Joint-sparing or Physeal-sparing Diaphyseal Resections

The Challenge of Holding Small Fragments

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Abstract

Background Joint-sparing or physeal-sparing diaphyseal resections are technically challenging when only a small length of bone is available for implant purchase.

Questions/purposes We describe a series of cases with the aim of generating some guidelines as to the choice of reconstruction method and the implant used.

Methods We retrospectively reviewed 25 patients with diaphyseal resections in which the remaining epiphyseal or metaphyseal segment provided 3 cm or less of purchase. Reconstruction was performed with bone (allograft, extracorporeally radiated autograft, or vascularized fibula) in 19 cases or a custom diaphyseal implant (CDI) in six. The implants used for holding the bone construct varied from standard plates to custom plates. The presence of union, function, complications, and disease status at last followup was recorded.

Results Sixteen of the 25 patients are disease-free and alive with the original construct at a median followup of 34 months (range, 12–66 months). Implant-related complications such as plate breakage (four) and angulation

(three) happened more frequently when weak plates such as reconstruction plates were used. Local recurrence with pulmonary metastases occurred in two cases. The two deep infections required an amputation or rotationplasty for control. Custom plates were successful in three of four patients.

Conclusions Weak plates such as reconstruction plates are best avoided for these reconstructions. Custom plates allow secure fixation with technical ease. CDIs allow immediate weightbearing and ability to lengthen with predictable good functional short-term outcome.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

The principles of limb salvage surgery for bone tumors involve resection of the tumor-bearing bone with a wide margin and reconstruction of the resulting gap. A 3-cm margin is recommended from the bony extent seen on MRI [12, 13]. Because most tumors are metaphyseal, resection often includes the articular surface for which endoprosthetic reconstructions are done. Megaprotheses do not allow full knee flexion [9] and require revisions for failure [2, 9, 15, 18]. Sometimes the tumors are localized to the metaphysis, allowing the surgeon to resect them with an adequate margin without sacrificing the joint or the growth plate. This may be particularly advantageous around the knee where a prosthesis has a higher failure rate [18] than the shoulder or proximal femur and the growth is maximum. With more effective chemotherapy and accuracy of MRI in delineating the tumor [10], closer margins are being used allowing more joint- or physeal-sparing resections [20].

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.

All investigations were conducted in conformity with ethical principles of research.

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Diaphyseal resections through the epiphysiometaphyseal area have been well documented [6, 14, 20]. Various reconstruction methods such as allografts, autografts, or diaphyseal implants have been reported [3, 4, 6, 11, 19, 20]. The challenge in these patients has been to use a construct that can reliably grip and hold the small joint- or physis-containing fragment. Various implants such as conventional or custom plates, nails, and segmental metal prostheses have been used [3, 4, 6, 11, 19, 20], but no guidelines exist as to the choice of the implant or construct. The challenge for the surgeon is to obtain secure fixation to allow uneventful healing with full function and without deformity or implant failure. Modern engineering technology is now making possible custom-made implants on a regular basis, but its impact on the surgical technique and outcome is not well known.

We determined patient survival and examined the complications and function of these diaphyseal constructs with one of the fragments containing 3 cm or less bone. Using our observations about construct failure, we formulated guidelines as to the construct and implant to be used when performing joint-sparing or physis-sparing surgery with short-length fragments.

Patients and Methods

We retrospectively reviewed 89 patients who had diaphyseal resections of the femur, tibia, or humerus while preserving the joints at either end of the long bone between January 2000 and December 2008. We selected only those 25 patients in whom at least one fragment containing either the physis or the joint was less than 3 cm in length and only those with resections of the large long bones, ie, femur, tibia, or humerus (Table 1). The length of the short fragment was calculated as the distance between the bone cut and either the physis or the articular surface, depending on whether a physis-sparing or joint-sparing resection was done. There were 18 males and seven females with ages ranging from 2 years to 43 years. Femur was involved in 14 patients, tibia in 10, and humerus in one case. Physis-preserving surgery was performed in eight patients and the other 17 were joint preservation surgeries. The minimum followup was 12 months (mean, 34 months; range, 12–66 months). No patients were lost to followup.

