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Periacetabular Resection for Bone Tumors: Is There Still a Role for Massive Allograft-prosthesis Composite Reconstructions?

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Abstract

Background Allograft-prosthesis composite reconstruction after periacetabular resections allows for bony union and internal repair, restoring bone stock for further revisions; the allograft-prosthesis composite can be shaped according to the pelvic resection to reconstruct the complex bone anatomy. Recently, endoprosthetic reconstruction has become one of the most frequently used options to restore large periacetabular bone defects. However, a prosthetic reconstruction impairs pelvic bone stock preservation and often takes a long time to manufacture. Allograft reconstructions, on the other hand, allow for bony union and internal repair, and they restore bone stock for further revisions. In addition, allografts are usually readily available and can be shaped according to the pelvic resection, fully restoring the complex bone anatomy. Pelvic biological reconstructions may have still a role, and to our knowledge, there are few long-term results of allograft-prosthesis composite reconstruction of the pelvis after periacetabular resections for bone tumors.

Questions/purposes (1) What is the cumulative incidence percentage of patients who experienced complications after reconstruction with allograft-prosthesis composites after resection of periacetabular tumors? (2) What was the functional result after surgical treatment as assessed by the Musculoskeletal Tumor Society (MSTS) score at a minimum of 2 years? (3) What was the survivorship of these reconstructions free from revision and graft removal at 15 years?

Methods Between February 1994 and April 2023, a total of 174 patients were treated at the university hospital of Florence for primary and secondary malignant or aggressive benign bone tumors of the pelvis with en bloc resection. Of treated patients, 51 underwent periacetabular resection and allograft-prosthesis composite reconstruction. We included in the study only patients with at least 24 months of follow-up or those who had complications earlier; thus 96% (49 of 51) of the patients had the required minimum follow-up and were included. Among the included patients, 88% (43 of 49) were available for a minimum follow-up of 24 months, whereas 12% (6) had < 24 months of follow-up but had complications earlier; thus, they were included for the analysis of complication-free survivorship. Seventy-eight percent (38) of patients were treated with a pelvic allograft combined

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Ethical approval for this study was obtained from the Comitato Etico Regione Toscana - Area Vasta Centro (ref. 10197/2017).
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with an acetabular cage, 16% (8) of patients received only a cemented cup, and 6% (3) of patients received a stemmed cementless cup. The mean ± SD follow-up time was 100 ± 77 months. The mean ± SD age at the time of reconstruction was 47 ± 17 years; 37% (18 of 49) of patients were female and 63% (31) were male. According to the Enneking and Dunham classification of pelvic resections, 39% (19) of patients had a Type I-II resection, 24% (12) had a Type II, 22% (11) had a Type II-III, 8% (4) had a Type I-II-III, 4% (2) had a Type I-II-IV, and 2% (1) had a Type I-II-III-IV. All patients had primary or secondary malignant or benign aggressive bone tumors: high-grade central chondrosarcoma (39% [19 of 49]), Ewing sarcoma (14% [7]), high-grade osteosarcoma (10% [5]), metastasis from carcinoma (10% [5]), dedifferentiated chondrosarcoma (10% [5]), peripheral low-grade chondrosarcoma (2% [1]), giant cell tumor of bone (2% [1]), osteoblastoma (2% [1]), hemangioendothelioma of bone (2% [1]), undifferentiated pleomorphic sarcoma of bone (2% [1]), malignant peripheral nerve sheath tumor of bone (2% [1]), radiation-induced sarcoma (2% [1]), or solitary plasmacytoma (2% [1]). The cumulative incidence of major complications, defined as surgical revision of any component of the reconstruction for mechanical complications and/or infections either surgically treated or not, and removal of the allograft as endpoints indicating failure, respectively, were estimated according to the competing-risk method. Complications were assessed through the revision of clinical charts. Death before the primary event of interest was considered a competing event. Comparisons of cumulative incidence curves across patient subgroups were performed with the Gray test. Normality of variables was assessed using the Shapiro-Wilk test, and heteroscedasticity was assessed using the Levene test. Accordingly, postoperative functional outcomes were compared across groups using a Welch t-test. Group means were reported in each plot. The relationship between functional score and length of follow-up was determined using a Pearson correlation coefficient. Significance was set at $p < 0.05$. The functional results were assessed using the MSTS score. The MSTS score was evaluated in patients with at least 2 years of follow-up in whom the pelvic allograft was retained at last clinical follow-up. Functional outcomes were assessed through the review of our institutional database.

Results The cumulative incidence of major complications was 24% (95% confidence interval [CI] 13% to 37%) at 5 years and 33% (95% CI 20% to 46%) at 10 and 15 years. The mean ± SD MSTS score was 23 ± 5, assessed 10 ± 6 years after the procedure. The cumulative incidence of graft removal was 8% (95% CI 3% to 18%) at 5 and 10 years and 12% (95% CI 4% to 24%) at 15 years.

Conclusion Allograft-prosthesis composite may represent an effective reconstructive option after periacetabular resection for primary bone tumors even in the era of 3D-printed implants; it still could have a role in patients with long life expectancy who are treated for tumors that were not managed with chemotherapy or radiotherapy and in whom the iliac wing is fully or partially preserved. Larger studies comparing periacetabular allograft-prosthesis composite with other reconstructive options such as modular and custom-made endoprostheses, as well as recycled autograft-prosthesis composites, are warranted to assess the potential benefits of one technique over the other.

Level of Evidence Level IV, therapeutic study.

Introduction

The pelvis is a relatively common site for primary and secondary bone tumors, accounting for approximately 15% of all bone sarcomas and up to 20% of metastatic lesions [16, 18]. Although during the last several decades limb salvage surgery has become the most widely used option because of effective chemotherapy and radiotherapy protocols and improvements in imaging tools, pelvic bone tumors are usually associated with a worse outcome than extremity tumors, mainly because of the large size of the tumor at presentation and the proximity to neurovascular structures, which makes it difficult for the surgeon to achieve adequate surgical margins. Furthermore, the reconstruction of pelvic bone defects remains one of the most difficult challenges, in particular for those involving the periacetabular area [13]. However, patients with primary malignant bone tumors are often children and young adults with high functional demands. Therefore, for patients who survive their neoplasms, a long-term durable reconstruction is advised.

