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Reconstructive techniques in musculoskeletal tumor surgery : management of pelvic and extremity bone tumors

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Chapter 6

Hemicortical Resection and Inlay Allograft Reconstruction for Primary Bone Tumors

*A Retrospective Evaluation in the Netherlands
and Review of the Literature*

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Abstract

Background: Selected primary tumors of the long bones can be adequately treated with hemicortical resection, allowing for optimal function without compromising the oncological outcome. Allografts can be used to reconstruct the defect. As there is a lack of studies of larger populations with sufficient follow-up, little is known about the outcomes of these procedures.

Methods: In this nationwide retrospective study, all patients treated with hemicortical resection and allograft reconstruction for a primary bone tumor from 1989 to 2012 were evaluated for (1) mechanical complications and infection, (2) oncological outcome, and (3) failure or allograft survival. The minimum duration of follow-up was 24 months.

Results: The study included 111 patients with a median age of 28 years (7 to 73). The predominant diagnoses were adamantinoma ($n = 37$; 33%) and parosteal osteosarcoma ($n = 18$; 16%). At the time of review, 104 patients (94%) were alive (median duration of follow-up, 6.7 years). Seven patients (6%) died, after a median of 26 months. Thirty-seven patients (33%) had non-oncological complications, with host bone fracture being the most common ($n = 20$, 18%); all healed uneventfully. Other complications included nonunion ($n = 8$; 7%), infection ($n = 8$; 7%), and allograft fracture ($n = 3$; 3%). Of 97 patients with a malignant tumor, 15 (15%) had residual or recurrent tumor and six (6%) had metastasis. The risk of complications and fractures increased with the extent of cortical resection.

Conclusions: Survival of hemicortical allografts is excellent. Host bone fracture is the predominant complication; however, none of these fractures necessitated allograft removal in our series. The extent of resection is the most important risk factor for complications. Hemicortical resection is not recommended for high-grade lesions; however, it may be superior to segmental resection for treatment of carefully selected tumors, provided that it is possible to obtain adequate margins.

Introduction

The ability to accurately stage primary bone tumors has improved dramatically during recent decades, mainly because of progression of preoperative imaging techniques^{1,2}. Concomitant advances in surgical techniques gave rise to the idea that segmental resection may not always be necessary to adequately excise primary tumors of the long bones³.

Bone tumors frequently arise in close proximity to joints, commonly necessitating resection of adjacent joints. Osteoarticular allografts, allograft-prosthetic composites, or endoprostheses may then be used for joint replacement. Endoprostheses are generally considered the gold standard, although recent literature describes relatively high short and long-term revision rates due to infection, component wear, and loosening^{4,5}. If the adjacent joint can be salvaged and a segmental resection is performed, vascularized fibular autografts or intercalary allografts may be used. Autografts, however, can cause donor-site morbidity and, until solid union is achieved, are at substantial risk for fracture. Therefore, long non-weight-bearing periods are required⁶. Intercalary allografts offer superior initial stability, but demonstrate high rates of nonunion (27% to 47%), fracture (16% to 29%), and infection (1% to 14%), causing failures in 14% to 24% of cases⁷⁻¹⁰.

Compared with the aforementioned techniques, hemicortical resection offers potential advantages, including preservation of joints, bone stock, and cortical continuity. It may result in lower complication rates and allow faster and more complete rehabilitation^{3,11,12}. Various reconstructive techniques have been described, including implantation of cortical allografts, autografts, and autologous iliac crest grafts^{3,11-15}. Allografts have been most commonly used, but there is a lack of studies of large series with such reconstructions.

Most reports on hemicortical resection focused on treatment of low-grade and surface tumors of bone, such as parosteal osteosarcoma, adamantinoma, and peripheral chondrosarcoma^{3,11,12,14,15}. More recently, authors have described experiences with limited resection of high-grade lesions^{13,16}. The authors of most studies on hemicortical resection of bone tumors reported that no recurrences occurred^{3,11-15}. However, they described small case series that mostly lacked long-term follow-up, and low-grade tumors may recur years after surgery¹⁷⁻²⁰.

The aims of our study were to evaluate (1) mechanical complications and infection, (2) oncological outcome, and (3) failures and allograft survival after hemicortical resection and subsequent allograft reconstruction in patients treated for a primary tumor of a long bone.



Materials and Methods

To identify patients who were eligible for this nationwide retrospective study, we searched an electronic database of our national bone bank for massive allografts that had been delivered to all four appointed centers of orthopaedic oncology from 1989 to 2012. We then evaluated the diagnosis and procedure information of the patients who had received the grafts, and all of those who had been treated for a primary tumor of a long bone with hemicortical resection and allograft reconstruction were included. The minimum duration of follow-up was 24 months.