All patients had standard orthogonal radiographs and MRI to assess the local extent, chest radiograph and CT scan of the chest to screen for pulmonary metastases, and a bone scan or a positron emission tomography scan for assessing skeletal metastases. Fourteen patients had an open biopsy performed elsewhere; their slides were reviewed at our institute and a histologic diagnosis made. For others, a core needle biopsy was performed to establish

the histologic diagnosis. There were 13 patients with osteosarcomas, 11 with Ewing's sarcoma, and one with chondrosarcoma. All osteosarcomas and Ewing's sarcomas were given neoadjuvant chemotherapy as per the institution protocol.

A joint-sparing or physis-sparing resection was planned if 1.5 cm of tumor-free bone could be preserved from the articular surface or physis, respectively, after at least a 2-cm margin was obtained from the tumor. Wherever possible, a 3-cm bony margin was obtained. Frozen section was used to confirm a negative margin. The margins were tumor-free in all patients. The length of resection varied from 7 cm to 28 cm (mean, 18 cm). Various methods were used to reconstruct the defect (Table 2). Allografts alone were used in two patients, both for femoral defects. The allografts were frozen and irradiated and were processed and procured from the in-house tissue banking facility. Allograft was combined with a vascularized fibula in one other case of femoral resection. Extracorporeal irradiation and reimplantation (ECRT) [1, 5] was used in 10 patients. The specimen was stripped of the soft tissues and then wrapped in sterile layers of towels and a plastic sheet and transferred to the in-house radiation facility to receive 5000 rads in a single dose and then brought back for reimplantation (Fig. 1). This process of transfer and retrieval took between 60 and 90 minutes.

In three cases, tibialization of the fibula (TOF) [7, 16, 17] was performed (Table 1). The fibula was osteotomized 1 cm proximal and distal to the tibial cut and then translated into the defect, keeping the soft tissue envelope for vascularity and telescoped into the medullary cavity of the tibia (Fig. 2).

The fixation methods varied from standard plates of various types to customized plates and implants (Table 3). In some cases, customization was in the form of just an extralong standard implant like a Dynamic condylar screw (DCS) (Sushrut Surgicals, Devrukh, India) plate or dynamic hip screw (DHS) (Sushrut Surgicals). In four patients, completely customized plates were used. For this, a plan and design was discussed with the manufacturer (Stanmore Implants Worldwide, London, UK) and CT scans of the entire bone were provided to them. The plates were designed in such a way as to allow purchase for at least three screws in the small fragment (Fig. 1). Three of the plates were made of titanium and coated with hydroxyapatite (HA) and sourced from Stanmore (London, UK). One plate was made in stainless steel by a local implant manufacturer (Sushrut-Adler). We contoured standard plates or long standard implants to ensure proper fitting of the plate to the bone. If a DCS plate was used medially, proper contouring was necessary for anatomic alignment (Fig. 2). The long standard plates were made of vacuum-remelted stainless steel. The custom diaphyseal

Table 1. Demographic and reconstruction details with oncologic and functional outcome