Several options to reconstruct periacetabular bone defects after tumor resection have been reported, including iliofemoral or ischiofemoral arthrodesis, hip transposition, massive allografts, recycled autografts, custom-made and modular endoprostheses, and the combination of a massive allograft and a THA called an allograft-prosthesis composite [4, 13]. Each reconstruction method has its own advantages and drawbacks, with infections and dislocations being the most frequently reported complications [4, 13]; thus, there is no agreement on a standard reconstruction technique after periacetabular resections. Recently, with the improvements in computer-assisted design and three-dimensional (3D) printing techniques, endoprosthetic reconstruction has become one of the most frequently used options to restore large periacetabular bone defects because of its initial stability, exact geometry, satisfactory cosmetic results, and early functional recovery [13]. However, a prosthetic reconstruction impairs pelvic bone stock preservation, particularly in young patients. Furthermore, periacetabular custom-made endoprostheses often take a long time to manufacture, and they lack intraoperative adjustability and flexibility, which may necessitate cutting guides or computer-guided navigation to obtain a precise bone resection [14]. Allograft reconstructions with or without a prosthesis, on the other hand, allow for bony union and internal repair and restore bone stock for further revisions. In addition, allografts are usually readily available and can be shaped according to the pelvic resection, fully restoring the complex bone anatomy. However, full functional recovery is delayed and is related to the occurrence of graft union, and the use of large pelvic allografts is technically demanding, making this reconstruction approach much less widely used than prosthetic options. With that said, pelvic biological reconstructions still may have a role, although to our knowledge, despite few studies [6, 7] focusing on allograft-prosthesis composite reconstruction of the pelvis after periacetabular resections for bone tumors, current research lacks data on long-term outcomes and factors affecting functional results in this group of patients.

We therefore asked: (1) What is the cumulative incidence percentage of patients who experienced complications after reconstruction with allograft-prosthesis composites after resection of periacetabular tumors? (2) What was the functional result after surgical treatment as assessed by the Musculoskeletal Tumor Society (MSTS) score at a minimum of 2 years? (3) What was the survivorship of these reconstructions free from revision and graft removal at 15 years?

Patients and Methods

Study Design and Setting

This was a retrospective study performed over a 30-year time span at the University Hospital of Florence by an experienced orthopaedic oncology team.

Patients

Between 1994 and 2023, a total of 174 patients were treated at our institution for primary and secondary malignant or aggressive benign bone tumors of the pelvis with en bloc resection. We excluded patients who underwent amputation. Of the patients treated, 36% (62 of 174) had iliac wing tumors without periacetabular involvement and underwent resection without reconstruction in partial iliac resections or reconstruction with a massive allograft or recycled autograft in resections of the entire ilium leading to a pelvic discontinuity; 14% (25 of 174) had anterior pelvic ring resections preserving the acetabulum that were not treated with reconstruction.

Fifty percent (87 of 174) of patients had a bone tumor of the periacetabular area, and they were treated with a periacetabular resection. Before 2016, at our institution, we typically used reconstruction with massive allograft with or without a hip prosthesis after periacetabular pelvic resection for primary and secondary malignant or aggressive benign bone tumors in young or adult patients with long life expectancy and high functional demands. From 2016 onward, a 3D-printed, custom-made endoprosthesis has been routinely used in such patients, except for skeletally immature patients, in whom massive allografts are still used at our institution. We usually avoid acetabular reconstructions in older patients, patients with metastatic lesions, and in patients with a poor prognosis. According to the previously mentioned indications, 5% (4 of 87) of patients underwent massive allograft reconstruction preserving the native femoral head because they were still growing and had a long life expectancy, 14% (12 of 87) underwent hip transposition, 23% (20 of 87) underwent prosthetic reconstruction, and 59% (51 of 87) underwent allograft-prosthesis composite reconstruction.

We included in the study only patients with at least 24 months of follow-up or those who had complications earlier; thus, 96% (49 of 51) of the patients had the required minimum follow-up time and were included. Among the included patients, 88% (43 of 49) were available for a minimum follow-up of 24 months, whereas 12% (6) had < 24 months of follow-up but had complications earlier; thus, these patients were included with a mean follow-up time of 100 ± 77 months. Six percent (3) of patients have not been seen in the last 2 years and were not known to have died. These patients had 99, 147, and 168 months of follow-up, respectively, and they were included in this study. In 78% (38) of patients, the massive pelvic allograft was treated with an acetabular antiprotrusio cage combined with a cemented cup, 16% (8) of patients received a cemented cup without an acetabular cage, and 6% (3) received a stemmed cementless cup. The femoral stem was cemented in 78% (38) of patients and uncemented in 16% (8) of patients, whereas 6% (3) of patients underwent proximal femur megaprosthetic reconstruction because of an extraarticular hip resection. Uncemented stems were usually used in young patients or in adults who were not treated with chemotherapy and radiation therapy, whereas cemented stems were used in patients in whom preoperative or postoperative chemotherapy and/or radiotherapy were delivered or in patients with poor bone quality. In 84% (41) of patients, a constrained liner was used to reduce the likelihood of hip dislocations, in 8% (4) of patients a dual-mobility cup was used, and in the other 8% (4), a conventional liner combined with a prolene reinforcing mesh was used.

Allograft fixation was performed combining different fixation methods according to the resection type to achieve adequate contact between the osteotomies to enhance the union between host bone and allograft. In resections involving the sacroiliac joint, the fixation was performed using two or three cannulated screws through the joint. For resections on the iliac wing, fixation was usually performed by combining a posterior column plate and screw fixation with the acetabular cage or the stemmed cup to achieve a bridging fixation. For resections on the pubic rami or after symphysis disarticulation, a fixation using one or two cannulated screws was usually adopted (Fig. 1). Our policy was to use an acetabular cage combined with a massive allograft in patients undergoing periacetabular resection involving part of or the entire iliac wing to achieve osteotomy compression and to prevent allograft weakening, respectively.

Descriptive Data

The mean ± SD age at the time of the reconstruction was 47 ± 17 years; 37% (18 of 49) of patients were female and 63% (31) were male. According to the Enneking and Dunham classification of pelvic resections [10], 39% (19) of patients had a Type I-II resection, 24% (12) had a Type II, 22% (11) had a Type II-III, 8% (4) had a Type I-II-III, 4% (2) had a Type I-II-IV, and 2% (1) had a Type I-II-III-IV (Table 1).

