Multiplanar Osteotomy with Limited Wide Margins

A Tissue Preserving Surgical Technique for High-grade Bone Sarcomas

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Abstract

Background Limb-salvage surgery has been used during the last several decades to treat patients with high-grade bone sarcomas. In the short- and intermediate-term these surgeries have been associated with relatively good function and low revision rates. However, long-term studies show a high rate of soft tissue, implant, and bone-related complications. Multiplanar osteotomy with limited wide margins uses angled bone cuts to resect bone tumors with the goal of complete tumor removal while sparing host tissue although its impact on local recurrence is not known. **Questions/purposes** We determined whether multiplanar osteotomy was associated with local recurrences, reconstruction failures, and allograft nonunions. **Patients and Methods** We retrospectively reviewed the charts of six patients. Four patients had an osteosarcoma, one had a Ewing's sarcoma, and one had a chondrosarcoma.

Investigation was performed at the University of Chicago. Each author certifies that he or she has no commercial associations (eg consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article. Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent was obtained.

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Patient and treatment factors such as age, diagnosis, percent of tumor necrosis (if applicable), margin status, and time to allograft union were recorded. In all patients, reconstruction was performed with an intercalary allograft cut to fit the residual defect. The minimum followup was 25 months (average, 39 months; range, 24–66 months).

Results No patient experienced a local recurrence or metastasis, and all patients were alive and disease-free at the most recent followup. All allografts healed during the study period.

Conclusion With careful patient selection, the multiplanar osteotomy resection technique may be considered an option for treating patients with high-grade bone sarcomas, and, when compared with traditional surgical techniques, may lead to improved healing and function of the involved extremity.

Level of Evidence Level IV, therapeutic study. See the guidelines online for a complete description of levels of evidence.

Introduction

Surgery for bone sarcomas involves either amputation of the affected extremity or resection of the tumor and reconstruction of the resulting defect. Improvements in imaging technology, adjuvant chemotherapy, and surgical techniques have made it possible for the majority of patients with bone sarcomas to undergo successful limb-sparing surgical procedures [2]. Some authors have reported short- and intermediate-term implant or allograft survival ranging from 83% to 98% at 5 years followup [4, 20]. However long-term followup studies report high failure rates, ranging from 10% to 42%, owing to mechanical failure, aseptic loosening of implants, allograft nonunion, and fracture

[21, 22, 32]. Other complications such as local recurrence, nerve palsies, and infection reportedly occur in 3% to 12% of patients [4, 14, 20, 21, 32]. These reports suggest most patients who survive their underlying disease eventually will require a repeat operation to treat a failed reconstruction. The high rates of failure are attributed to the extensive bone and soft tissue removed during tumor resection [26], the difficulty achieving stable fixation of implants, high loads transmitted across implants, and vulnerability to infection [7, 14, 15, 17, 22].

To decrease the risk of complications associated with limb-salvage reconstructions, such as implant failure, allograft nonunion, and infection, surgeons attempt to preserve host tissues during tumor resection that requires minimizing the margin of healthy tissue surrounding the tumor. However, inadequate tumor resection is associated with a high risk of local recurrence that in turn affords a poor overall prognosis [5, 27, 30]. One study of 237 patients with high-grade osteosarcomas reported only 11% of patients who had local recurrences were living at the most recent followup [25]. Given the high risk of local recurrence with a contaminated margin [2] and the resulting poor prognosis, many physicians are reluctant to perform a resection that achieves less than generously wide margins [1, 2]. In contrast, some authors have reported no local recurrences and no nonunions, with a resection technique used for low-grade surface osteosarcomas that retains part of the cortical circumference [1, 8, 19]. This technique, termed hemicortical or hemicylindrical resection, removes the tumor while maintaining a portion of the host cortex to enhance healing and function [1, 8, 19]. In high-grade tumors near joints, one report suggests trying to save the articular surface by performing a transepiphyseal osteotomy [23]. This is accomplished by performing a standard transverse osteotomy and requires adequate residual bone in the epiphysis to which an allograft may be

secured. We use a technique with a limited wide margin to surgically treat select patients with high-grade bone sarcomas with the goal of minimizing bone and soft tissue ablation. Rather than standard transverse or step-cut osteotomies, this technique is performed by making angled bone cuts around a tumor, with the goal of preserving as much host bone as possible, important soft tissue attachments to bone, and in some cases, a portion of the cortical circumference. The technique often involves a geometric pattern of osteotomies to resect the tumor, and at some locations results in a limited wide margin near the tumor, thus the name ‘multiplanar osteotomy with limited margins’.