Joint- or physis-sparing	Bone involved	Which is the small fragment	Reconstruct	Gender/age (years)	Type of plate used (length)	Size of small fragment	Comments	Histology	Date of surgery	Disease status	MSTS score
Joint-sparing	Femur	Distal	Allograft	F/9	DCS (26 cm)	3 cm	DCS contoured and applied medially	OGS	March 2005	DF	29
			Allograft	F/13	DCS (33 cm)	3 cm	BG for union, plate breakage, revised to Allo with VF 1 month ago	OGS	April 2006	DF	NA
			Allo-VF	M/10	Recon. plate	3 cm	Angulation	OGS	March 2004	DF	27
			ECRT	F/16	DCS (32 cm)	3 cm	Excellent function and incorporation of implanted bone	Ewing's	June 2006	DF	29
			ECRT	M/17	Hockey stick plate (29 cm)	3 cm	Hockey stick plate revised recently with another plate for nonunion and severe angulation	OGS	August 2008	DF	NA
		Proximal	MIEJSI	M/12	NA	2.5 cm	100° knee flexion	Ewing's	July 2007	DF	27
			NIEJSI	F/10	NA	2.5 cm	120° knee flexion	OGS	August 2008	DF	29
			ECRT	M/16	DHS 34 cm	3 cm	Infection, implant removed and rotationplasty done	Ewing's	December 2006	DF	NA
			VF	M/8	2 contoured DCPs	3 cm	Good growth from proximal physis, lateral plate removed, excellent function	Ewing's	May 2003	DF	30
			NIEJSI	M/8	NA	2 cm distal, 4 cm prox.	Proximal fragment also small (4 cm), Rhino stem to fix implant into neck	OGS	May 2008	DF	29
Physis-sparing	Tibia	Proximal	TOF	M/12	L plate	3 cm	United, LR + PM at 18 months	OGS	April 2002	LR + PM dead	NA
			ECRT	M/9	Hockey stick plate	1.5 cm	United uneventfully with good function	Ewing's	March 2006	PM at 1 year	29
			ECRT	M/14	Hockey stick plate	2 cm	Soft tissue LR, excised 1 year ago	OGS	June 2006	DF	29
			JSI	F/13	NA	1.5 cm	Chemotherapy related complications causing death at 8 weeks	Ewing's	February 2007	Dead	NA
			JSI	M/43	NA	2 cm	Good extension, full ROM, good gait	Ewing's	October 2008	DF	29
	Humerus	Distal	TOF	M/43	Custom plate	2.5 cm	Walking FWB, united	Chondrosarcoma	July 2008	DF	29
			ECRT	M/10	Recon. plate, revised to DCP	3 cm	Recon. plate breakage revised	Ewing's	March 2007	PM, dead	NA
			JSI	M/11	NA	2 cm	Excellent function; good growth from distal physis	OGS	July 2007	DF	30
			ECRT	F/8	Custom plate	1.5 cm	Varus and antecurvatum deformity, revised to locking plate, LR + PM	OGS	July 2008	LR and PM at 1 year	NA
			ECRT	M/11	Custom plate	2 cm	Excellent healing and function	OGS	November 2008	DF	30
		Distal and proximal	ECRT	M/2	Custom plate	2.5 cm distal, 3 cm prox.	Excellent healing and function, good growth from the physis	Ewing's	March 2007	DF	30

Table 1. continued

Joint- or physio-sparing	Bone involved	Which is the small fragment	Reconstruct	Gender/age (years)	Type of plate used (length)	Size of small fragment	Comments	Histology	Date of surgery	Disease status	MSTS score
	Tibia	Proximal	VF	M/11	Recon. plate	3 cm	Plate breakage after union, solitary bone met. in opposite femur resected recently	OGS	April 2004	DF	30
			VF	F/6	Recon. plate	2 cm	Infection, nonunion, AK amp done	Ewing's	April 2004	DF	NA
			ECRT	M/9	T-plate (22 cm)	1.5 cm	United, excellent function	OGS	March 2008	DF	30
		Distal	TOF	M/14	Recon. plate	3 cm	Angular deformity	Ewing's	December 2005	DF	28

MSTS = Musculoskeletal Tumor Society; F = female; M = male; Allo-VF = allograft with vascularized fibula, BG = bone grafting; DCP = Dynamic Compression Plate; DCS = Dynamic Condylar Screw; DF = disease-free; DHS = Dynamic Hip Screw; ECRT = extracorporeal irradiation and reimplantation; JSI = joint-sparing implant; LFU = lost to followup; LR = local recurrence; MIEJSI = minimally invasive expandable joint sparing implant; NA = not applicable; NIEJSI = noninvasive expandable joint sparing implant; OGS = osteosarcoma; PM = pulmonary metastases; prox. = proximal; Recon. plate = reconstruction plate; TOF = tibialization of the fibula; VF = vascularized fibula.

Table 2. Construct used along with the implant

Construct	Number	Bone involved	Implants used
Allografts	2	Femur	DCS
Allo-VF	1	Femur	Reconstruction plate
ECRT	10	6 femur	DCS/DHS (2)
		3 tibia	Hockey stick plate (3)
		1 humerus	T-plate(1)
			Reconstruction plate (1)
VF	3	1 proximal femur	Custom Plate (3)
		2 proximal tibia	Reconstruction plate (2)
TOF	3	1 proximal tibia	DCP (1)
		2 distal tibia	L-plate (1)
			Reconstruction plate (1)
DI	6	4 femur	Custom plate (1)
		2 tibia	3 expandable femur (2 noninvasive)
			3 nonexpandable

Allo-VF = allograft with vascularized fibula, ECRT = extracorporeal irradiation and reimplantation; VF = vascularized fibula; TOF = tibialization of the fibula; DI = diaphyseal implant; DCS = Dynamic Condylar Screw; DHS = Dynamic Hip Screw; DCP = Dynamic Compression Plate.