All patients had primary or secondary malignant or benign aggressive bone tumors as follows: high-grade central chondrosarcoma (39% [19 of 49]), Ewing sarcoma (14% [7]), high-grade osteosarcoma (10% [5]), metastasis from carcinoma (10% [5]), dedifferentiated chondrosarcoma (10% [5]), peripheral low-grade chondrosarcoma (2% [1]), giant cell tumor of bone (2% [1]), osteoblastoma (2% [1]), hemangioendothelioma of bone (2% [1]), undifferentiated pleomorphic sarcoma of bone (2% [1]), malignant peripheral nerve sheath tumor of bone (2% [1]), radiation-induced sarcoma (2% [1]), and solitary plasmacytoma (2% [1]). Experienced pathologists diagnosed all patients after biopsy. At diagnosis, no patients had pathologic fractures, and according to the MSTS staging system [11], two benign tumors were Stage III, two malignant tumors were Stage IB, two were IIA, 36 were IIB, and one was Stage IIIB.

Surgical Technique, Aftercare, and Cancer Treatment

All operations were performed through a utilitarian pelvic approach with the patient in a lateral floppy position, adding an ilioinguinal incision in patients who underwent Type III resection to allow mobilization of major vessels and nerves. We usually adopt an approach that includes an incision that begins at the posterior-superior iliac spine and

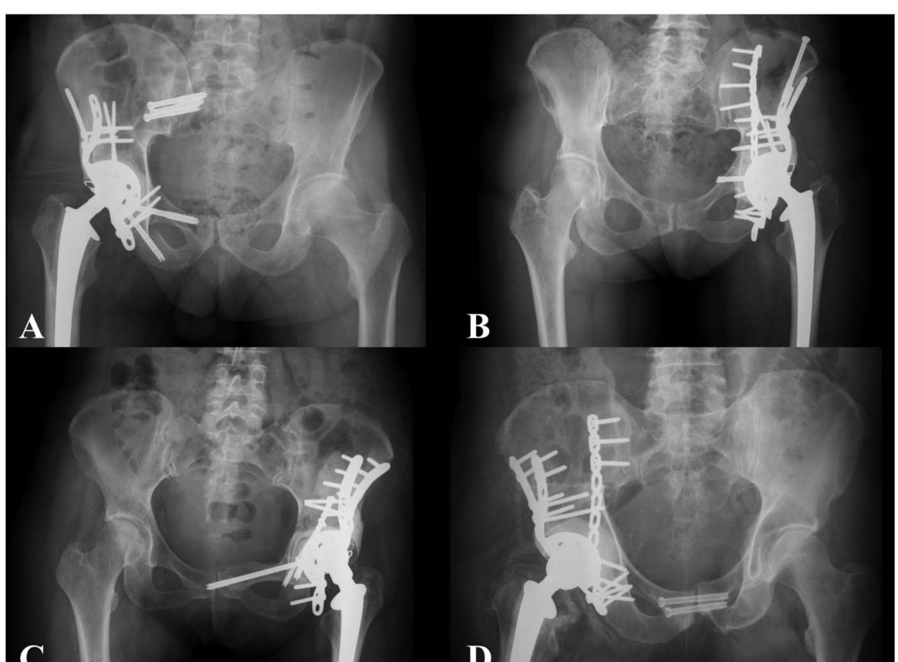

Fig. 1 Different types of graft fixation according to resection type: (**A**) fixation with cannulated screws on the sacroiliac joint, (**B**) fixation with an acetabular cage and posterior column plate on the iliac wing, (**C**) fixation with a cannulated screw on the pubic rami, and (**D**) fixation with cannulated screws on the pubic symphysis.

Table 1. Patient characteristics

Characteristic	Value (n = 49)
Gender, female	37 (18)
Age in years	47 ± 17
Diagnosis	
Central chondrosarcoma (Grades 2 and 3)	39 (19)
Ewing sarcoma	14 (7)
Osteosarcoma (high grade)	10 (5)
Dedifferentiated chondrosarcoma	10 (5)
Metastasis from carcinoma	10 (5)
Peripheral chondrosarcoma (low grade)	2 (1)
Hemangioendothelioma of bone	2 (1)
Undifferentiated pleomorphic sarcoma	2 (1)
Malignant peripheral nerve stealth tumor	2 (1)
Radiation-induced sarcoma	2 (1)
Plasmacytoma	2 (1)
Giant cell tumor	2 (1)
Osteoblastoma	2 (1)
Stage (Enneking)	
2	4 (2)
IA	0 (0)
IB	4 (2)
IIA	4 (2)
IIB	73 (36)
IIIB	2 (1)
Treated with chemotherapy	57 (28)
Preoperative	31 (15)
Postoperative	27 (13)
Treated with radiotherapy	22 (11)
Preoperative	16 (8)
Postoperative	6 (3)
Pelvic resection type (Enneking)	
I-II	39 (19)
II	24 (12)
II-III	22 (11)
I-II-III	8 (4)
I-II-IV	4 (2)
I-II-III-IV	2 (1)
Acetabular reconstruction	
Acetabular cage	78 (38)
Cemented cup	16 (8)
Stemmed cup	6 (3)
Liner type	
Constrained snap fit	61 (30)
Fully constrained	22 (11)
Dual mobility	8 (4)
Conventional	8 (4)

Data presented as % (n) or mean ± SD.

continues along the iliac crest, extending over the first third of the thigh and then curving laterally. After the posterior reflection of the gluteus maximus flap, this allows for the exposure of either the sciatic notch, posterior pelvic ligaments, ischium, or lateral margin of the sacrum, and also the retroperitoneal space through the detachment of the abdominal wall muscles. In 69% (34) of patients, hip abductors were preserved during the tumor resection. Upon histologic examination of the resected tumors, surgical margins were wide in 78% (38) of patients and marginal in 10% (5); surgical margins were not assessed in secondary bone tumors.

