseptic loosening. Forty-one patients (76%) required no reoperations for tumor- or prosthesis-related complications. The median Musculoskeletal Tumor Society (MSTS) score at last follow-up was 84% of normal. The authors comment that the majority of mechanical failures were attributable to early-generation implants.

Mittermayer *et al.* [8•] analyzed the rate of aseptic loosening of the noncemented Kotz endoprostheses. They reported a 26% incidence of radiographic loosening for distal femoral implants and a 15% incidence of loosening for proximal tibial implants, noted at a mean interval of 12 months. This type of implant utilizes a fixed-hinge knee prosthesis, which increases the stress at the prosthetic-bone junction. Plotz *et al.* [9•] described 64 consecutive patients with endoprosthetic reconstructions of tumors about the knee. A variety of implants and both cemented and noncemented reconstruction were used. The overall limb salvage rate at 10 years was 95%, but the complication rate was relatively high: 45% (29/64) of patients required reoperation, the large majority as a result of mechanical complications. Eleven percent of uncemented stems loosened; no cemented stem loosened.

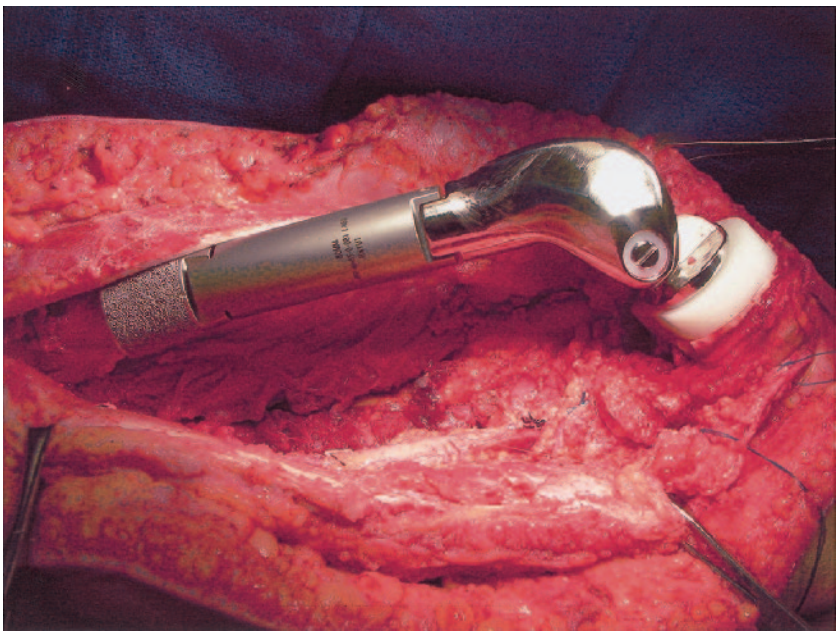
In one of the largest series to date, the authors report a low rate of prosthetic failure in 105 consecutive modular distal femoral and proximal tibial endoprostheses [10•]. Several surgical techniques were consistently used, including routine cementation of the stem, gastrocnemius rotational flaps to cover tibial implants, and bone grafting of the prosthetic-bone junction to improve extracortical fixation. The development of extracortical fixation is thought to prevent aseptic loosening by preventing particulate debris from reaching the bone-cement interface. The reported endoprosthesis survival for both distal femur and proximal tibial implants was 94% at the median follow-up interval of approximately 30 months and 86% at 5 years. The majority (57%) of prosthetic and soft-tissue complications requiring reoperation did not result in prosthetic failure. Of the five patients with failure due to prosthetic complications, two were for aseptic loosening (2%), and three (3%) were for polyethylene failure or breakage of the stem. The limb salvage rate was 92% at the median follow-up interval of 37 months and 88% at 5 years.

Expandable prosthesis

Approximately 70% of the total growth of the lower limb is the result of growth of the distal femur and proximal tibial growth plates. For this reason, resection of the knee joint in very young patients (usually younger than 10 years) can eventually cause significant limb discrepancy. In the authors' experience, approximately 10% of patients with bony sarcoma require an expandable prosthesis. Two reports focused on the use of expandable prostheses at the 2002 meeting of the Musculoskeletal Tumor Society [11•,12]. Neel *et al.* [11•] reported on the short- and intermediate-term results of the expandable Phenix (Wright Medical, Inc.) prosthesis in 16 patients. This device uses an externally applied electromagnetic field to control lengthening, thus avoiding the need for an open surgical procedure. At an average of 25 months, 58 lengthening procedures had been performed, resulting in a total average expansion of 38 mm. There were five component fractures and one stem loosening requiring revision of the implants. There was only one failure of lengthening.