Allografts were harvested under sterile conditions during postmortem tissue donation and stored at -80°C afterward²¹. Grafts were processed by either Osteotech (Eatontown, New Jersey) or the Musculoskeletal Transplant Foundation (Edison, New Jersey) and either not subjected to additional sterilization or sterilized with low-dose gamma radiation (<25 kGy). In most patients, biopsies were performed to obtain a histological diagnosis and the biopsy track was excised in continuity with the tumor. A wedge resection was performed in all patients — in some cases because of an atypical presentation or unclear diagnosis preoperatively. Resections were planned with use of an array of conventional radiographs, magnetic resonance imaging (MRI) scans, and computed tomography (CT) scans. All patients received prophylactic cephalosporins prior to surgery. Allografts were thawed in saline solution with antibiotics during the resection and subsequently cut to fit the resected defect. Osteosynthesis was performed if the reconstruction was not considered intrinsically stable.

Medical files were evaluated to obtain characteristics of the patients, tumors, surgery, reconstruction, and treatment. Tumor grade was stratified into four groups: benign, low-grade malignant, intermediate-grade malignant, and high-grade malignant. Surgical margins were defined as being adequate (marginal or wide with no tumor cells at the margins)²², questionable (the pathologist in doubt about whether there were tumor cells at the margins), or intralesional. The reconstruction length and the percentage of the cortical circumference that was resected were measured on conventional radiographs in two directions and corrected for magnification. The extent of cortical resection was classified as $<25\%$, 25% to 50% , 51% to 75% , or $>75\%$.

Complications and reasons for failure were classified as mechanical (nonunion or fracture), infection, and oncological according to the system described by Henderson *et al*²³. A patient was considered to have had a nonunion if a surgical intervention had been performed to facilitate osseous union⁷. Fractures were

diagnosed on images or intraoperatively. A patient was considered to have had an infection if any surgical procedure had been done to treat a deep infectious process around the allograft. Allografts that were partially or completely removed for any reason were defined as failures. The presence of residual or recurrent tumor and metastases was assessed on radiographic images, and on pathology reports if surgery was performed. Before 2006, routine radiographic follow-up was done with conventional radiographs and MRI was performed when recurrence was suspected. From 2006 onward, malignant lesions were followed according to national guidelines that included MRI at one, two, five, and ten years.

Student t tests and Mann-Whitney U tests were used to compare continuous variables between groups. Kaplan-Meier curves were used to estimate construct survival. Logistic and Cox regression analyses were performed to assess factors of influence on the occurrence of complications and time to failure. Outcomes are expressed with the odds ratio and hazard ratio (OR and HR), 95% confidence interval (95% CI), and p-value. A 5% level of significance was used in the analyses.

Results

We included 111 patients (44 males; 40%) with a median age of 28 years (7 to 73) at surgery (table 1). Ninety (81%) were treated at one center and seven (6%) were treated at each of the other centers. The resected specimen revealed a diagnosis other than a neoplasm in three patients (3%) — reactive bone and cartilage formation in two and bizarre parosteal osteochondromatous proliferation in one — all of whom had been suspected of having parosteal osteosarcoma preoperatively. Eleven patients (10%) had a benign tumor and 97 had a malignant tumor, which was low-grade in 61 (55%), intermediate-grade in 22 (20%), and high-grade in 14 (13%). The predominant diagnoses were adamantinoma ($n = 37$; 33%) and parosteal osteosarcoma ($n = 18$; 16%). Computer-assisted navigation was used in five patients (5%). Twelve patients (11%) received chemotherapy, and six (5%) underwent radiation therapy.

At the time of the review, 104 patients (94%) were alive after a median duration of follow-up of 6.7 years (2 to 23). Seven patients (6%) had died during the follow-up period, at a median of 26 months (7 months to 6.4 years) postoperatively. Six of these deaths were due to disease (two Ewing sarcomas, two grade 2 chondrosarcomas, one osteosarcoma, and one periosteal osteosarcoma).



Most lesions were located in the tibia ($n = 54$; 49%) (figures 1A, 1B, and 1C) or femur ($n = 48$; 43%) (figures 2A, 2B, and 2C). Forty-four (40%) extended from metaphyseal into diaphyseal bone, and 40 (36%) were strictly diaphyseal. The median length of the reconstruction was 8 cm (2 to 20). In most cases, <25% ($n = 46$; 41%) or 25% to 50% ($n = 46$; 41%) of the cortical circumference was resected. The mean surgical duration was 3.0 hours (standard deviation [SD] = 1.7 hours).