For the reconstruction, we used nonirradiated pelvic allografts harvested under sterile conditions, stored at -80°C in an institutional bone bank, and selected according to the native pelvic size as assessed on radiographs or CT scans when available. Serologic tests to exclude transmissible disease were performed on the donor before the graft harvesting. After the tumor resection, the massive allograft was thawed in a warm antibiotic solution of rifampicin in 250 mg per liter of saline solution, then sectioned and shaped according to the residual periacetabular defect to achieve the best anatomic match. The shaped massive allograft was fixed to the host residual pelvic bone using a different fixation method according to the previously mentioned criteria to achieve adequate contact of the osteotomies. Then, a THA with a cemented cup was implanted in most patients combined with an acetabular cage or a stemmed acetabular cup. Finally, the hip abductors tendons, if preserved, and abdominal wall musculature were sutured to the graft with nonabsorbable sutures. No local or free flaps were performed to cover the soft tissue defect secondary to tumor excision. The mean ± SD operative time was 8 ± 1 hours.

Until 2010, our institutional antibiotic protocol was that all patients receive perioperative antibiotic prophylaxis with intravenous vancomycin (1 gram every 12 hours) combined with tobramycin (1 mg/kg every 8 hours); from 2010 onward, vancomycin was combined with piperacillin and tazobactam (4.5 grams every 8 hours). This protocol was used until drain removal.

After surgery, all patients were mobilized with two crutches and wore a pelvic-hip brace, which allowed controlled passive movements of the surgically treated hip. Partial weightbearing was allowed until evidence of graft union on radiographs. Full weightbearing was permitted after evidence of complete osteotomy healing. We defined graft-host bone union as the disappearance of the osteotomies on radiographs with cortical fusion.

Thirty-one percent (15 of 49) of patients—14 with a diagnosis of either high-grade osteosarcoma, Ewing sarcoma, or malignant peripheral nerve sheath tumor of the bone and one with a diagnosis of dedifferentiated chondrosarcoma—received preoperative and postoperative chemotherapy; three of seven patients with Ewing sarcoma had concomitant preoperative radiotherapy and three underwent it postoperatively. Ten percent (5) of patients, who had radiation-induced sarcoma, undifferentiated pleomorphic sarcoma of the bone, and metastasis from carcinoma, underwent only preoperative chemotherapy, which in one patient was combined with radiotherapy, and one patient with a dedifferentiated chondrosarcoma received only postoperative chemotherapy. Three of five patients treated for metastatic disease received only preoperative radiotherapy. In patients who received preoperative chemotherapy, the surgery was usually planned 3 weeks after the last drug administration, whereas it was planned after 4 weeks in patients who underwent preoperative radiotherapy, which is not different from other reconstructive options that we adopt.

Data Sources and Variables

All patients were periodically reviewed according to oncologic follow-up, and they underwent periodic clinical and radiologic examinations. After the primary surgery, we reviewed patients with malignancies every 3 months during the first 2 years, every 4 months during postoperative year 3, every 6 months during years 4 and 5, and then annually until 10 years. Patients with benign tumors were reviewed every 6 months during the first 5 years and then annually until 10 years. Data extracted from medical records were registered in our database.

At the last clinical follow-up, after a mean ± SD of 100 ± 77 months from primary surgery, 37% (18 of 49) of patients were continuously disease free. Ten percent (5) of patients had no evidence of disease after treatment of local recurrence (6% [3]) and distant metastasis (4% [2]). Fifty-one percent (25) of patients died from metastatic disease after a mean 35 ± 21 months from the index surgery, and 2% (1) of patients died of another cause after 109 months.

Primary and Secondary Study Outcomes

Our primary study goal was to evaluate the percentage of complications after reconstruction with allograft-prosthesis composites after resection of periacetabular tumors and to analyze the survivorship of these reconstructions free from revision and graft removal. Complications and graft removal were recorded during follow-up and assessed through the revision of clinical charts. We defined complication as every unplanned further surgery performed for any reason; major complication was defined as a mechanical complication leading to the surgical revision of any component of the reconstruction or an infection either surgically managed or not. In all patients, union of the graft with host bone was radiographically assessed.

Our secondary study goal was to evaluate the functional outcome after surgical treatment at a minimum of 2 years of follow-up. The functional results were assessed using the MSTS score [9], which is a well-known system to evaluate functional outcomes in patients treated for bone tumors. In lower limb reconstructions and pelvic girdle, the score considers six parameters: pain, function, emotional acceptance, supports, walking, and gait, with values ranging from 0 to 5 according to specific criteria. The sum of the individual scores defines the overall functional score with a maximum of 30 points [9]. The MSTS score was evaluated in patients in whom the pelvic allograft was retained at last clinical control and with at least 2 years of follow-up. Functional outcomes were assessed through the review of our institutional database.

Ethical Approval

We obtained ethical approval for this retrospective observational study from the Comitato Etico Regione Toscana - Area Vasta Centro (ref. 10197/2017).

Statistical Analysis

The cumulative incidence of complications that were treated surgically, major complications, and graft removal was estimated according to the competing-risk method, including further surgery for any complications, surgical revision of any component of the reconstruction for mechanical complications or infections either surgically managed or not, and removal of the allograft as endpoints indicating failure, respectively. Competing-risk curves were computed using R, version 4.3.2. Death before the primary event of interest was considered as a competing event. Comparisons of cumulative incidence curves across patient subgroups were performed with the Gray test. Normality of variables was assessed using the Shapiro-Wilk test, and heteroscedasticity was assessed using the Levene test. Accordingly, postoperative functional outcomes were compared across groups using a Welch t-test for binomial comparisons and the Kruskal-Wallis test for multinomial comparisons. The effect size for the Kruskal-Wallis test was computed as eta-squared based on the

H-statistic. Group means were reported in each plot. The relationship between functional score and length of follow-up was determined using a Pearson correlation coefficient. Significance was set at $p < 0.05$.

Results

Complications and Reoperations

The cumulative incidence of major complications, with surgical revision of any allograft-prosthesis composite component for mechanical complications or infection either surgically managed or not as the endpoint, was 24% (95% confidence interval [CI] 13% to 37%) at 5 years and 33% (95% CI 20% to 46%) at 10 and 15 years (Fig. 2). All but four of the major complications occurred within the first 5 postoperative years. During follow-up, complications that were treated with further operative procedures were observed in 45% (22 of 49) of patients after a mean ± SD of 30 ± 43 months (Table 2).