Figure 1. Intraoperative photograph of a distal femur endoprosthesis being implanted.

The use of modular implants allows the surgeon to precisely tailor the size of the implant to the bone defect at the time of surgery. Note the rotating hinge mechanism at the knee.



All other techniques require expansion of the implanted prosthesis by an open surgical procedure and a "crank-type" mechanism. The maximum lengthening at any one procedure is 1 or 2 cm. Today, many manufacturers and surgeons are concentrating on designing prostheses that do not require an open procedure.

Autograft

Autogenous fibula grafts have been used for bone reconstruction for many years, most commonly in the upper extremity. Four reports focused on the use fibular grafts for reconstruction of lower limb defects after tumor resection [12,13•,14,15]. Chang *et al.* [15] used fibulas to reconstruct the limbs of 26 patients, of whom 14 received autoclaved tumor bone and 12 received vascularized fibula grafts. Joint preservation was achieved in half of the patients, and 84% of those who had preserved knee joints achieved good-to-excellent results. El-Gammal *et al.* [13•] used vascularized fibula osteoseptocutaneous flaps on 25 patients with lower limb tumors with an average bone defect of 16 cm. Most patients had fixation augmented with an intramedullary nail or external fixator. Grafts united at an average of 4.5 months, and full weight bearing was achieved after an average delay of 7.5 months. Most patients (85%) demonstrated significant graft hypertrophy at an average of 10 months; three patients suffered graft fractures that were treated conservatively. These techniques are not generally used in the United States.

Allograft and arthrodesis

Only one report was published in 2002 on the use of cadaveric bone in reconstructions about the knee. Deijkers *et al.* [16], writing about low-grade tumors of the bone surface, reported the use of hemicortical allografts after partial cortical resections in 22 patients. Patients experienced fewer complications with this approach than with intercalary grafts (in which the entire width of bone is replaced); however, six patients still required treatment for fractures of the remaining hemicortex. No patients had local recurrence at a mean follow-up of 64 months.

Two reports focused on the use of allograft-arthrodesis for bone reconstruction [17•,18]. Donati *et al.* [17•] evaluated 92 patients who underwent allograft-arthrodesis of the knee at two institutions and found an infection rate of 20%, a fracture rate of 25%, and a nonunion rate of 44%. They concluded, "Other approaches should be considered unless there are special indications for this procedure." In general, resection-arthrodesis is not recommended.

Proximal femur

Surgical challenges

The proximal femur is the second most common site for primary bone tumors. Resection of the proximal femur can result in instability of the hip joint due to loss of the strong native hip capsule and loss of hip abductor strength. Surprisingly, despite the heavy mechanical loading of the proximal femur, implant failure, whether metallic or allograft, has been less prevalent at the femur than at the knee. Endoprostheses and APCs are used most often at this site.

In the authors' experience, arthroplasty of the acetabulum has not become necessary after reconstruction with a "bipolar" femoral head, even with long-term follow-up [10•,19]. The authors routinely perform a layered capsulorraphy by preserving the hip capsule, which is reinforced with 3 mm Dacron tape and augmented with local muscle transfers. Recently, Bickels *et al.* [20] reported results at an average follow-up of 80 months from 57 patients with proximal femur tumors whose limbs were reconstructed with bipolar endoprostheses and hip capsulorraphy. No patient required acetabular resurfacing. There was only one dislocation and no local recurrences in the hip capsule. Other series have reported dislocation rates of the prosthesis from the acetabulum of up to 20% [20–22].

Endoprosthesis

Only one report specific to endoprosthetic reconstruction of the proximal femur was published in 2002. In it, Ilyas *et al.* [23•] reviewed 15 patients who received uncemented Kotz proximal femoral prostheses. At a mean follow-up of 6.7 months, there was one loosening and two infections. The dislocation rate was 20%.

Allograft-prosthesis composite

Donati *et al.* [24•] reported on 27 patients who underwent reconstruction after proximal femur resection with an APC consisting of standard hip stem and bipolar head surrounded by and cemented to an allograft proximal femur. The minimum follow-up was 36 months. Patients were restricted from full weight bearing for 6 months. There were numerous graft-related complications, with 14 patients experiencing fracture of the greater trochanter (which the authors attributed to the learning curve of the procedure). Almost all such complications were treated nonoperatively. Only two patients, both approximately 60 years of age, required acetabular replacement due to wear. At last follow-up, 73% of patients had excellent results and 18% had good results according to the MSTS scoring system. Furthermore, 14 patients had no Trendelenburg gait and 6 patients had only a slight Trendelenburg gait. The authors conclude, "These results compare favorably with those of megaprostheses for tumor resection of the proximal femur, where a Trendelenburg gait almost always is present."