implants were made of titanium alloy. They had a customized profile at the ends to match the bone cut (Fig. 3). CT data were used for the customization. Three of these custom implants were expandable (one minimally invasive and two noninvasive) to compensate for the growth loss from the resected femoral physis. All the custom diaphyseal implants had an HA coating on the ends for osseointegration and small lateral extracortical plates for additional stability by screw fixation (Fig. 4A–B) on the side of the small fragment and a cemented stem on the other side. Conventional implants were used in 12 patients and custom implants in 13. In two patients with femur resection, both the proximal and the distal fragments were short.

The rehabilitation protocol was customized to the patient depending on the construct used and the rigidity of fixation. For all bone grafts, nonweightbearing ambulation was started immediately when the fixation was judged as rigid. In some patients, the screw hold was poor and a cast was used for additional support until healing was seen radiographically. For diaphyseal implants, weightbearing as tolerated was started within 48 hours of surgery.

Patients were followed every 3 months. We performed clinical examinations and recorded Musculoskeletal Tumor Society scores [8] for functional assessment 1 year after surgery. Functional scoring was possible in 17 patients. We obtained standard orthogonal radiographs of the operated area at each visit to look for recurrences. Either radiographs or CT scan of the chest were used to identify

Fig. 1A–E The use of extracorporeal irradiation and reimplantation (ECRT) and custom plate in a 2-year-old boy with Ewing's sarcoma of the femur is shown. (A) Preoperative MRI showing the disease extent in the femoral diaphysis close to the proximal and distal physis. (B) Surgical plan showing the levels of cuts and the proposed custom plate design superimposed on the radiograph. The plate would be in the form of two "C" clamps connected by the shaft. This would allow

three screw holds in each fragment without damage to the physis. (C) The custom plate coated with hydroxyapatite. (D) Three-month postoperative radiograph. The proximal junction is still visible. Note that the tip of the screw extends close to the physis. (E) Radiograph at 2 years followup showing the excellent growth from the distal femoral as well as the proximal physis. The screw tip appears proximal as a result of growth from the physis.

Fig. 2 An example of a reconstruction using a frozen radiated allograft is shown. A DCS is used to hold the construct. The plate has been placed from the medial side and therefore requires considerable contouring.

metastases. The radiographs were assessed for union across the junctions in cases where a bone graft was used by one of two authors (MA, AP) who were also the treating physicians. To avoid ambiguity, union was defined as bridging bone across three of the four cortices evaluated at each junction in the biplane radiographs.

The records were prospectively maintained in an Excel spreadsheet (Microsoft Inc, Redmond, WA) until 2005 and then in a custom database and retrospectively analyzed for this study. The demographic profile, the length of defect, the method of reconstruction, implant used, proximal and distal margins, the time to union, tumor status, and function at last followup were entered in an Excel spreadsheet for analysis.

Results

Sixteen of the 25 patients were alive and disease-free with the original construct at a median followup of 34 months (range, 12–66 months). There were five deaths. One patient died of chemotherapy-related complications at 8 weeks. There were four deaths from disease recurrence. Two patients had local recurrence (LR) and died of pulmonary metastases (PM) and two from isolated pulmonary metastases. Two of the patients with disease recurrence also had surgery for implant failure before the detection of disease recurrence. Another patient had a solitary bone metastasis to the opposite femur, which was resected and reconstructed with a prosthesis, and is now disease-free 1 year later (Table 1).

Table 3. Results categorized by the implant used

Implant	Number	Bone (number)	Comments
DCS/DHS	4	All femur	1 breakage for nonunion after 4 years 1 infection converted to rotationplasty
Reconstruction plate	5	Femur (1) Humerus (1) Proximal tibia (2) Distal Tibia (1)	Mild angulation in femur and distal tibia Humerus breakage, revised to DCP Tibia breakage caused infected nonunion leading to AK amp, 1 proximal tibia breakage after union
Hockey stick plate	3	Femur (1) Proximal tibia (2)	Plate failure in femur revised
T- or L-plate	2	Both proximal tibia	Both united
DCP	1	Proximal femur	2 DCPs used, one anterior, one lateral
Custom plate	4	Femur (3) Tibia (1)	1 SS plate allowed angulation through poor hold in porotic bone
Diaphyseal implants	6	Femur (4) Tibia (2)	1 patient with knee flexion restricted to 100°

DCS = Dynamic Condylar Screw; DHS = Dynamic Hip Screw; DCP = Dynamic Compression Plate; AK = above knee; SS = stainless steel.