Ten percent (5 of 49) of patients had persistent postoperative common peroneal nerve palsy and were treated with an orthosis. Two percent (1) of patients had a partial femoral nerve palsy, and 2% (1) of patients had a persistent sciatic nerve palsy. Within the first postoperative month, 2% (1) of patients had a wound dehiscence and 2% (1) developed a postoperative hematoma. Hip dislocations were assessed in 18% (9) of patients, with recurrent dislocations in 4% (2) of patients; all but two patients had a dislocation that occurred within the first 2 months of the index surgery. Four of nine patients with dislocations underwent nonoperative reduction, while the remaining five patients underwent a surgical revision of the femoral head, stem, or cup to increase stability, which was effective for all patients.

Aseptic loosening was observed in 8% (4 of 49) of patients, which involved the cup in three of the four patients and an uncemented femoral stem in one patient, at a mean ± SD of 70 ± 41 months from primary resection. With the number of patients we had, the risk of aseptic loosening of the cup was higher when the cup was directly cemented onto the graft without an acetabular ring (3% versus 25%, HR 7.21 [95% CI 0.23 to 15.7]; p = 0.04) (Table 3). No patients had allograft nonunion or fracture.

Deep infection was observed in 20% (10 of 49) of patients at a mean 26 ± 41 months after the primary

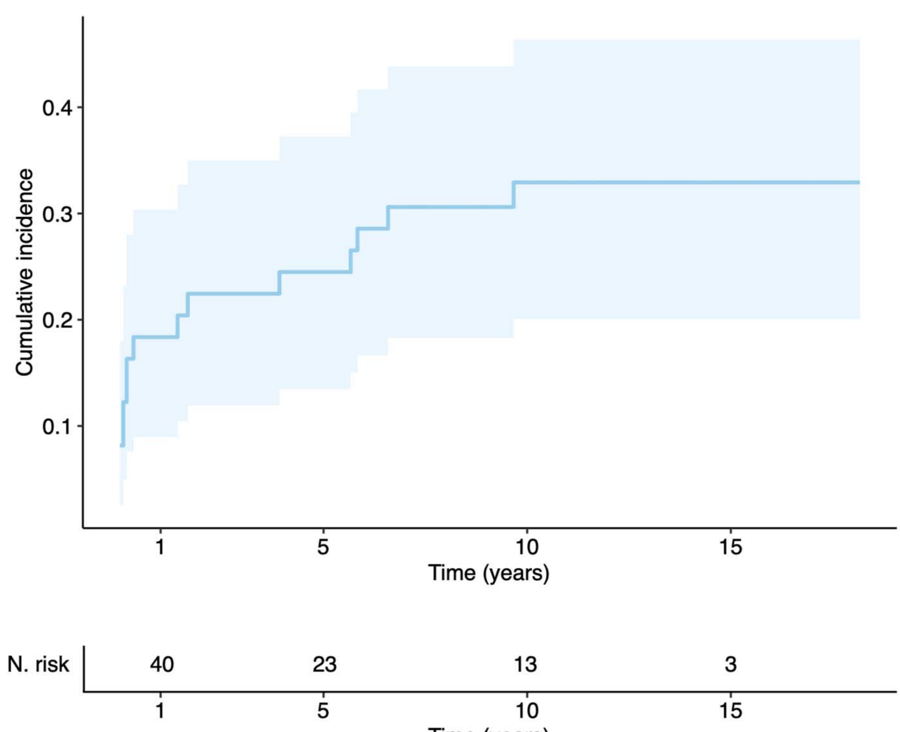

Fig. 2 Cumulative incidence of major complications, with surgical revision of any allograft-prosthesis composite component for a mechanical complication of the reconstruction or infection either surgically managed or not as an endpoint. The risk was 24% (95% CI 13% to 37%) at 5 years and 33% (95% CI 20% to 46%) at 10 and 15 years. The light blue area represents CIs. N. risk = the number of patients still being followed and at risk of the event at a specific time point.

Table 2. Complications that led to surgical treatment

Patient	Diagnosis	Resection type[a]	Acetabular reconstruction	Complication type	Major complication[b]	Time in months from surgery	Treatment of complication	Outcome	Graft removal[c]	MSTS score[d]	Oncologic outcome
1	Dedifferentiated chondrosarcoma	I-II-III-IV	Acetabular ring	Deep infection	Yes	2	Debridement and intravenous antibiotics	Persistent infection	No	20	DOD
2	Ewing sarcoma	I-II-III	Acetabular ring	Dislocation with femoral stem loosening	Yes	1	Stem revision and reduction	Healed	No	15	DOD
3	Grade 2 chondrosarcoma	I-II	Acetabular ring	Postoperative hematoma	No	0	Debridement and hemostasis	Resolved	No	27	DOD
3				Recurrent dislocations	Yes	2	Cup revision and reduction	Resolved	No		
4	Grade 2 chondrosarcoma	I-II-IV	Acetabular ring	Wound dehiscence	No	0	Debridement and closure	Healed	No	24	DOD
5	Metastasis	I-II	Acetabular ring	Deep infection	Yes	1	Debridement and intravenous antibiotics	Persistent infection	Yes (1)		DOD
6	High-grade osteosarcoma	I-II	Acetabular ring	Dislocation	No	0	Open reduction	Resolved	No	23	DOD
7	Metastasis	I-II	Acetabular ring	Deep infection	Yes	1	Debridement and intravenous antibiotics	Healed	No	21	DOD
8	High-grade osteosarcoma	I-II-III	Acetabular ring	Deep infection	Yes	0	Debridement and intravenous antibiotics	Healed	No	15	DOD
9	Ewing sarcoma	I-II	Acetabular ring	Deep infection	Yes	20	Debridement and intravenous antibiotics	Persistent infection	No	15	DOD
10	Dedifferentiated chondrosarcoma	II-III	Stemmed cup	Deep infection	Yes	0	Debridement and intravenous antibiotics	Persistent infection	Yes (34)		CDF
11	Grade 2 chondrosarcoma	I-II-III	Acetabular ring	Local recurrence	No	149	Hindquarter amputation	Healed	Yes (149)		NED
12	Undifferentiated pleomorphic sarcoma	II	Acetabular ring	Local recurrence	No	43	Excision	Lung metastasis	No	25	DOD