Farid *et al.* [25] compared functional outcomes in 20 patients with APC reconstruction with outcomes in 45 patients with endoprosthetic reconstruction after proximal femur resection. The authors presented the results at the

recent 2003 meeting of the American Academy of Orthopedic Surgeons. Although the groups were somewhat heterogeneous, they found a mean abductor strength of 3.1 in the endoprosthesis group and 4.6 in APC group ($P < .05$).

Proximal humerus

Surgical challenges

The proximal humerus is the third most common site for osteosarcoma. Joint involvement is common in patients with high-grade malignancies of the proximal humerus, and therefore extra-articular resection is commonly performed for large, high-grade proximal humerus tumors [26•]. A recent histologic study of shoulder resection specimens confirms that 7 of 17 patients with preoperative radiologic evidence of intra-articular extension had histologic evidence of intra-articular tumor [27]. Intra-articular resection is reserved for small (stage IIA) tumors, since the risk of local recurrence is greater (4% vs. 16%) when intra-articular resection is performed for stage IIB tumors [28•].

The most important functional goal after surgery is preservation of shoulder stability, which will permit good hand and elbow function. The choice of implant probably does not affect outcome in the upper extremity as much as it does in the lower extremity, since the risk of implant failure is generally lower with all modalities in the upper extremity. Active shoulder abduction of 90 degrees or more is rare after shoulder reconstruction, regardless of the reconstruction method. The aim of surgery is to create a stable shoulder that permits the placement of the hand in space. Maintenance of rotation is important; thus, arthrodesis is usually not preferred.

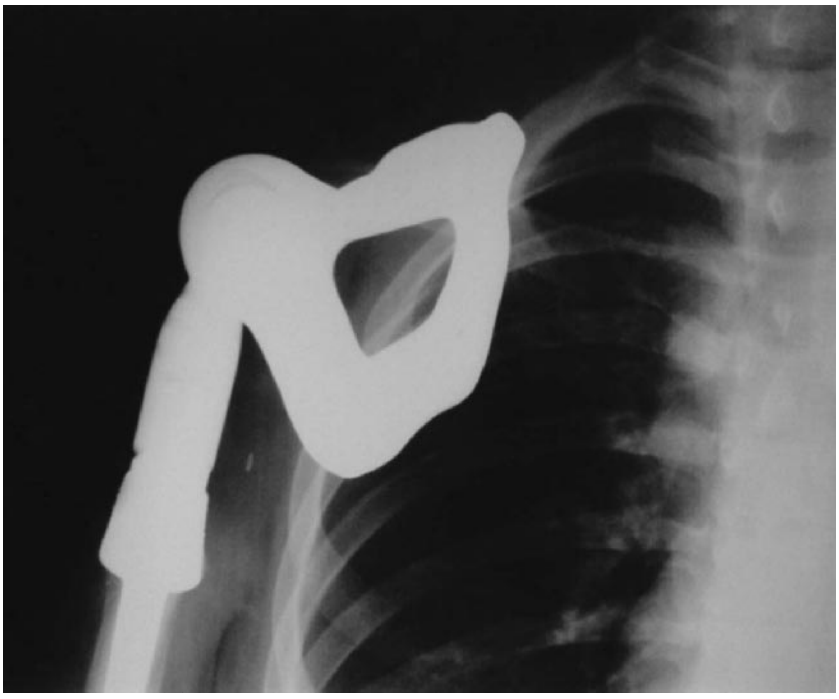
Endoprosthesis

Rodl *et al.* [29] reviewed 45 patients with a minimum 2-year follow-up who underwent proximal humerus resection and reconstruction with one of three methods: allograft (11 patients), endoprosthesis (19 patients), or the *clavicula pro humero* operation (15 patients), in which the native clavicle is transposed with intact acromioclavicular ligaments to substitute for a humeral defect. Extra-articular resection was performed in 25 patients and intra-articular resection in the remaining 20. There were five local and systemic recurrences and five failures of reconstruction. The greatest number of complications occurred with the *clavicula pro humero* patients. No significant difference in functional outcome was found among the three reconstruction subsets or by comparison of glenoid preservation with glenoid resection. Five patients had "unstable" shoulder joints postoperatively, but all refused further surgery.