We describe the technique and report six patients who underwent this technique and identified the: (1) number of local recurrences; (2) the number of allograft nonunions; and (3) the functional scores and complications.

Patients and Materials

Between January 2000 and August 2008, 101 patients with high-grade bone sarcomas of the pelvis and extremities were treated by our orthopaedic oncology service. Of these 101 patients, six met the indications for, and underwent, multiplanar osteotomy resection with limited wide margins and intercalary allograft reconstruction (Table 1). We offered patients the option of this surgical technique if, based on preoperative assessment, all of the following criteria were met: (1) it likely would offer an advantage over standard surgery with respect to postoperative function or healing (eg, preserving the joint, native bone, tendon, or ligament); (2) there would be a minimum of 1 cm margin of normal bone after osteotomy; and (3) a stable reconstruction could be achieved based on the senior surgeon’s assessment. Although 1 cm was the required

Table 1. Patient demographics and tumor-related variables

Patient	Gender, age (years)	Diagnosis	Site	Size (cm)	Enneking stage	Duration of followup (months)	Induction chemotherapy	Tumor necrosis (%)	Partial cortex intact
1	F, 19	Chondrosarcoma	Proximal femur	2.2 × 3.0 × 2.0	IIA	66	NA	NA	Yes
2	F, 17	Osteosarcoma	Distal femur	2.4 × 3.3 × 3.0	IIA	36	Doxorubicin, etoposide, ifosfamide	100	Yes
3	M, 11	Ewing’s sarcoma	Distal tibia	6.0 × 3.1 × 4.1	IIA	25	Vincristine, cyclophosphamide, doxorubicin, etoposide	90	Yes
4	M, 14	Osteosarcoma	Proximal tibia	7.2 × 4.0 × 4.9	IIB	31	Doxorubicin, etoposide, ifosfamide	100	No
5	F, 19	Osteosarcoma	Distal femur	8.0 × 5.5 × 3.9	IIB	40	Doxorubicin, etoposide, ifosfamide, carboplatin	100	No
6	M, 13	Osteosarcoma	Proximal tibia	2.5 × 3.0 × 2.9	IIB	35	Doxorubicin, etoposide, ifosfamide	100	No

minimum margin, which was decided arbitrarily based on the senior surgeon's experience, in situations where there was sufficient tissue, a larger margin was obtained at the discretion of the senior surgeon if it was thought that it may benefit the patient without substantially adding to the surgical morbidity. Patients were excluded from consideration for this type of surgery if they had tumor progression while receiving neoadjuvant chemotherapy. Patients were informed of the advantages, disadvantages, and surgical alternatives to the resection technique. Proper location and direction of the osteotomies were determined by evaluating axial, coronal, and sagittal images from the most recent MRI (Fig. 1). No patients who met the preoperative planning criteria were excluded or refused surgery. Given most recurrences of high-grade bone sarcomas occur within 2 years after surgical treatment [5], the minimum followup was set at 2 years. The patients were followed for a minimum of 25 months (average, 39 months; range, 25–66 months).

No patients were lost to followup. We obtained prior permission from the Committee on Human Research to perform this study. Informed consent to participate in the study was obtained from each subject. This study was performed in accordance with relevant regulations of the US Health Insurance Portability and Accountability Act (HIPAA).

All diagnoses were made after open biopsy using strict musculoskeletal oncology principles to minimize surrounding tissue contamination and review of histologic slides by a pathologist specializing in musculoskeletal tumors [12]. Patients with chemosensitive tumors such as osteosarcoma and Ewing's sarcoma received neoadjuvant chemotherapy administered by an oncologist whereas patients with chemoresistant tumors did not (Table 1). All patients underwent diagnostic imaging with plain radiographs and MRI at the time of diagnosis and after induction chemotherapy, if applicable. T1 and T2-weighted, STIR, and gadolinium-enhanced T1 fat-suppressed images were

Fig. 1A–D Patient 4 was a 14-year-old boy with a high-grade osteosarcoma. **(A)** An example of preoperative planning on a coronal T2 MR image is shown. The yellow lines represent proposed osteotomy planes. Similar planning was completed on sagittal and axial images. The osteotomy spares a portion of the medial collateral ligament that provides stability to the final reconstruction. **(B)** An intraoperative photograph shows residual host bone after the multiplanar osteotomy making it possible to perform a joint-sparing intercalary osteotomy. **(C)** Anteroposterior and **(D)** lateral radiographs obtained 18 months after surgery show united allograft to host bone.

used to evaluate the extent of the tumor. Bone marrow showing increased signal on T2 and STIR images or enhancement after gadolinium administration was considered to be involved with the tumor.