Allografts were laid into the defect with cortical contact and fixed under compression, with the use of screws in 78 (70%) of the patients and a plate with or without additional lag screws in 20 (18%), 15 of whom had a femoral reconstruction. Plate fixation was applied significantly more often in reconstructions of the femur ($p = 0.002$). No osteosynthesis was applied to 11 allografts (10%), eight of which were <8 cm in length and all of which comprised <25% of the cortex. Seventy-eight patients (70%) had additional bone grafting, with either allogeneic ($n = 73$; 66%) or autologous ($n = 5$; 5%) bone, to obtain an optimal fit.

Table 1. Study data

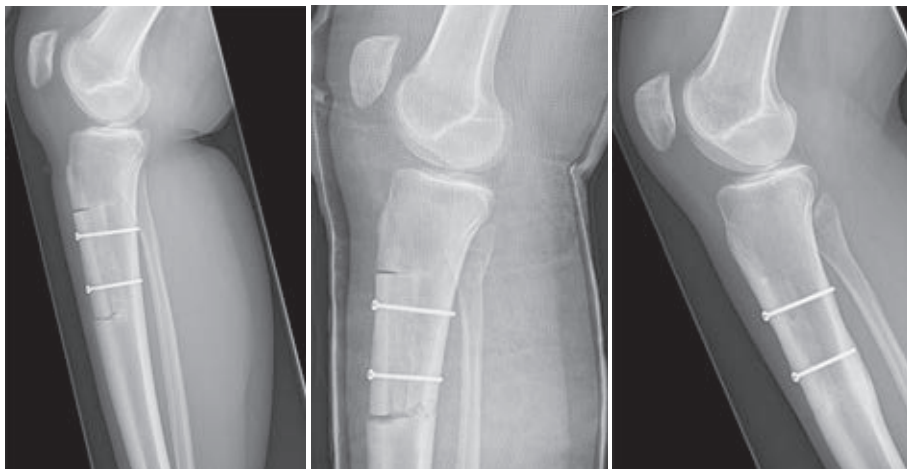
	No.	%
<i>Sex</i>		
Male	44	40
Female	67	60
<i>Diagnosis</i>		
Adamantinoma	37	33
Parosteal osteosarcoma	18	16
Periosteal chondrosarcoma	8	7
Chondrosarcoma, grade 1	7	6
Chondrosarcoma, grade 2	6	5
Osteosarcoma (conventional type)	6	5
Periosteal osteosarcoma	6	5
Chondromyxoid fibroma	2	2
Ewing sarcoma	2	2
Giant cell tumor of bone	2	2
High-grade surface osteosarcoma	2	2
Leiomyosarcoma	2	2
Osteoblastoma	2	2
Reactive bone and cartilage formation	2	2
Aneurysmal bone cyst	1	1
Bizarre parosteal osteochondromatous proliferation	1	1
Hemangioma	1	1
Low-grade osteosarcoma	1	1
Non-ossifying fibroma	1	1
Osteochondroma	1	1
Osteofibrous dysplasia	1	1
Sarcoma not otherwise specified	1	1
Synovial sarcoma	1	1

Table 1. continued

	No.	%
<i>Long bone involved by tumor</i>		
Tibia	54	49
Femur	48	43
Humerus	5	5
Radius	2	2
Ulna	2	2
<i>Portion of bone involved by tumor</i>		
Metaphysis-diaphysis	44	40
Diaphysis	40	36
Metaphysis	17	15
Epiphysis-metaphysis	6	5
Epiphysis-diaphysis	4	4
<i>Graft length</i>		
<4 cm	7	6
4 – 7.9 cm	41	37
8 – 12 cm	45	41
>12 cm	18	16
<i>Cortical circumference resected</i>		
<25%	46	41
25%-50%	46	41
51%-75%	13	12
>75%	6	5
<i>Osteosynthesis</i>		
Screws	78	70
Plate	16	14
None (press-fit)	11	10
Plate and screws	4	4
Cerclage wires	2	2
<i>Adjuvant therapy</i>		
Chemotherapy	12	11
Radiation therapy	6	5
<i>Complications of the reconstruction</i>		
Fracture of host bone	20	18
Infection	8	7
Nonunion	8	7
Allograft fracture	3	3
<i>Patients with ≥ 1 reoperation(s)</i>	41	37
<i>Failures</i>		
Mechanical reasons	2	2
Non-mechanical reasons	13	12
<i>Follow-up</i>		
≥5 years	70*	63
≥10 years	31	28

*Includes the 31 patients with ten or more years of follow-up.





Figures 1A-C. Lateral radiographs of a 17-year-old girl diagnosed with an adamantinoma of the tibia. (1A) Radiograph made six weeks after resection of the anterior portion of the tibia and reconstruction with a 9-cm-long inlay allograft fixed to the host bone with two screws. (1B) Two weeks later, the remaining cortex fractured at the level of the distal osteotomy site and was treated conservatively with a cast. (1C) Radiograph of the affected leg made 30 months after the index surgery. The fracture healed uneventfully, and there is sound incorporation at both osteotomy sites.