Table 2. continued

Patient	Diagnosis	Resection type[a]	Acetabular reconstruction	Complication type	Major complication[b]	Time in months from surgery	Treatment of complication	Outcome	Graft removal[c]	MSTS score[d]	Oncologic outcome
13	Dedifferentiated chondrosarcoma	I-II	Acetabular ring	Dislocation	Yes	0	Femoral head revision and reduction	Resolved	No	21	CDF
14	Grade 2 chondrosarcoma	II	Acetabular ring	Local recurrence	No	3	Hindquarter amputation	Healed	Yes (3)		NED
15	Grade 2 chondrosarcoma	II-III	Cemented cup	Recurrent dislocation	Yes	3	Stem revision and reduction	Resolved	No	15	DOD
16	Ewing sarcoma	II-III	Acetabular ring	Deep infection	Yes	68	Debridement and intravenous antibiotics	Healed	No	21	NED
17	Grade 2 chondrosarcoma	II-III	Acetabular ring	Cup loosening	Yes	116	Cup revision with acetabular ring removal and stemmed cup reconstruction	Resolved	No	30	CDF
18	Grade 2 chondrosarcoma	II	Cemented cup	Cup loosening	Yes	70	Cup revision adding an acetabular ring	Resolved	No	26	CDF
19	Grade 3 chondrosarcoma	I-II	Cemented cup	Deep infection	Yes	47	Debridement and intravenous antibiotics	Healed	Yes (47)		CDF
20	Giant cell tumor	II	Cemented cup	Cup loosening	Yes	79	Cup revision adding an acetabular ring	Resolved	No	24	CDF
21	Grade 2 chondrosarcoma	II-III	Acetabular ring	Stem loosening	Yes	17	Stem revision	Resolved	No	20	CDF
22	Grade 2 chondrosarcoma	II	Acetabular ring	Screw loosening	No	41	Screw removal	Resolved	No	29	CDF

DOD = died of disease; CDF = continuously disease free; NED = no evidence of disease.
[a]Resection type according to Enneking and Dunham classification: I = iliac area; II = periacetabular area; III = ischiopubic rami; IV = sacral ala.
[b]Major complication: mechanical complication leading to the surgical revision of any component of the reconstruction or an infection either surgically managed or not.
[c]If yes, parentheses indicate months from initial surgery.
[d]MSTS score assessed at last clinical follow-up, after the complication was treated; it ranges from 0 to 30, with 30 points representing less pain and better functional outcomes.

surgery. Two infections that occurred at 1 and 10 years after primary surgery were managed nonoperatively with oral suppressive antibiotic therapy, and eight patients received surgical debridement and intravenous antibiotics; five of the eight patients had a persistent infection, which led to a graft removal in three of the eight patients, whereas three patients eventually healed. A lower infection rate was observed in conventional chondrosarcomas (5% versus 31%, HR 7.22 [95% CI 0.27 to 54.1]; p = 0.03), while the delivery of preoperative (38% versus 17%, HR 6.38 [95% CI 0.22 to 43.7]; p = 0.04) or postoperative radiotherapy (67% versus 17%, HR 4.13 [95% CI 1.25 to 13.7]; p = 0.02) increased the risk of this complication (Table 3).

Eighteen percent (9 of 49) of patients had local recurrence at a mean ± SD of 40 ± 47 months after tumor excision, which led to a hindquarter amputation with graft removal in 4% (2) of patients because of the graft's involvement with major vessels and nerves. At last clinical follow-up, a mean ± SD leg-length discrepancy of 2.3 ± 1.0 cm was observed in 27% (13) of the patients who retained their original graft and who were between 13 and 69 years of age at the time of surgery, with only one skeletally immature patient. The discrepancies were managed with a shoe lift in all patients.

Outcome Scores for Pain and Function

At a mean ± SD of 111 ± 75 months, the mean MSTS score was 23 ± 5. Pain and emotional acceptance ranged between 4 and 5 points, and function scores, walking, and

Table 3. Allograft prosthesis composite mechanical and infective complications

	Major complications		Dislocation		Aseptic loosening		Infection	
Variable	**HR (95% CI)**	**p value**	**HR (95% CI)**	**p value**	**HR (95% CI)**	**p value**	**HR (95% CI)**	**p value**
Gender, male (n = 31) (reference: female)	0.97 (0.36-2.57)	0.94	2.24 (0.5-9.98)	0.29	0.17 (0.02-1.53)	0.09	1.29 (0.34-5)	0.71
Diagnosis, chondrosarcoma (n = 20) (reference: other diagnosis)	1.3 (0.5-3.38)	0.59	0.86 (0.24-3.31)	0.82	4.57 (0.5-41.63)	0.18	7.22 (0.27-54.1)	0.03
Preoperative chemotherapy, yes (n = 15) (reference: no)	0.83 (0.3-2.23)	0.72	1.06 (0.29-3.81)	0.85	-	-	3.46 (0.91-18.17)	0.05
Preoperative radiation therapy, yes (n = 8) (reference: no)	1.4 (0.38-5.19)	0.62	1.49 (0.33-6.64)	0.6	-	-	6.38 (0.22-43.7)	0.04
Resection type, iliac wing resected (n = 21) (reference: iliac wing preserved)	1.31 (0.51-3.37)	0.64	3.27 (0.68-15.8)	0.11	-	-	3.97 (0.86-18.31)	0.06
Acetabular reconstruction, cemented cup (n = 8) (reference: acetabular ring)	1.6 (0.48-5.26)	0.6	3.34 (0.87-18.12)	0.07	7.21 (0.23-15.7)	0.04	2.38 (0.5-9.84)	0.23
Acetabular reconstruction, stemmed cup (n = 3) (reference: acetabular ring)	0.81 (0.2-2.13)	0.78	-	-	-	-	0.81 (0.3-2.13)	0.65
Postoperative chemotherapy, yes (n = 13) (reference: no)	0.73 (0.24-2.22)	0.56	1.15 (0.03-4.44)	0.79	-	-	1.55 (0.45-5.27)	0.54
Postoperative radiation therapy, yes (n = 3) (reference: no)	2.31 (0.74-7.25)	0.15	1.84 (0.31-10.97)	0.58	-	-	4.13 (1.25-13.7)	0.02
Hip abductor resection, yes (n = 15) (reference: no)	1.13 (0.39-3.26)	0.82	1.98 (0.55-7.11)	0.29	-	-	1.62 (0.47-5.54)	0.44

"Reference" indicates the comparator group (HR of 1.0). Missing values refer to comparisons with not enough observations.