Intravenous antibiotics were administered immediately before surgery. Intraoperative landmarks such as the femoral epicondyles, patella, greater trochanter, and subchondral bone were correlated to preoperative planning by palpation and fluoroscopic imaging. After proper location and direction of the bone cuts were determined, a combination of an oscillating saw and osteotomes was used to perform the resection using fluoroscopy to verify accuracy. Frozen section examination was performed, and once the margins were confirmed to be negative, the allograft bone was thawed in warm antibiotic saline solution. Allografts that most closely matched host bone size and anatomy were selected from a commercial bone bank (AlloSource, Centennial, CO). The defect was measured in all planes (longitudinal, anteroposterior, mediolateral). The angles between the resection planes were measured with a goniometer when possible; otherwise the shape of the defect was traced on paper using a sterile marker. Based on these measurements, the allograft bone then was shaped to match the defect using an oscillating saw, and secured in place using plates and screws in five patients and an intramedullary nail with cerclage wires in one. In three patients the

resections were performed such that a segment of the patient's cortex remained intact (Figs. 2, 3, 4). For proximal tibia allografts the donor patellar tendon was cut to overlap the residual host tendon and sutured in place to reconstruct the extensor mechanism. A gastrocnemius flap was rotated over the allograft to provide soft tissue coverage.

Antibiotics were administered postoperatively for a minimum of 24 hours, or until the deep drains were discontinued. Patients were restricted from weightbearing for 3 to 6 months after reconstruction based on radiographic evidence of allograft healing.

Followups were performed 2 weeks, 6 weeks, and 3 months after surgery, then every 3 months until 2 years after surgery, and then every 6 months until 5 years after surgery. Plain radiographs and physical examination were performed at each followup. Chest CT was performed every 3 months until 2 years after surgery and then every 6 months to evaluate for metastatic disease. Outcomes including allograft healing, nonunion, tumor recurrence, fracture, hardware failure, infection, and pain were recorded. Functional outcome was evaluated at the most recent followup using the revised system established by the Musculoskeletal Tumor Society (MSTS) and adopted by the International Society of Limb Salvage (ISOLS) [10]. This score measures outcome in six categories including pain, function, use of walking aids, emotional acceptance,

Fig. 2A–F Patient 2 was a 17-year-old girl with a high-grade distal femur osteosarcoma. The tumor can be seen on this (A) AP radiograph. (B) A gadolinium-enhanced T1 fat-saturated axial MR image shows the lesion after neoadjuvant chemotherapy.

Intraoperative photographs show (C) the defect in the distal femur after tumor resection and (D) the intercalary allograft after reconstruction. Eighteen months after surgery, union at the allograft-host bone junction is seen on these (E) AP and (F) lateral radiographs.

Fig. 3A–J Patient 1 was a 19-year-old woman with a high-grade chondrosarcoma of the left proximal femur. The tumor can be seen in this (A) AP radiograph. (B) Gadolinium-enhanced T1 fat-saturated coronal and (C) axial MR images show the extent of the tumor in the proximal femur. (D) An intraoperative photograph shows the planned surgical incision to excise the biopsy tract with the tumor. (E) An intraoperative photograph shows the intact medial cortex after tumor

excision, and (F) an intraoperative fluoroscopic image shows the extent of the bony resection. (G) An allograft was shaped to fit the defect and stabilized with cerclage wires and an intramedullary nail. (H) The resection specimen was bivalved to reveal the tumor and biopsy tract (arrow). (I) AP and (J) lateral radiographs were obtained 3 months after surgery. A greater trochanter avulsion fracture can be seen; the patient was asymptomatic at final followup.

walking ability, and gait. Each parameter is scored 0 to 5 and combined for a possible total score of 30.