In contrast, Wittig *et al.* [28•] reviewed 23 patients with osteosarcoma of the proximal humerus with a median follow-up of 10 years. All but one patient underwent extra-articular shoulder resection for stage IIB lesions; one underwent intra-articular resection for a stage IIA lesion. The joints of all patients with extra-articular resections were reconstructed using a combination of "static" suspension of the cemented endoprosthesis from the scapula and clavicle using 3 mm nonabsorbable su-

Figure 2. Endoprosthetic replacement of the scapula.

This replacement allows for a stable, reliable reconstruction of the shoulder girdle with better functional outcome than simple suspension of the humerus.



tures and "dynamic" suspension utilizing local muscle transfers, principally the pectoralis major. There were no local recurrences in the 23 patients. Prosthetic survival was 100%. Complications included eight transient nerve palsies and one periprosthetic fracture and subsequent asymptomatic radiographic loosening after a patient fall. All shoulders were stable and pain-free at last follow-up. MSTS scores for the 15 survivors ranged from 80 to 90%.

Autograft

Amin and Ebeid [30] describe a technique using the osteotomized axillary border of the scapula, with its vascular supply intact, to reconstruct a proximal humerus defect of less than 15 cm after tumor resection. Shoulder arthrodesis was performed with this technique in 14 patients while two others had reconstructions of an intercalary humerus defect with preservation of the shoulder joint. Twelve patients had intra-articular resections. The average time to union was 6 months. Two patients required bone grafting of the distal bone-graft junction for nonunion. The average functional score using the MSTS scoring system was 75%. The authors conclude that the technique is inexpensive and durable, and that it leads to predictable functional outcomes.

Scapula

Surgical challenges

The scapula is a relatively common site for Ewing sarcoma, chondrosarcoma, and metastatic renal cell carcinoma. Most high-grade lesions of the scapula involve the body as well as the glenoid. Characteristically, Ewing's sarcoma, hypernephromas, and chondrosarcomas have large extraosseous components that extend anterior and posterior to the scapula body. In the past, reconstruction after extra-articular resection of the scapula and glenohumeral joint ("Tikhoff-Linberg" procedure, developed in 1928) consisted of suspension of the remaining humerus from the clavicle or chest wall. This usually left the patient with limited stability of the shoulder and the upper extremity.

Major advances have recently been made in endoprosthetic design and surgical technique for scapular reconstruction [31•,32•]. Along with these developments has come a better understanding of the indications and requirements for this procedure.

Endoprosthesis

The authors have used a scapular endoprosthesis for reconstruction after scapular resection on selected patients since 1981. The design of the implant has undergone several revisions and now includes a constrained or "rotator-cuff" substituting articulation between a short humerus component and a snap-fit polyethylene cup on the scapular component. Wittig *et al.* [31•] described the technique and results of the first several patients. In brief, the scapular prosthesis is tenodesed to the preserved periscapular muscles—namely, the trapezius, rhomboids, and latissimus dorsi—after which the humerus, with its cemented component, is snapped into the scapular component, providing immediate scapulohumeral stability. The deltoid and axillary nerve must be preserved for this technique.

A retrospective comparison of patients undergoing scapular resection and reconstruction with and without an endoprosthesis was presented by the authors at recent meetings of the Musculoskeletal Tumor Society and American Academy of Orthopedic Surgeons [32•]. Compared with patients with no endoprosthesis, patients with endoprosthetic reconstruction had higher average MSTS scores (86% vs. 62%), a larger arc of active abduction (60–90% vs. 10–20%), and improved cosmesis. The major contraindication to this procedure is inability to preserve the deltoid and trapezius muscles. It is important to note that most bony sarcomas of the scapula are "contained" by the subscapularis muscle anteriorly and the infraspinatus muscle posteriorly. Only large suprascapular tumors cannot be treated with an endoprosthesis.