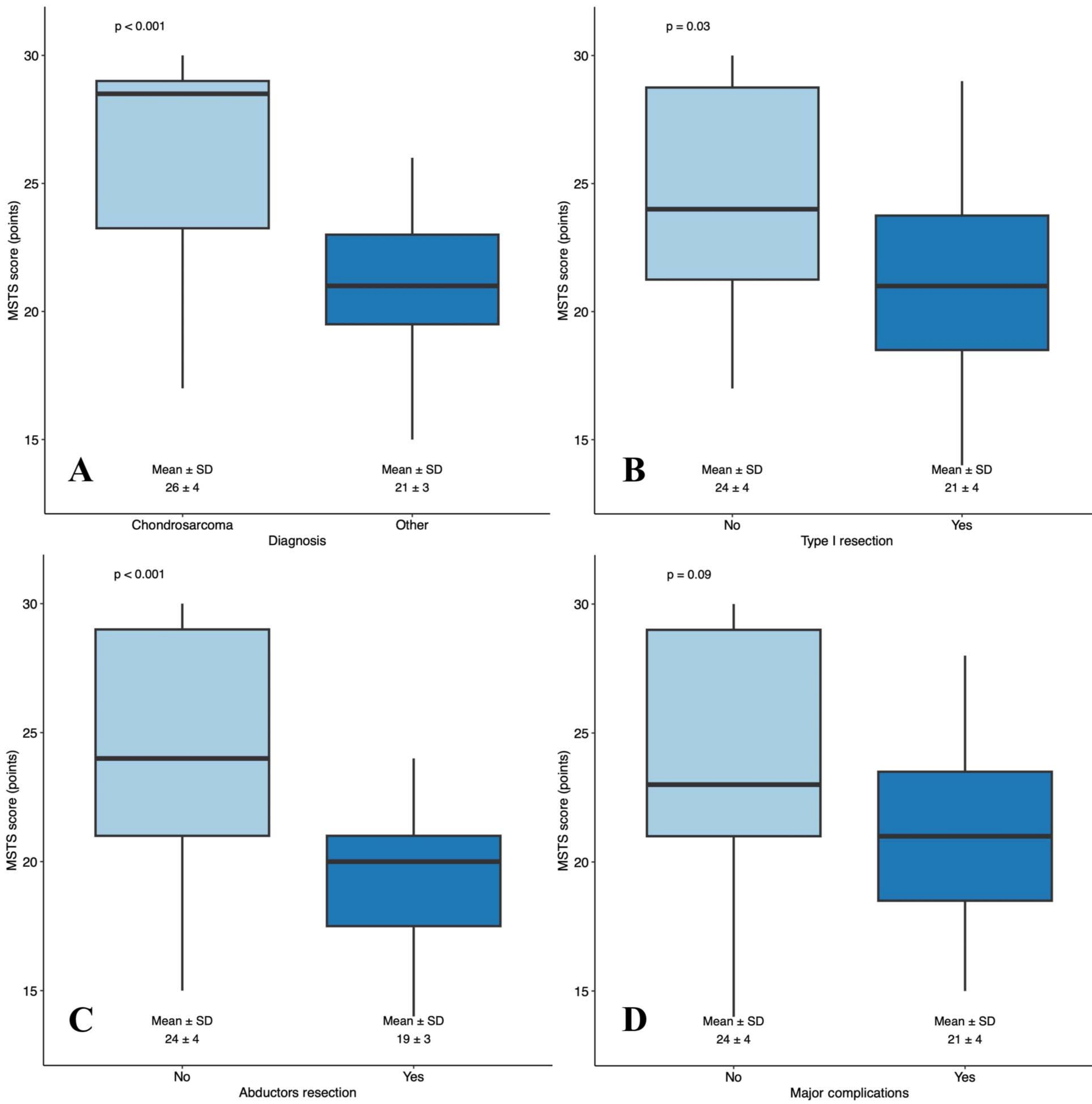

Fig. 3 Differences in MSTS scores according to (**A**) diagnosis, (**B**) resection of the iliac wing, (**C**) resection of hip abductors, and (**D**) occurrence of major complications.

gait ranged between 2 and 5 points; use of supports ranged between 0 and 5 points, with 22% (11 of 49) of patients walking without aids, 45% (22) using one cane, and 24% (12) walking with two crutches.

Functional results assessed using the MSTS score were higher in patients with longer follow-up time (R = 0.47; p = 0.001). Furthermore, the MSTS score was higher in patients treated for a conventional chondrosarcoma (26 ± 4 versus 21 ± 3 points, mean difference 5.17 [95% CI 2.51 to 7.82]; p < 0.001) and in whom the iliac wing (24 ± 4 versus 21 ± 4 points, mean difference 3.05 [95% CI 0.26 to 5.84]; p = 0.03) or hip abductors (24 ± 4 versus 19 ± 3 points, mean difference 4.88 [95% CI 2.38 to 7.38]; p < 0.001) were preserved; functional results were not worsened by complications that were treated surgically (Fig. 3). In the 19 patients who were alive and retained their original graft, at last clinical control the mean MSTS score was 25 ± 4 points, with nine patients walking without aids and the other nine with one cane.