Two of us (TP, RA) evaluated all serial radiographs. Blinding was not possible because all authors were familiar with the six patients in the study. Union was defined by the

criteria for allograft healing described by Enneking and Mindell [11]. Cancellous healing was indicated by the presence of a narrow zone of increased radiodensity that had advanced into the allograft, and cortical healing was indicated by bridging external callus advancing from the

host bone onto the allograft on at least three cortices. We did not consider a radiolucent gap at the osteotomy as necessarily indicating nonunion. Nonunion was defined as failure of the allograft to incorporate after 1 year from the time of reconstruction.

Results

At the final followup, no patient experienced a local recurrence or metastasis (Table 2). The resection margins were greater than 1 cm in all patients. There were no hardware failures. Two patients had nonunion at the diaphyseal junction site and underwent hardware augmentation and bone grafting. At last followup, both patients had achieved healing without additional complications. One patient had apparent delayed union of the diaphyseal junction site. An external bone stimulator was applied and union was achieved by final followup. All three patients who underwent partial cortical resection experienced fracture of the reconstruction, and all achieved healing with conservative measures with no additional complication. One patient (Patient 6), who had a gastrocnemius flap and split thickness skin graft to cover a proximal tibial reconstruction, experienced wound dehiscence and skin necrosis. This occurred during the immediate postoperative period and was treated with débridement and transposition of a free fasciocutaneous flap. The patient's wound healed without additional complications. No patients in the study experienced an infection.

The average MSTS/ISOLS score at the most recent followup was 29 points (range, 29–30 points). All patients were pain-free or had only occasional pain that responded to antiinflammatory medication. All patients resumed activities of daily living without restriction. Five patients resumed sporting activities including golf, soccer, distance running, basketball, and volleyball.

Discussion

Surgery for high-grade bone sarcomas is associated with a high complication rate including hardware failure, allograft nonunion, fracture, and infection [4, 15, 20–22, 24, 32]. This likely is attributable to the extensive amount of soft tissue and bone that must be removed during tumor resection [17, 23, 32]. We describe a technique called multiplanar osteotomy with a limited wide margin to surgically treat a few select patients with high-grade bone sarcomas with a goal of minimizing ablation of healthy bone and soft tissue. This technique is performed by making angled bone cuts around a tumor rather than standard transverse osteotomies with the goal of preserving host bone, important soft tissue attachments to bone, and in some cases, a portion of the cortical circumference. We report the local recurrences, nonunions, functional outcomes, and complications in a group of patients who underwent multiplanar osteotomy with a limited wide resection of high-grade bone sarcomas.

Table 2. Clinical outcomes and complications

Patient	Healed at final followup (yes/no)	Local recurrence	Function	Activities	Complication	Complications—time to occurrence (months)	Complication treatment	Complication outcome
1	Yes	No	28	Recreational	Greater trochanter fracture	2	Observation	Healed, no sequelae
2	Yes	No	30	Running, volleyball	Nondisplaced femoral condyle fracture	1	Observation	Healed, no sequelae
3	Yes	No	30	Soccer	Nondisplaced fracture at proximal junction	24	None (fracture spontaneously healed without intervention)	Healed, no sequelae
4	Yes	No	29	Recreational	Diaphyseal nonunion	14	Iliac crest bone graft and revision of broken screws	Healed, no sequelae
5	Yes	No	29	Recreational	Diaphyseal nonunion	16	Revision of hardware and allograft bone grafting	Healed, no sequelae
6	Yes	No	29	Competitive golf	Wound dehiscence; Diaphyseal delayed union	0.33, 12	Free fasciocutaneous flap; External bone stimulator	Healed, no sequelae

◀ **Fig. 4A–L** Patient 3 was an 11-year-old boy with Ewing's sarcoma of the right distal tibia. The tumor can be seen on these (A) AP and (B) lateral radiographs. (C) Gadolinium-enhanced T1 fat-saturated axial and (D) coronal MR images were obtained before chemotherapy. (E) Gadolinium-enhanced T1 fat-saturated axial and (F) coronal MR images obtained after chemotherapy are shown. (G) Intraoperative photographs were taken at completion of the osteotomies and (H) after tumor removal. (I) An allograft was shaped to fit the defect and stabilized with a plate and screw construct. (J) The resection specimen was bivalved to reveal the tumor. (K) AP and (L) lateral radiographs obtained 6 months after surgery show union at the allograft host bone junction sites.