Figures 2A-C. Lateral radiographs of a 24-year-old woman diagnosed with a periosteal chondrosarcoma. (2A) Preoperative radiograph showing a lesion, with alternating osteolytic and sclerotic areas, in close relationship with the dorsal cortex of the distal part of the femur. (2B) Three months after resection of the tumor and fixation of an allograft to the host bone with a single screw, there are no clear signs of allograft incorporation. (2C) Four years after the index procedure, there is sound incorporation of the allograft.

Mechanical Complications and Infection

Thirty-seven patients (33%) had a mechanical complication or infection (Henderson type 1, 2, 3, or 4 complication²³). Forty-one patients (37%) required one or more reoperations (1 to 7). Patients experienced their first complication after a median of 11 months (one day to 8.6 years) and their last after a median of 15 months (1 day to 20.0 years).

Non-oncological complication rates were comparable among different tumor locations ($p = 0.24$), between reconstructions with and those without osteosynthesis ($p = 0.26$), among fixation methods ($p = 0.62$), and between procedures that took place before ($n = 23$; 21%) and those that took place after 1995 ($p = 0.84$). Osteosynthesis materials were removed because of pain or irritation in seven patients (6%). Complication rates were higher after reconstructions of ≥ 8 cm (OR = 2.0) and increased with the extent of the cortical resection (table 2). The extent of resection retained its significance in multivariable analysis (table 3).

Table 2. Univariable analysis for factors of influence on the occurrence of complications.

Complications and covariable(s)	OR	95% CI	p-value
<i>All non-oncological complications (types I-IV) (n = 37; 33%)</i>			
Reconstruction length ≥ 8 cm	2.9	1.2 - 6.7	0.02
% of cortical circumference resected			
<25% (reference)	(1)		
25%-50%	3.3	1.3 - 8.8	0.01
51%-75%	4.1	1.1 - 15.4	0.04
>75%	9.5	1.5 - 61.1	0.02
<i>Mechanical: fracture of host cortex (n = 20; 18%)</i>			
Reconstruction length ≥ 8 cm	5.5	1.5 - 20.2	0.01
% of cortical circumference resected			
<25% (reference)	(1)		
25%-50%	6.9	1.4 - 33.3	0.02
51%-75%	9.8	1.5 - 61.7	0.02
>75%	22.0	2.6 - 186.5	0.005
Nonunion of allograft-host junctions	9.8	2.1 - 45.3	0.004
<i>Mechanical: nonunion of allograft-host junctions (n = 8; 7%)</i>			
Reconstruction length ≥ 8 cm	5.9	0.7 - 49.5	0.10
<i>Non-mechanical: infection (n = 8; 7%)</i>			
Reconstruction of tibial diaphysis	4.2	1.0 - 18.0	0.06
>50% of cortical circumference resected	9.8	2.1 - 45.3	0.004
<i>Non-mechanical: residual or recurrent tumor (n = 15; 15%*)</i>			
Inadequate margins	14.4	4.1 - 50.8	<0.001

*Of the 97 patients with a malignant lesion.

Host bone fracture was the most frequent complication ($n = 20$; 18%). Three of these fractures (two in the femur and one in the tibia) occurred during the index surgery and 17 (ten in the tibia, six in the femur, and one in the radius) occurred at a median of eight weeks (1 day to 5.8 years) postoperatively. Two patients (2%) had a concomitant allograft fracture. One patient (1%) had an isolated fissure fracture

of the allograft during the primary surgery. Fractures were treated conservatively or with internal ($n = 9$) or external ($n = 1$) fixation; all healed uneventfully. Of the 20 patients with a host bone fracture, 17 had had a reconstruction of ≥ 8 cm and four had had plate fixation. In univariable analysis, reconstruction length of ≥ 8 cm (OR = 5.5), nonunion (OR = 9.8), and the extent of cortical resection significantly influenced the risk of host bone fracture (table 2). In multivariable analysis, nonunion and the extent of resection retained significance (table 3).

Nonunion occurred in eight patients (7%). Five (5%) underwent revision of the osteosynthesis, combined with allogeneic bone grafting ($n = 2$), allogeneic and autologous bone grafting ($n = 2$), or tibial autografting ($n = 1$). Nonunion resulted in graft failure in two of the patients, five and 24 months after the index procedure. Of the eight patients with nonunion, two received chemotherapy ($p = 0.20$) and one had radiation therapy ($p = 0.38$). The nonunion risk was higher for reconstructions of ≥ 8 cm in length (OR = 5.9) but this was not a significant factor (table 2).