Fig. 3A–D An example of a physis-sparing resection reconstructed by a custom diaphyseal implant is shown. (A) The custom diaphyseal implant made of titanium. The hydroxyapatite coated collar is to facilitate extracortical bridging. The lateral plate is to provide additional stability because the intramedullary stem is short. (B) The distal metaphyseal end is custom made as per the bone profile at the level of the resection. Note the small extracortical plates. The ends are hydroxyapatite (HA)-coated for osteointegration. (C) Postoperative radiograph showing the seating of the implant. (D) Radiograph at 2 years showing the growth from the distal femur.

Fig. 4 An allograft combined with vascularized fibula used to reconstruct a diaphyseal defect is shown. A 4.5-mm reconstruction plate contoured as an L plate was used to hold the construct. Note the mild angulation in the frontal as well as the sagittal plane. The patient did not have any functional or cosmetic defect.

There were two infections. One patient had a rotationplasty and another underwent an above-knee amputation after repeated attempts at securing union failed. There were

four plate breakages, of which three have been revised. One reconstruction plate broke after union and did not require treatment. Another implant failure resulted from very poor hold of the screws in the osteoporotic distal femur reconstructed after ECRT with a custom plate. Two of these four patients revised for implant failures have died of recurrent disease (one LR with PM, one PM). Union was seen in 14 of the 19 cases in which allograft or autograft bone was used. Two constructs were removed for infection and four were revised for failure. One of these had a plate and allograft failure 4 years after the allograft had united. Mild angulation was seen on plain radiographs in two constructs with reconstruction plates (Fig. 4). Both were clinically asymptomatic. Another reconstruction plate broke after the union in TOF and did not cause any functional compromise. Of six diaphyseal implants used, one patient died of chemotherapy-related complications as already stated. The other five patients were disease-free with an intact implant at followup ranging from 12 to 27 months. Two patients had deep infections.

The Musculoskeletal Tumor Society score ranged from 27 to 30. Growth was seen from the physis in five of the seven evaluable physis-sparing resections.

Discussion

Precise imaging and effective chemotherapy allow the surgeon to resect the tumor-bearing bone with a wide margin yet preserve the joint or the growth plate in selected cases. The gap is reconstructed either with bone (autograft fibula, ECRT, allograft) or with a custom diaphyseal implant. Because most tumors are metaphyseal, the challenge for the surgeon is to obtain secure purchase in the short fragment, which is close to the joint or the physis. A variety of constructs and implants have been used and reported in the literature without any guidelines as to the choice of the construct. The number of such cases has been small with different surgeons using different constructs. We have used a variety of different constructs with one of the fragments containing 3 cm or less bone. We determined patient survival and examined the complications and function of these diaphyseal constructs. We then formulated guidelines based on retrospective analysis of our cases in which the length of bone available for fixation was 3 cm or less.

We note two major limitations. First, we had a small number of patients with many potentially confounding variables, and therefore no definitive treatment guidelines can be derived. The number of cases with a specific construct or implant was very small for drawing any firm conclusions. However, there is no paper in the literature that has specifically looked at reconstructions in which the

fragment available for fixation has been very small. This is a subset that is particularly challenging for the surgeon. The primary aim was to determine how many of these constructs functioned in the short term. Second, the followup is short and therefore no definitive recommendations can be made, particularly for the diaphyseal prosthesis. Allografts as well as radiated bone constructs may fail late even after union has occurred. This article, however, focuses on the early results of the implant's ability to hold the construct until union has been achieved. This has not been addressed in any other publication. Third, this is a retrospective study and over a period of time, the method of reconstruction has changed. Reconstruction plates are less likely to be used and custom implants are more likely used. This, in fact, may be an advantage and demonstrates the evolution in the management of these complex reconstructions.