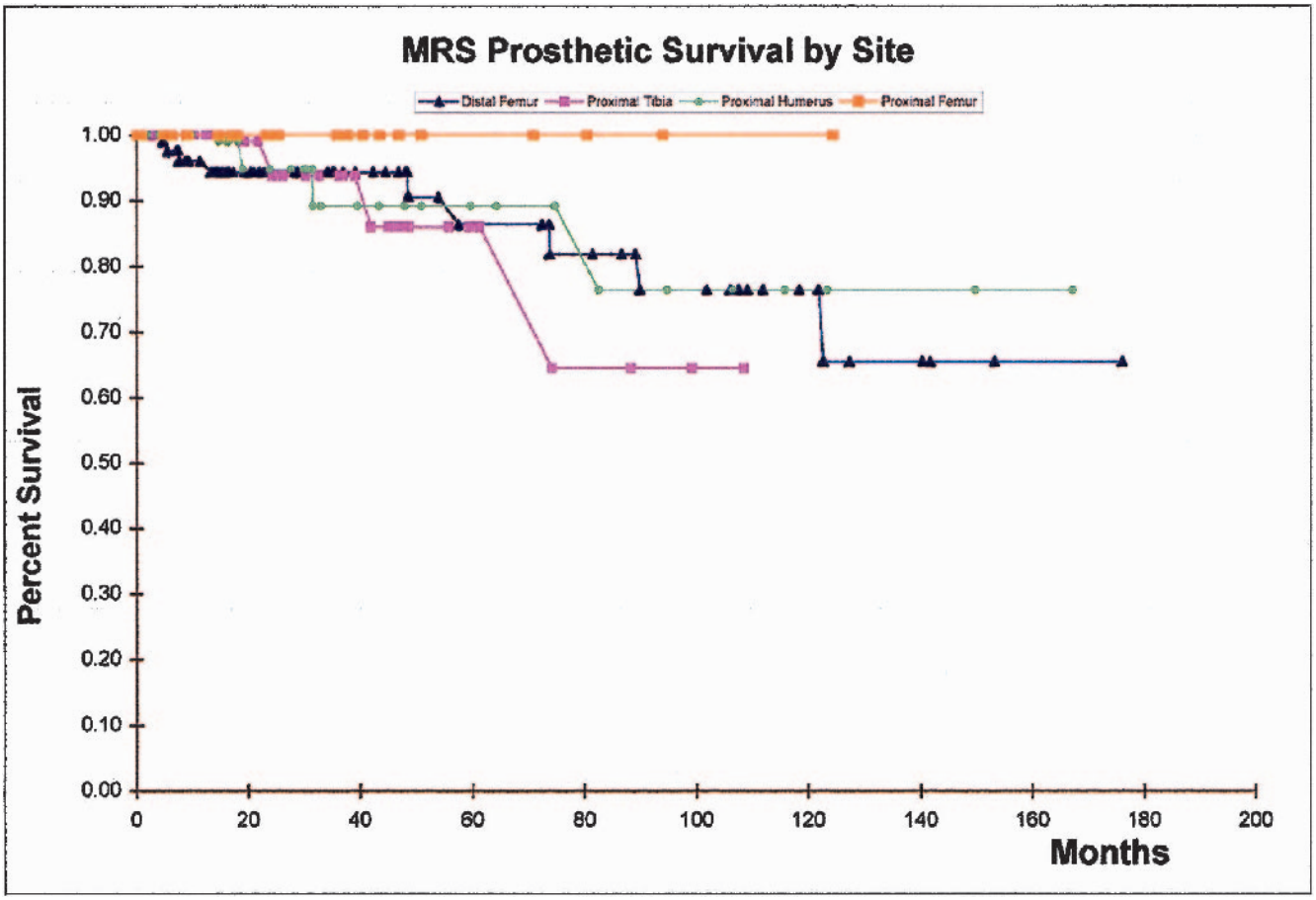
Pelvis and acetabulum

Malignant tumors of the pelvis remain the most challenging for the musculoskeletal oncologist, in terms of achievement of reliable local control and in reconstruction. Resections involving only the supra-acetabular ilium, or pelvic floor (pubic rami and ischium) do not routinely require reconstruction [33]. For tumors involving the acetabulum, however, joint reconstruction remains a challenge, with no method enjoying a clear advantage.

Ozaki *et al.* [34] reported poor results after pelvic reconstruction using custom-manufactured metallic hemipelvic prostheses. The average functional score was 39% in the 42% of prostheses surviving, and scores were even lower in patients whose implants were removed. Schwameis *et al.* [35] reported their results in 30 young patients after pelvic reconstruction at a mean follow-up of 52 months. Reconstruction methods included endoprosthesis (10 patients), autograft (7 patients), APC (2 patients), and other (2 patients); 9 patients underwent no reconstruction. Endoprosthetic reconstruction that was performed with custom-designed pelvic prostheses articulating with the femur through a total hip arthroplasty resulted in the most complications and the poorest functional outcomes, with average MSTS scores of 60%. Patients with autograft arthrodesis reconstruction, either iliac crest bone or autologous medial tibial cortex, fared best, with average functional scores (81%).

Fuchs *et al.* [36••] were able to obtain more consistent surgical and functional results with iliofemoral arthrodesis in a group of 32 patients undergoing periacetabular

Figure 3. Kaplan-Meier curves for modular endoprostheses at multiple anatomic sites.