Deep infection developed after eight reconstructions (7%), five in the tibia, two in the femur, and one in the radius. Three infections (3%) were eradicated with surgical debridement and antibiotics, and the other five resulted in graft failure (5%): two within the first postoperative month and one each after eight, 33, and 34 months. The mean duration of surgery for the patients with an infection was 3.9 hours (SD = 3.6 hours) compared with 2.9 hours (SD = 1.5 hours) for those without an infection ($p = 0.10$). Reconstructions of the tibial diaphysis (OR = 4.2) and those comprising $>50\%$ of the cortical circumference (OR = 9.8) were associated with a significantly higher risk of infection (table 2).

Oncological Outcome

The margins obtained during excision of the eleven benign lesions were adequate in seven, questionable in two (one patient had additional cryosurgery), and intralesional in two (one patient had cryosurgery and one had phenolization), but clear margins were not the aim in all patients.

Of the 97 patients with a malignant lesion, ten (10%) had questionable margins and ten (10%) had an intralesional resection (table 4). The rates of inadequate margins were comparable among the grades of malignancy ($p = 0.36$). All computer-navigated resections resulted in adequate osseous margins, but there was one contaminated soft-tissue margin. Residual or recurrent tumor was diagnosed in 15 (15%) of the 97 patients with a malignant tumor, after a median of 12 months (1 day to 13 years). Of the 61 patients with a low-grade malignant tumor,

Table 3. Multivariable analysis for factors of influence on the occurrence of complications.

Complications and covariable(s)	OR	95% CI	p-value
<i>All non-oncological complications (types I-IV) (n = 37; 33%)</i>			
Reconstruction length ≥8 cm	1.6	0.6 - 4.3	0.33
% of cortical circumference resected			
<25% (reference)	(1)		
25%-50%	2.7	1.0 - 7.4	0.06
51%-75%	3.1	0.7 - 12.5	0.12
>75%	6.1	0.9 - 43.8	0.07
<i>Fracture of host cortex (n = 20; 18%)</i>			
Reconstruction length ≥8 cm	2.4	0.6 - 10.2	0.23
% of cortical circumference resected			
<25% (reference)	(1)		
25%-50%	4.4	0.8 - 23.4	0.08
51%-75%	5.2	0.7 - 38.8	0.11
>75%	15.1	1.5 - 146.5	0.02
Nonunion of allograft-host junctions	7.5	1.5 - 37.9	0.02

16% (n = 10 — five with an adamantinoma, four with a parosteal osteosarcoma, and one with a grade 1 chondrosarcoma) had residual or recurrent tumor during the follow-up period. Of the 22 with an intermediate-grade malignancy, 9% (two — both with grade 2 chondrosarcoma) had residual or recurrent tumor, and the rate was 21% (three — Ewing sarcoma, leiomyosarcoma, and conventional osteosarcoma) in the 14 with a high-grade malignancy. For the 97 patients with a malignant lesion, the risk of experiencing a residual or recurrent tumor was significantly higher if adequate margins had not been obtained during the index procedure (OR = 14.4) (table 2). All patients with residual or recurrent tumor had secondary surgery. In seven (6%) of the 97 patients, the residual or recurrent tumor was resected without violating the reconstruction: four soft-tissue recurrences, two recurrences in the same bone but outside the allograft, and one residual tumor (a parosteal osteosarcoma, diagnosed on imaging one day postoperatively, after resection the allograft was put back in place). In the remaining eight patients (8%), the allograft was removed, after a median of 17 months (7 months to 13 years); four had a secondary reconstruction and four underwent an ablative procedure (figure 3).

Metastasis was diagnosed in six patients (6% of the patients with a malignant lesion), two with grade 2 chondrosarcoma, two with Ewing sarcoma, one with leiomyosarcoma, and one with periosteal osteosarcoma, after a median of 15 months (2 to 47).



Table 4. Residual or recurrent malignant tumors and ablative surgery, stratified according to grade of malignancy and surgical margins.

Grade of malignancy and margins obtained	Total		Residual or recurrent malignant tumor		Ablative surgery	
	No.	%	No.	%	No.	%
Low-grade	61	100	10	16	1	2
Adequate	50	82	4	8	1	2
Questionable	4	7	1	25	0	-
Intralesional	7†	11	5	71	0	-
Intermediate-grade	22	100	2	9	1	5
Adequate	16	73	0	-	-	-
Questionable	5	23	1	20	0	-
Intralesional	1	5	1	100	1	100
High-grade	14	100	3	21	3	21
Adequate	11	79	1	9	1‡	9
Questionable	1	7	1	100	1	100
Intralesional	2	14	1	50	1	50

*The percentage of the corresponding group (with equal tumor grade and surgical margins). †One of these patients underwent secondary surgery due to an infection of the allograft; in the same procedure, an additional piece of bone was removed at the contaminated osteotomy site. ‡No attempt was made to resect the recurrent tumor; a below-the-knee amputation was performed because of a concomitant infection.