Capanna et al. [3] described a construct using allograft with live fibula. They recommended crossed screws in physis-sparing implants and whenever the fragment was small and separate proximal and distal plates for others. They described a 10.5% nonunion rate and 13.3% incidence of fractures but did not specifically discuss the fixation and whether it contributed to the complications, because the paper was focused on the allograft-live fibula construct. Chang and Weber [4] also used a lateral locking plate or DCS with an allograft and vascularized fibula combination but did not discuss the osteosynthesis or the subgroup with small distal fragment. Deijkers et al. [6] used an allograft in 35 diaphyseal resections. In some of their resections, the distal fragment was only 1 cm long. In 11 of their 35 patients, a long plate spanning both junctions was used. In the rest, staples alone or soft tissue were used at the epiphyseal junction and an intramedullary nail or plate at the diaphyseal junction. None of the 11 allografts fixed with the bridging plate failed compared with 12 failures with other methods of fixation. They recommend rigid stable fixation for reconstruction. Our data also suggest rigid fixation is associated with a lower failure rate than if more pliable plates like reconstruction plates are used. In our series, of the five constructs fixed with a reconstruction plate, three broke and two had healing with an angulatory deformity. The failure seen with some of the thicker plates was not because of the plate strength. One failure was from an allograft fracture even after union at the junctions. The other failure was from nonunion at the junction in an ECRT femur construct.

Standard plates often required contouring and therefore more operative time. At times the long length required is not available in the standard range. In such cases, we have had standard plates with long lengths custom-manufactured for our requirements. In our experience, even the precontoured standard plates need some contouring to conform to

the construct. This contouring is often time-consuming and also difficult (especially in a thick titanium plate) owing to the small size of the distal or proximal fragment. Malleable templates are often not available for the long length, forcing the surgeon to contour by trial and error, resulting in longer operative time. Custom-made precontoured plates made anatomic fixation easy and quick in our experience. The contouring was accurate because it was based on the CT scans done preoperatively. The custom “double C-clamp” design allowed at least three screws to be passed in the small fragment (Fig. 1). In our experience, the reduction was quick and fixation straightforward with these plates. We believe custom plates are an alternative to using separate proximal and distal plates and offer the advantage of requiring less screws in the grafted bone. In one case of a custom plate, the fixation was not rigid as a result of poor screw hold in the severely osteoporotic bone and a deformity resulted. We believe the addition of a locking facility on the custom plate can improve the fixation in such a situation.

For the femur, a DCS or DHS seems to be a reliable implant providing secure purchase. The distal femur locking plates also seem adequate but are not available in long lengths. Conventional implants provide a satisfactory solution as long as the construct is rigid. The failures of conventional implants that we have seen are from allograft fracture or nonunion at the junction leading to fatigue failure of the implant.

The diaphyseal implant [11, 19] allows immediate weightbearing, which is a psychologic advantage for the patient who is often emotionally low from the diagnosis of cancer as well as the side effects of chemotherapy. The surgical time is shortened compared with a vascularized fibula or ECRT. When the growth plate is sacrificed, the option of having expansion, especially in a noninvasive way, will prevent limb length discrepancy. No other method involving bone grafting has this advantage. The downside is that it is expensive, needs to be customized, and implantation can be technically demanding. Knee stiffness can sometimes be a problem [11] as seen in one of our patients.

Thus, diaphyseal resections with small remaining fragments have provided good functional results along with disease control. From analyzing our cases we recommend several guidelines. We found thin plates, like reconstruction plates, had high complication rates and we do not recommend them. We recommend that strong plates be used so that failure or angulation does not occur before union at the junction. When conventional implants are not suitable, custom plates should be used. Custom plates provide rigid fixation and make the surgery technically easier. The locking option may improve purchase in the bone. Diaphyseal implants allow immediate weightbearing

apart from a shorter operating time. However, they are expensive and their long-term results are not yet known. They appear most suitable for cases in which the physis is resected and limb length needs to be maintained.