Survival was 93% for all modular prostheses at the median follow-up of 30 months, 86% at 5 years, and 76% at 10 years. Survival was approximately 85% for distal femur and proximal tibia prostheses at 5 years. Published with permission [10].

resections. They note that patients with the greatest preservation of supra-acetabular ilium are the best candidates for this type of reconstruction. Arthrodesis was performed between the greater trochanter and ilium and sometimes augmented by vascularized iliac crest bone. The radiographic union rate was 86%. At a mean follow-up of 97 months, average MSTS scores were 64%; scores were higher for patients who achieved union.

Other literature

The most difficult postoperative complication after any type of reconstruction is deep infection. Grimer *et al.* [37••] reviewed their experience with staged reimplantation of tumor endoprostheses in 34 patients after initial débridement and placement of antibiotic-containing cement spacers. Their results were encouraging: 91% of infections were controlled at 1 year and 74% at 5 years. Six patients required amputation. Previous radiotherapy and multiple procedures were risk factors for infection.

Finally, Suk *et al.* [38] presented an interesting solution to the problem of finding matched allografts with which to fashion allograft-prosthesis composites. They used the patient's own resected bone, treated with "low heat" (i.e., a 30-minute soak in saline warmed to 65°C) to kill tumor cells without denaturing all proteins. Twelve patients, six with proximal femur and six with proximal humerus reconstructions, were reported. There were no local recurrences or deep infections. The union rate was 92% at a mean of 4.7 months. Three patients had reoperations, one for graft resorption and two for graft fractures after falls.

Conclusion

Extremity reconstruction after resection for bone tumors has clearly advanced over the last 10 years. Durable reconstruction and good function can now be routinely obtained with endoprosthetic reconstruction about the knee. Despite some recent improvements, reconstructions involving the tibia remain more difficult than those of the distal femur. In the shoulder girdle, the type of resection and soft-tissue technique used in reconstruction are probably more important than the type of implant used. Extra-articular resection is recommended for most large stage IIB tumors. Techniques of scapula replacement have advanced and now can provide better

upper extremity function following scapula resection than resection alone with only soft-tissue ("hanging") reconstruction in most cases. In the pelvis and lower extremity, allograft-prosthetic composites and proximal femoral modular prostheses provide reliable and stable hip reconstructions. Acetabular components are not required. Attention to capsular reconstruction is necessary to prevent hip dislocation. Acetabular reconstruction remains challenging, and the literature provides no clear indication on the best option. Arthrodesis remains a good option to complicated and difficult endoprosthetic and/or allograft reconstruction.

Acknowledgments

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • Of special interest
- •• Of outstanding interest

1 Enneking WF, Shirley PD: Resection-arthrodesis for malignant and potentially malignant lesions about the knee using an intramedullary rod and local bone grafts. J Bone Joint Surg Am 1977, 59:223–236.

2 Gebhardt MC, Flugstad DI, Springfield DS, et al: The use of bone allografts for limb salvage in high-grade extremity osteosarcoma. Clin Orthop 1991, 270:181–196.

3 Mankin HJ, Doppelt SH, Sullivan TR, et al: Osteoarticular and intercalary allograft transplantation in the management of malignant tumors of bone. Cancer 1982, 50:613–630.

4 • Brigman BE, Hornicek FJ, Gebhardt MC, et al: Allograft Reconstructions in Young Patients with High-Grade Sarcomas about the Knee. Paper presented at the annual meeting of the American Academy of Orthopaedic Surgeons, Dallas, TX, 2002. Available at: http://www.aaos.org/wordatml/anmt2002/scicess.htm

Retrospective review of osteochondral allografts at one institution. The authors make note of the rate of fracture, infection, and nonunion complications leading to implant failures.

5 Tsuchiya H, Abdel-Wanis ME, Sakurakichi K, et al: Osteosarcoma around the knee: intraepiphyseal excision and biological reconstruction with distraction osteogenesis. J Bone Joint Surg Br 2002, 84:1162–1166.

6 •• Bickels J, Wittig JC, Kollender Y, et al: Distal femur resection with endoprosthetic reconstruction: a long-term followup study. Clin Orthop 2002, 400:225–235.

A large consecutive series of 110 patients who had distal femur resection and endoprosthetic reconstruction. The overall prosthetic survival was 93% at 5 years and 88% at 10 years.

7 Yasko AW, Rutledge J, Tolley S, et al: The Finn Rotating Hinge Segmental Knee Prosthesis Clinical Results at 5–10 year Follow Up. Paper presented at the annual meeting of the Musculoskeletal Tumor Society; Toronto, Canada, 2002. Available at: http://msts.org/Meetings/MSTS/2002/index.htm

8 • Mittermayer F, Windhager R, Dominkus M, et al: Revision of the Kotz type of tumour endoprosthesis for the lower limb. J Bone Joint Surg Br 2002, 84:401–406.