Failures and Allograft Survival

Fifteen allografts (14%) were removed: two (2%) for mechanical reasons (both nonunion), five (5%) because of infection, and eight because of residual or recurrent tumor (8% of the patients with a neoplasm). Fourteen failures occurred within three years postoperatively, and the remaining patient had a recurrence after 13 years. With failure for any reason as the end point, estimated two- and ten-year allograft survival rates were 92% and 87%, respectively (figure 4). Allograft survival was significantly worse for patients with an infection (HR = 10.4, 95% CI = 3.5 to 31.2, $p < 0.001$).

Ablative procedures were performed to treat four residual or recurrent tumors and one infection. The overall limb-salvage rate was 95% ($n = 106$). Ablative procedures were more frequent in patients with a high-grade lesion (OR = 13.0, 95% CI = 1.9 to 86.2, $p = 0.008$); for them, the limb-salvage rate was 79% (11 of 14).

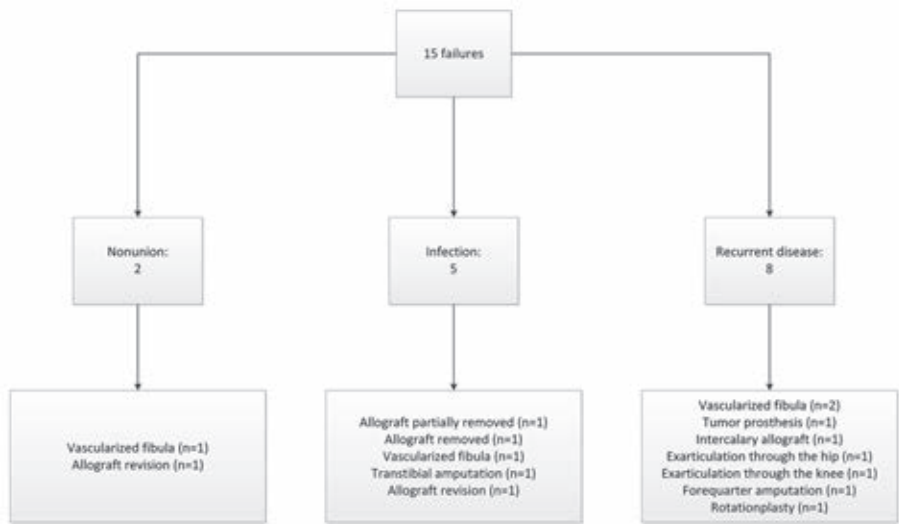


Figure 3. Failed reconstructions, with the reasons for failure and the final outcomes.

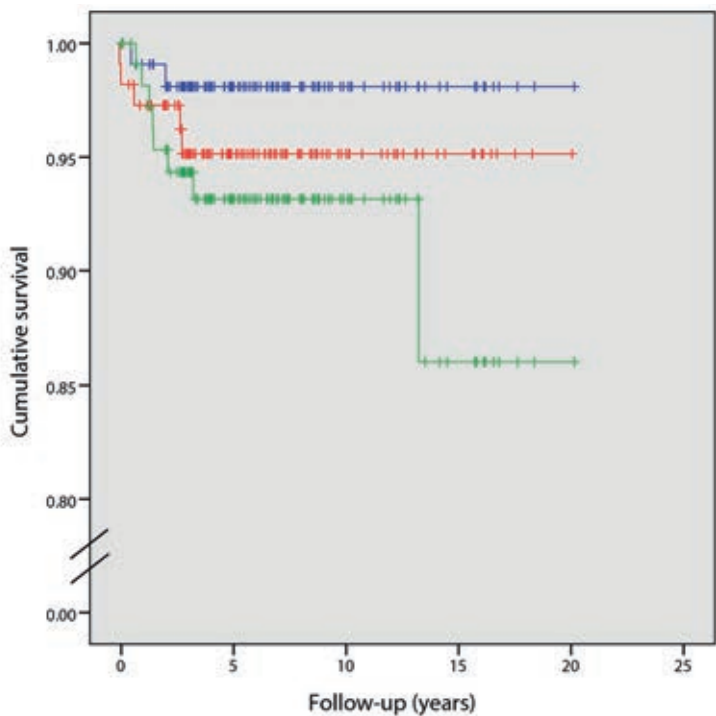


Figure 4. Kaplan-Meier curve for survival of the reconstruction, with failure for mechanical reasons (nonunion or fracture) as the end point (blue line), failure due to infection as the end point (red line), and failure due to locally recurrent or residual tumor as the end point (green line).