Several limitations of this study should be noted. First, given the limited scope of our study, we cannot make any conclusions regarding the appropriate margin for high-grade bone sarcomas; however, the absence of any local recurrence in our patients suggests that multiplanar osteotomy resection with limited wide margins may be adequate for patients who meet the inclusion criteria described in our study. The technique we describe relies on a narrow but wide margin of resection. We assumed that a minimum 1-cm margin was adequate for the surgeries we performed based on the senior surgeon's experience and expertise. However, the best size of the surgical margin is controversial and depends on several factors including tissue type of the margin, tumor grade, histology, and response to neoadjuvant treatment [2, 3, 5, 6, 25]. As a result, instead of quantifying the margin, some authors report margins as either adequate or inadequate if there is a tumor or reactive tissue at the margin [2, 3, 5, 23, 25]. Second, the multiplanar osteotomy with limited wide-margin technique relies on careful patient selection and only a small proportion of patients (6 of 101) with high-grade bone tumors were candidates for this type of surgery. Although we relied on objective criteria to determine patient eligibility, we recognize patient selection is a difficult and somewhat subjective process that relies on several factors including surgeon experience, ability to interpret MR images, and ability to measure tumor response to neoadjuvant treatment, for which there is no validated measure. These difficulties highlight that this technique is not appropriate for the majority of patients with bone sarcomas. Finally, given the small and heterogeneous patient population with respect to age and diagnosis, we can make no conclusions regarding whether or how the pathologic characteristics such as histologic subtype of a given tumor or the effect of neoadjuvant therapy influence the safety of this technique.

The rate of local recurrences and functional outcome scores in our study are similar to those reported in other studies that use either angled bone cuts or limited margins to treat bone sarcomas (Table 3). Reports on a surgical technique similar to the one we describe with respect to angled bone cuts and host bone preservation, albeit to treat

low-grade tumors, have indicated there were no local recurrences or metastasis [1, 8, 19]. In a study of 13 patients with a high-grade metaphyseal osteosarcoma around the knee who underwent transepiphyseal resection and reconstruction with an intercalary allograft, Musculo et al. reported one local recurrence [23]. Our study differs from these reports because our patients all had high-grade tumors, and in all patients we used angled bone cuts rather than standard transverse osteotomies. Local recurrence is associated with a poor prognosis in patients with bone sarcomas, with one study reporting only 11% long-term survival [2] in patients who had a local recurrence. Resection of bone tumors with wide margins is recognized as being important in minimizing the risk of local recurrence [2, 5, 9, 13]. However, the best margin for a given tumor is unknown because many variables such as tumor histology, biologic behavior, response to neoadjuvant therapy, and tissue type at the margin contribute to determining the ideal margin [5, 25, 30]. It is a challenge to the musculoskeletal oncologist to know how to balance the amount of tissue resection needed to adequately resect a tumor with the quantity of tissue needed for maximizing the reconstructive and functional outcomes. The use of MRI helps with this challenge when planning a bone tumor resection [28, 30, 31] as it allows the surgeon to determine the extent of the tumor and its relationship to surrounding structures, which can be correlated to intraoperative landmarks [23] to estimate the location of the tumor and the osteotomies required to resect it. MR images also can be used to estimate the degree of tumor necrosis by comparing the size of the tumor from images obtained at the time of diagnosis with those obtained after neoadjuvant chemotherapy [28, 33]. We used this approach to treat patients with high-grade bone sarcomas using multiplanar osteotomies with limited wide margins. The absence of local recurrence suggests this technique may be an appropriate option for select patients with high-grade bone tumors. Neoadjuvant chemotherapy likely reduced the risk of local recurrence in the current series; however, our patient with a chondrosarcoma did not receive chemotherapy and has been disease-free for 66 months. More experience is needed to confirm whether the procedure is associated with low recurrence rates when the margins are narrow without effective adjuvant chemotherapy. Thorough preoperative evaluation and proper patient selection are critical to ensure that a tumor can be resected using multiplanar osteotomies without compromising the margin and increasing the risk of local recurrence.