A single-institution review of 251 patients over a period of 15 years using uncemented endoprostheses in the lower limb. The probability of a patient avoiding aseptic loosening for 10 years was 96% for a proximal femoral, 76% for a distal femoral, and 85% for a proximal tibial implant.

9 • Plotz W, Rechl H, Burgkart R, et al: Limb salvage with tumor endoprostheses for malignant tumors of the knee. Clin Orthop 2002, 405:207-215.

Report on 64 consecutive knee endoprostheses between 1976 and 1996. Fifty-eight reoperations were done in 29 patients because of complications. The probability of survival of the leg of the patient after 10 years was 95%.

10 • Wodajo FM, Wittig JC, Graney KK, et al: Low Complication Rate with Limb-Sparing Resection and Endoprosthetic Reconstruction: Survival Analysis of 251 Patients and Analysis of 20-Year Experience. Paper presented at the annual meeting of the American Academy of Orthopedic Surgeons; New Orleans, 2003. Available at: http://www.aaos.org/wordhtml/prevmeet.htm

A single institution review of 251 patients with endoprosthetic reconstructions over 20 years detailing types of complications and prosthetic survival. Overall modular prosthesis survival was 94% at a median of 30 months and 86% at 5 years.

11 • Neel MD, Wilkins RM, Rao BN, et al: Early Experience with a Non-Invasive Expandable Prosthesis for Reconstruction following Tumor Resection about the Knee. Paper presented at the annual meeting of the Musculoskeletal Tumor Society; Toronto, Canada, 2002. Available at: http://msts.org/Meetings/MSTS/2002/index.htm

The authors describe early experience with a new type of expandable prosthesis that uses a noninvasive method of lengthening. This type of implant may be advantageous for very young children who require lower extremity reconstructions.

12 Berlin OK, Bergh P, Gunterberg B, et al: Autobiological Reconstruction with Preserved Joint Function After Surgical Treatment of Bone Sarcomas in Children. In Proceedings of the Connective Tissue Oncologic Society; San Francisco, 2002.

13 • El-Gammal TA, El-Sayed A, Kotb MM: Microsurgical reconstruction of lower limb bone defects following tumor resection using vascularized fibula osteoseptocutaneous flap. Microsurgery 2002, 22:193–198.

A study of 25 patients with lower limb reconstruction by vascularized fibula osteoseptocutaneous flap. Significant hypertrophy (≥30% of original fibular diameter) occurred in 85% of patients after an average period of 10 months from the index operation.

14 Heller L, Phillips K, Levin LS: Pedicled osteocutaneous fibula flap for reconstruction in the lower extremity. Plast Reconstr Surg 2002, 109:2037–2042.

15 Chang HC, Pho RW, Kumar VP, et al: Extremity osteosarcoma: a Southeast Asian experience. Ann Acad Med Singapore 2002, 31:598–606.

16 Deijkers RL, Bloem RM, Hogendoorn PC, et al: Hemicortical allograft reconstruction after resection of low-grade malignant bone tumours. J Bone Joint Surg Br 2002, 84:1009–1014.

17 • Donati D, Giacomini S, Gozzi E, et al: Allograft arthrodesis treatment of bone tumors: a two-center study. Clin Orthop 2002, 400:217–224.

The authors review results of 92 consecutive allograft-arthrodeses of the knee and conclude that the procedure should not be used further unless there are specific indications.

18 Moon BS, Scarborough MT, Worrell D: Long Term Follow-Up of Patients With Allograft Arthrodesis of the Knee. In Proceedings of the American Academy of Orthopedic Surgeons; New Orleans, 2003.

19 Malawer MM, Chou LB: Prosthetic survival and clinical results with use of large-segment replacements in the treatment of high-grade bone sarcomas. J Bone Joint Surg Am 1995, 77:1154–1165.

20 Bickels J, Meller I, Henshaw RM, et al: Reconstruction of hip stability after proximal and total femur resections. Clin Orthop 2000, 400:218–230.

21 Johnson ME, Mankin HJ: Reconstructions after resections of tumors involving the proximal femur. Orthop Clin North Am 1991, 22:87–103.

22 Kabukcuoglu Y, Grimer RJ, Tillman RM, et al: Endoprosthetic replacement for primary malignant tumors of the proximal femur. Clin Orthop 1999, X:8–14.

23 • Ilyas I, Pant R, Kurar A, et al: Modular megaprosthesis for proximal femoral tumors. Int Orthop 2002, 26:170–173.