Discussion

In this nationwide retrospective survey, we evaluated (1) mechanical complications and infection, (2) oncological outcome, and (3) failures and allograft survival following hemicortical allograft reconstructions for the treatment of primary bone tumors. To the best of our knowledge, this study represents the largest series on hemicortical reconstructions to date.

Mechanical Complications and Infection

The most frequent complication was host bone fracture, the rate of which was 18%, which is in accordance with rates of 10% to 27% found in previous studies on hemicortical resection (table 5)^{3,11,15}. Other authors reported no fractures, but they did not describe the extent of cortical resection, which was the most important risk factor in our patients^{12-14,24}. The association between fractures and the extent of cortical resection may be explained by greater stresses acting on a smaller portion of remaining cortex²⁵. Additional factors should, however, be considered. First, perfect fitting of allografts may reduce fracture rates²⁶. Three-dimensional CT scanning of allografts²⁷ may aid in the selection of better-fitting grafts. Second, osteotomies with sharp angles and screw fixation perpendicular to the bone axis (figures 1A, 1B, and 1C) act as stress-risers and should be avoided^{28,29}. We advise surgeons to perform rounded osteotomies ("boat-shaped resections") when possible and to insert screws in an oblique fashion^{29,30}. Recommendations for when to use plate fixation are proposed in figure 5.

Nonunion occurred in 7% of our patients, and resulted in failure in 2%. In previous reports, none of the patients required surgery to facilitate union (table 5). Autograft use may improve union rates, but it is not suitable for reconstruction of larger defects. Also, harvesting of autografts has been associated with substantial complication rates, especially prolonged pain at the donor site³¹⁻³³. On the other hand, 24% to 47% of segmental allografts demonstrate nonunion so the rate in the current study may be considered encouraging⁷⁻¹⁰. Various factors may explain these differences, including the fact that hemicortical reconstructions have a larger contact surface between allogeneic and host bone. The extent of soft-tissue dissection is generally limited in hemicortical resections; authors have hypothesized that this provides a superior environment for incorporation^{3,28}. Moreover, the number of patients receiving adjuvant radiation or chemotherapy was limited in our study. Adjuvant therapies are known to delay bone-healing³⁴.

Our infection rate (7%) compares unfavorably with those in previous studies in which no infections were reported (table 5). On the other hand, infection rates after segmental allograft or endoprosthetic reconstructions typically range around 10%^{7,9,35-37}. Infection resulted in graft removal in five patients (four of whom were managed with a new biological reconstruction) in our series. The higher risk of infection following reconstructions of the tibial diaphysis may be explained by limited possibilities for soft-tissue coverage³⁸. We did not use muscle flaps; however, muscle transfers may be useful to reduce the risk of infection in these cases³⁹. The infection rate was associated with the extent of cortical resection; it is conceivable that extensive resections require more soft-tissue dissection and take longer, thereby increasing the infection risk⁴⁰.

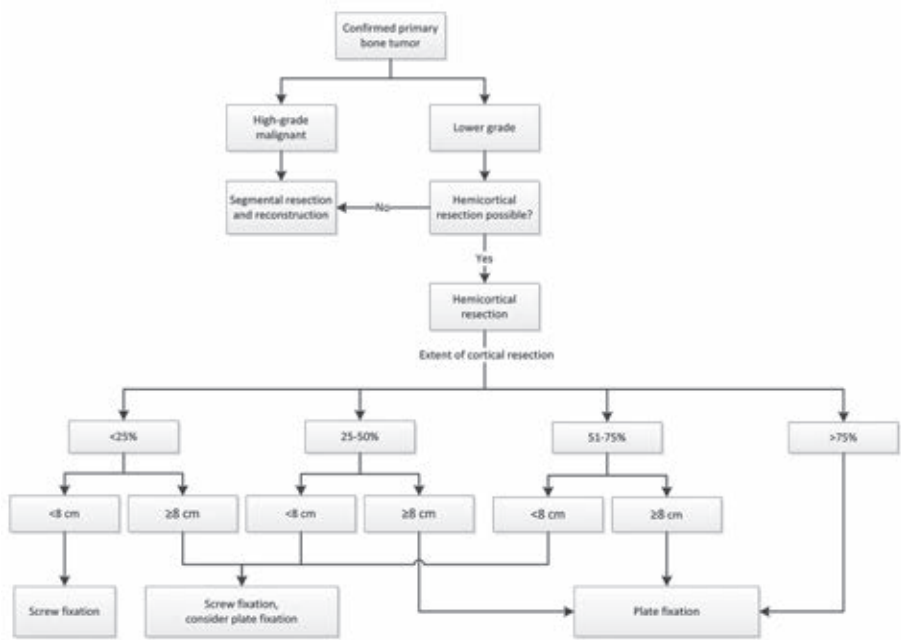


Figure 5. Recommendations for treatment of primary bone tumors and fixation of hemicortical allografts.