Nonunion or delayed union occurred in the three patients who had whole-segment allograft reconstructions. Nonunion is a known complication associated with allograft use and is more likely to occur in diaphyseal segments of the host bone [17, 24]. In a study of 116 patients with allograft reconstructions around the knee, Brigman et al. reported a nonunion rate of 34% of which 42% ultimately

Table 3. Comparison of published data

Study	Number of patients	Diagnosis	Grade	Type of surgery (ES, HC, GO)	Margin (as reported by authors)	Time to local recurrence (months)	Followup (months)	Complications	Revision surgery	MSTS function (average)
Deijkers et al. [8]	22	Parosteal osteosarcoma (6), Adamantinoma (10), Chondrosarcoma (6)	Low	HC	Wide (19) Marginal (3)	None	Mean 64	RSD (1 patient) at 2 years Fracture (6 patients) at 13 days to 1 months Fixation failure (2 patients) at 1 and 17 months	7 patients underwent surgery to treat a fracture or failed hardware	25.1
Agarwal et al. [1]	10	Parosteal osteosarcoma (8), Chondrosarcoma (1), High Grade surface osteosarcoma (1)	Low (9) High (1)	HC	Uninvolved (10)	None	Mean 51	Seroma (1) Common peroneal nerve palsy (1, resolved by 6 weeks) Fracture (1 patient)	1 patient underwent ORIF of fracture; 1 patient had seroma drainage	29.6
Lewis et al. [19]	6	Parosteal osteosarcoma	Low	HC	Wide (5) Marginal (1)	None	51.6	None	None	Good to excellent per Mankin score
Muscolo et al. [23]	13	Conventional osteosarcoma	High	ES	Adequate (13)	1 local recurrence, time not given	Not stated	Fracture (3) Diaphyseal nonunion (2) Deep infection (1) Local Recurrence (1) Cancer related death (1)	3 fractures replaced by new allografts; 2 patients with nonunions underwent revision of hardware and bone grafting; 1 patient with infection has had 2 I&Ds and allograft removal	27
Current authors	6	Conventional osteosarcoma (4) Ewing's sarcoma (1) Chondrosarcoma (1)	High	GO	Minimum 1 cm	none	Minimum 24	Fractures (3) Diaphyseal nonunion (2) Wound dehiscence (1) Delayed union (1)	2 patients with nonunions underwent hardware augmentation and bone grafting; 1 patient with wound dehiscence required free flap and delayed union in same patient healed with bone stimulator	29.2

ES = epiphyseal sparing with traditional osteotomy and allograft reconstruction; HC = hemicortical with allograft reconstruction; GO = geometric osteotomy with allograft reconstruction.

failed [7]. Our observations are consistent with those in previous reports [21, 23, 24] that allograft nonunion is a serious complication that can prolong the morbidity associated with surgery. Two of our patients required repeat surgery to treat allograft nonunions, and one underwent electrical stimulation with prolonged activity restriction. However, all three patients ultimately achieved healing of their osteotomies and have MSTs function scores of 28 or greater. Strategies to deal with nonunion include maximizing the anatomic fit and fixation stability of the allograft to the host bone, and ensuring the patient has adequate nutritional intake.

The three patients who had partial cortical preservation had fractures adjacent to their allografts, but all fractures healed without surgery. In one patient the fracture already had healed by the time the patient presented for evaluation. The fact that all fractures healed rapidly further supports the idea that an intact cortex stabilizes the reconstruction and facilitates recovery from complications. We now use several strategies to minimize the risk of fracture near a partial cortical resection. After tumor resection near the greater trochanter, we prophylactically stabilize the trochanter with large fragment screws. When tumors are located in the diaphysis or metadiaphysis, we perform resections with curved angles rather than sharp ones to optimize stress distribution and theoretically minimize the risk of fracture.

When treating patients with high-grade bone sarcomas, the surgical goal is to achieve tumor control, and do so in a manner that provides good function. During the last few decades the principle treatment for extremity sarcomas has transitioned from amputation to limb salvage [26, 29]. As diagnostic technology, adjuvant treatments, and surgical procedures continue to improve, function- and tissue-sparing procedures become easier to perform. We describe a new surgical technique for treating high-grade bone sarcomas that uses multiplanar osteotomies with limited wide margins to remove a tumor while preserving host bone. In certain cases, this allows the surgeon to preserve a portion of the native cortex or important soft tissue attachments that facilitates healing and affords strength to the reconstruction. Preserving these structures may provide stability to the reconstruction which may improve longevity of the joint [16, 18]. As a result, surgeons may consider taking advantage of the ongoing developments in adjuvant treatments and radiology techniques, including intraoperative imaging, to perform tissue-preserving surgeries that maximize functional outcome while adhering to tumor surgery principles.

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