Fifteen patients with endoprosthetic reconstruction of proximal femur are reviewed. The most frequent complication was hip dislocation, at 20%.

24 • Donati D, Giacomini S, Gozzi E, et al: Proximal femur reconstruction by an allograft prosthesis composite. Clin Orthop 2002, 394:192–200.

Twenty-seven patients with an allograft prosthesis composite reconstruction of the hip are reported. In most of the patients, the prosthesis was a long-stem revision type, cemented in the allograft and uncemented in the femoral shaft. The authors conclude that results compare favorably with those of endoprosthetic reconstruction, with which they state a Trendelenburg gait is common.

25 Farid Y, Lin PP, Weber KL, et al: A comparison of endoprosthetic and allograft-prosthetic composite reconstruction after major resection of the proximal femur for bone neoplasms. In Proceedings of the American Academy of Orthopedic Surgeons; New Orleans, 2003.

26 • Bickels J, Wittig JC, Kollender Y, et al: Limb-sparing resections of the shoulder girdle. J Am Coll Surg 2002, 194:422–435.

The authors summarize the oncologic and functional results of 134 shoulder resections, emphasizing the need for extra-articular resections for high-grade sarcomas.

27 Ozaki T, Putzke M, Rodl R, et al: Incidence and mechanisms of infiltration of sarcomas in the shoulder. Clin Orthop 2002, 395:209–215.

28 • Wittig JC, Bickels J, Kellar-Graney KL, et al: Osteosarcoma of the proximal humerus: long-term results with limb-sparing surgery. Clin Orthop 2002, X:156–176.

Twenty-three patients who underwent extra-articular resections and endoprosthetic reconstruction with local muscle transfers for osteosarcoma are reported. Musculoskeletal tumor society functional scores ranged from 80 to 90%. There were no local recurrences or prosthetic failures.

29 Rodl RW, Gosheger G, Gebert C, et al: Reconstruction of the proximal humerus after wide resection of tumours. J Bone Joint Surg Br 2002, 84:1004–1008.

30 Amin SN, Ebeid WA: Shoulder reconstruction after tumor resection by pedicled scapular crest graft. Clin Orthop 2002, 397:133–142.

31 • Wittig JC, Bickels J, Wodajo F, et al: Constrained total scapula reconstruction after resection of a high-grade sarcoma. Clin Orthop 2002, X:143–155.
A new design for a scapular endoprosthesis using a "snap-fit" mechanism between the humerus and scapular components is described. The authors emphasize the clinical indications, prosthetic design, surgical technique, and early functional results.

32 • Wodajo FM, Bickels J, Wittig JC, et al: Reconstruction with Scapular Endoprosthesis Provides Superior Results after Total Scapular Resection: Surgical Technique and Comparison to Patients Without Endoprosthetic Reconstruction. In Proceedings of the Musculoskeletal Tumor Society; Toronto, Canada, 2002.
The authors compare functional results in 23 patients with total scapular resections, 7 of whom underwent reconstruction with a scapular endoprosthesis. The prosthesis group had improved functional scores and significantly improved abduction and cosmesis. There were no prosthetic failures.

33 Enneking WF, Dunham WK: Resection and reconstruction for primary neoplasms involving the innominate bone. J Bone Joint Surg Am 1978, 60:731–746.

34 Ozaki T, Hoffmann C, Hillmann A, et al: Implantation of hemipelvic prosthesis after resection of sarcoma. Clin Orthop 2002, X:197–205.

35 Schwameis E, Dominkus M, Krepler P, et al: Reconstruction of the pelvis after tumor resection in children and adolescents. Clin Orthop 2002, 402:220–235.

36 •• Fuchs B, O'Connor MI, Kaufman KR, et al: Iliofemoral arthrodesis and pseudarthrosis: a long-term functional outcome evaluation. Clin Orthop 2002, 397:29–35.
Thirty-two patients underwent iliofemoral arthrodesis after resections of pelvic tumors. The radiographic union rate was 86%, and biomechanical analysis showed that the loss of motion in the hip is well compensated. The authors conclude that this method provides durable oncologic and functional long-term results.

37 •• Grimer RJ, Belthur M, Chandrasekar C, et al: Two-stage revision for infected endoprostheses used in tumor surgery. Clin Orthop 2002, 395:193–203.
The authors used a two-stage reimplantation for deep infection following endoprosthetic reconstruction in 34 patients and were able to obtain impressive overall success rates of 91% at 1 year and 74% at 5 years. Six patients required amputation.

38 Suk KS, Shin KH, Hahn SB: Limb salvage using original low heat-treated tumor-bearing bone. Clin Orthop 2002, 397:385-393.