References

1. Araki N, Myoui A, Kuratsu S, Hashimoto N, Inoue T, Kudawara I, Ueda T, Yoshikawa H, Masaki N, Uchida A. Intraoperative extracorporeal autogenous irradiated bone grafts in tumor surgery. *Clin Orthop Relat Res*. 1999;368:196–206.
2. Biau D, Faure F, Katsahian S, Jeanrot C, Tomeno B, Anract P. Survival of total knee replacement with a megaprosthesis after bone tumor resection. *J Bone Joint Surg Am*. 2006;88:1285–1293.
3. Capanna R, Campanacci DA, Belot N, Beltrami G, Manfrini M, Innocenti M, Ceruso M. A new reconstructive technique for intercalary defects of long bones: the association of massive allograft with vascularized fibular autograft. Long-term results and comparison with alternative techniques. *Orthop Clin North Am*. 2007;38:51–60.
4. Chang DW, Weber KL. Use of a vascularized fibula bone flap and intercalary allograft for diaphyseal reconstruction after resection of primary extremity bone sarcomas. *Plast Reconstr Surg*. 2005;116:1918–1925.
5. Davidson AW, Hong A, McCarthy SW, Stalley PD. En-bloc resection, extracorporeal irradiation, and re-implantation in limb salvage for bony malignancies. *J Bone Joint Surg Br*. 2005;87:851–857.
6. Deijkers RL, Bloem RM, Kroon HM, Van Lent JB, Brand R, Taminiau AH. Epidiaphyseal versus other intercalary allografts for tumors of the lower limb. *Clin Orthop Relat Res*. 2005;439:151–160.
7. Ebeid W, Amin S, Abdelmegid A, Refaat Y, Ghoneimy A. Reconstruction of distal tibial defects following resection of malignant tumours by pedicled vascularised fibular grafts. *Acta Orthop Belg*. 2007;73:354–359.
8. Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. *Clin Orthop Relat Res*. 1993;286:241–246.
9. Frink SJ, Rutledge J, Lewis VO, Lin PP, Yasko AW. Favorable long-term results of prosthetic arthroplasty of the knee for distal femur neoplasms. *Clin Orthop Relat Res*. 2005;438:65–70.
10. Gillespy T, Manfrini M, Ruggieri P, Spanier SS, Pettersson H, Springfield DS. Staging of intraosseous extent of osteosarcoma: correlation of preoperative CT and MR imaging with pathologic macroslides. *Radiology*. 1988;167:765–767.
11. Gupta A, Pollock R, Cannon SR, Briggs TW, Skinner J, Blunn G. A knee-sparing distal femoral endoprosthesis using hydroxyapatite-coated extracortical plates. Preliminary results. *J Bone Joint Surg Br*. 2006;88:1367–1372.
12. Kawaguchi N, Ahmed AR, Matsumoto S, Manabe J, Matsushita Y. The concept of curative margin in surgery for bone and soft tissue sarcoma. *Clin Orthop Relat Res*. 2004;419:165–172.
13. Malawar MM, Sugerbaker PH. *Musculoskeletal Cancer Surgery Treatment of Sarcomas and Allied Diseases*. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2001:465.
14. Manfrini M, Gasbarrini A, Malaguti C, Ceruso M, Innocenti M, Bini S, Capanna R, Campanacci M. Intraepiphyseal resection of the proximal tibia and its impact on lower limb growth. *Clin Orthop Relat Res*. 1999;358:111–119.
15. Morgan HD, Cizik AM, Leopold SS, Hawkins DS, Conrad EU III. Survival of tumor megaprotheses replacements about the knee. *Clin Orthop Relat Res*. 2006;450:39–45.

16. Puri A, Subin BS, Agarwal MG. Fibular centralisation for the reconstruction of defects of the tibial diaphysis and distal metaphysis after excision of bone tumours. *J Bone Joint Surg Br.* 2009;91:234–239.
17. Shapiro MS, Endrizzi DP, Cannon RM, Dick HM. Treatment of tibial defects and nonunions using ipsilateral vascularized fibular transposition. *Clin Orthop Relat Res.* 1993;296:207–212.
18. Sharma S, Turcotte RE, Isler MH, Wong C. Cemented rotating hinge endoprosthesis for limb salvage of distal femur tumors. *Clin Orthop Relat Res.* 2006;450:28–32.
19. Spiegelberg BG, Sewell MD, Aston WJ, Blunn GW, Pollock R, Cannon SR, Briggs TW. The early results of joint-sparing proximal tibial replacement for primary bone tumours, using extracortical plate fixation. *J Bone Joint Surg Br.* 2009;91:1373–1377.
20. Tsuchiya H, Abdel-Wanis ME, Sakurakichi K, Yamashiro T, Tomita K. Osteosarcoma around the knee: intraepiphyseal excision and biological reconstruction with distraction osteogenesis. *J Bone Joint Surg Br.* 2002;84:1162–1166.