Oncological Outcome

Most recurrences involved adamantinomas and parosteal osteosarcomas. These lesions recur frequently, especially after intralesional or marginal excision^{19,41-43}. Until recent years, we routinely performed subperiosteal resections for these

tumors. We no longer employ this technique because we assume that it results in a higher recurrence rate. The advantages of limited resection may outweigh the elevated risk of recurrence for low-grade lesions; however, 21% (three) of the 14 high-grade lesions in our series recurred and all resulted in ablative surgery. Apparently, hemicortical resection does not provide adequate local control of high-grade lesions. We therefore recommend segmental *en bloc* resections for high-grade tumors (figure 5).

Computer-assisted navigation may prove useful for resecting tumors with minimal but adequate margins. All osseous margins obtained with computer-navigated resection were adequate. Several authors have shown that computer navigation is accurate and useful for bone tumor surgery^{44,45}. Computer navigation may also be used to obtain precise matching of host and allograft osteotomies and thus superior fit^{26,46}.

Failures and Allograft Survival

Nearly all reconstruction failures occurred in the first three postoperative years. This finding is in accordance with statements in previous reports that allografts offer a reliable and lasting reconstruction if they survive the first critical years^{9,47,48}. The ten-year allograft survival rate (87%) in our series compares favorably with ten-year survival rates of 58% to 69% reported in large series on endoprosthetic reconstructions after resections of bone tumors^{4,49,50}. In those series, however, the majority of patients had high-grade malignant tumors and thus, presumably, more extensive resections. As those patients would not have been considered eligible for hemicortical resection, the results are difficult to compare.

Study Limitations

Our study had several limitations. As a result of its retrospective design, it was not possible for us to accurately assess time to union of allograft-host junctions. We were also unable to acquire functional outcome scores. Previous research, however, indicates that postoperative function is generally good after hemicortical reconstruction³.

Overview

In conclusion, we report excellent long-term rates of survival of hemicortical allograft reconstructions. Rates of non-oncological complications were acceptable, especially after reconstructions comprising <25% of the cortical circumference

and those <8 cm in length. Hemicortical resection is not recommended for high-grade lesions. The elevated risk of residual or recurrent tumor may, however, be acceptable for low and intermediate-grade lesions, given the excellent mechanical complication rates and the fact that most failures can be managed with a second (limb-salvaging) procedure. Modern imaging techniques play a pivotal role in ensuring that clear margins are obtained. If the aforementioned requirements are met, hemicortical resection and allograft reconstruction is a safe and reliable alternative to more comprehensive segmental resections.

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Table 5. Overview of literature on hemicortical resections and reconstructions.

Year	Deijkers et al ³	Agarwal et al ¹¹	Liu et al ¹⁵	Funovics et al ¹²	Lewis et al ¹⁴	Chen et al ¹³	Lindner et al ²⁴	Current study
No. of patients	22	10	13	8†	6	6	4	111
Diagnoses (%)								
Benign	-	-	-	-	-	-	-	13
Low-grade malignant	100	90	100	100	100	-	100	55
Intermediate-grade malignant	-	-	-	-	-	-	-	20
High-grade malignant	-	10	-	-	-	100	-	13
Long bone involved by tumor (%)								
Humerus	9	10	-	-	-	-	-	5
Ulna	-	-	-	-	-	-	-	2
Radius	-	10	-	-	-	-	-	2
Femur	45	60	100	88	100	17	100	43
Tibia	45	20	-	13	-	83	-	49
Intralesional excisions (%)	-	-	-	25	-	-	25	11
Reconstruction (%)								
Allograft	100	50	-	25	100	33	-	100
Autograft	-	30	100	25	-	67	100	-
Autogenous iliac crest	-	20	-	50	-	-	-	-
Mean follow-up (range) (mo)	64 (27 - 135)	51 (40 - 61)	102 (58 - 142)	107 (14 - 289)	51 (38 - 63)	52 (24 - 96)	88 (20 - 161)	89 (8 - 274)
Mean reconstruction length (range) (cm)	11 (6 - 20)	10 (4-16)	11 (8 - 13)	NR	NR	NR	NR	9 (2 - 20)
Infection (%)	-	-	NR	13	-	-	-	7
Fracture of host bone (%)	27	10	15	-	-	-	-	18
Allograft fracture (%)	-	-	NR	-	-	-	-	3
Nonunion (%)	-	-	-	-	-	-	-	7
Residual / recurrent tumor (%)	-	-	8	13	-	-	-	14
Failure (%)	-	-	-	13	-	-	-	14

*NR = not reported. †The study population comprised twenty-eight patients, but only eight had hemicortical resection. The results in this table refer to those patients only.

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