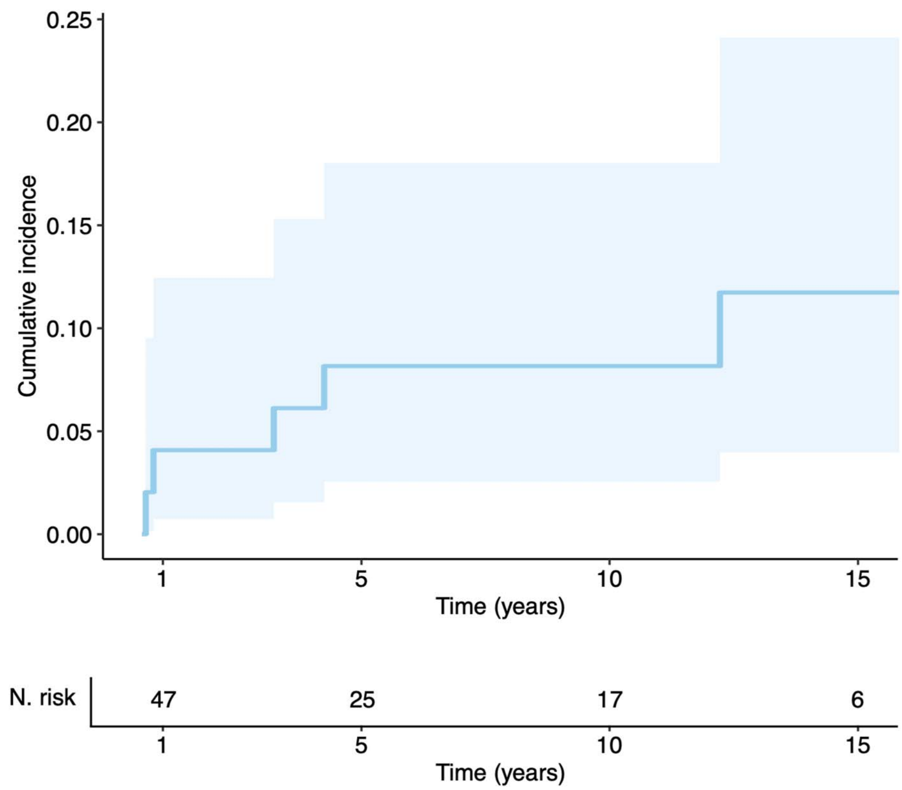

Fig. 4 Cumulative incidence of graft removal, with removal of graft as the failure endpoint. The risk was 8% (95% CI 3% to 18%) at 5 and 10 years and 12% (95% CI 4% to 24%) at 15 years. The light blue area represents CIs. N. risk = the number of patients still being followed and at risk of the event at a specific time point.

Survivorship of Pelvic Grafts

The cumulative incidence of graft removal, with removal of the graft as the failure endpoint, was 8% (95% CI 3% to 18%) at 5 and 10 years and 12% (95% CI 4% to 24%) at 15 years (Fig. 4); graft removal was undertaken in 10% (5 of 49) of patients after a mean of 47 ± 61 months. Overall, 4% (2) of patients underwent amputation because of local relapse, and 6% (3) had graft and prosthesis removal with flail hip because of persistent early infection; no other patients underwent amputation attributed to infectious complications. Among the 47% (23) of patients who were alive at last follow-up, 83% (19 of 23) retained their original graft at a mean of 167 ± 51 months from primary surgery.

Discussion

After periacetabular resection for a bone tumor, the reconstruction should restore a functional lower limb with an acceptable risk of reoperation and loss of the implant, in particular over longer follow-up periods. The combination of a massive pelvic allograft with a hip arthroplasty is one reconstructive option. Even though the procedure may sometimes delay functional recovery and weightbearing, allograft reconstruction may restore bone stock for further revisions. Furthermore, allografts are usually readily available and can be shaped according to the pelvic defect, fully restoring the complex bone anatomy. In this study, we aimed to investigate the long-term results of this technique. Although the risk of dislocations and infectious complications was highest in the first postoperative years, approximately 90% of patients retained their reconstruction at 15 years, and 19 of 23 patients who remained alive had an intact graft after a mean 13 years from primary surgery. The proportion of patients experiencing acetabular loosening was low when we cemented the cup inside an acetabular ring or used a stemmed cup, whereas perioperative radiotherapy increased the infection risk. Functional results were higher in patients with long-term follow-up, especially in those in whom hip abductors and the iliac wing were preserved.

Limitations

This study had limitations. First, there might have been selection bias regarding the indication for periacetabular reconstruction using an allograft-prosthesis composite rather than other reconstructive options, but during the study period, this reconstruction approach was the most frequently used in patients with an expected good prognosis. Second, three patients were not seen in the last 2 years, and they may have undergone further procedures for complications elsewhere. However, all these patients had > 8 years of follow-up confirming graft survival. Third, we did not investigate a comparison group with different periacetabular reconstructions, focusing only on allograft reconstructions with a hip prosthesis; the aim of this study, rather, was to analyze the complication pattern, frequency of complications, and survival with this reconstructive option. Fourth, we included allograft-prosthesis composite reconstructions either using an acetabular cage, a stemmed cup, or the cup directly cemented onto the graft, but the numbers were too small for us to be able to detect a difference in complication risk between these reconstructive types, except for aseptic cup loosening. Fifth, we did not include functional outcomes of patients who underwent amputation; if we had included them, the scores would have been lower. Finally, 12% (6 of 49) of patients were not included in the functional analysis because they were lost to follow-up before 2 years; thus, the outcome scores may appear better than they really were.

Complications and Reoperations

In this study, the cumulative incidence of major complications was 24% (95% CI 13% to 37%) at 5 years and 33% (95% CI 20% to 46%) at 10 and 15 years; complications that were treated with further surgeries were observed in 45% (22) of patients after a mean of 30 ± 43 months from the index surgery. Dislocations and infections were the most frequently assessed complications in our study and have been reported elsewhere [4]. Despite the use of a constrained liner in most of our reconstructions, dislocations occurred in 18% (9) of patients, mainly during the first postoperative months. Dislocation is a well-known complication after periacetabular resection for bone tumors; it has been reported to range between 2% and 26%, and it is mainly related to the hip abductors, capsule loss, and the shift of center of rotation [4, 17, 20]. As Ji et al. [16] have suggested, to reduce the risk of this complication, the systematic use of a fully constrained liner with suture of the hip capsule, when preserved, or its reconstruction using nonabsorbable mesh to create a pseudocapsule is advised in all patients undergoing a periacetabular reconstruction, even with an allograft-prosthesis composite, and particularly in those in whom the iliac wing should be resected.

Infection was observed in 20% (10) of patients, with one-half of the infections occurring within the first postoperative months; three of these 10 patients eventually healed after surgical debridement, whereas graft removal attributed to persistent infection was undertaken in three other patients. The infection rate was lower in patients treated for a conventional chondrosarcoma, while it was higher in those treated with perioperative radiotherapy. Infection is one of the most common and devastating complications after resection of pelvic and periacetabular tumors, reaching an incidence of almost 50% in some studies [2, 4, 12, 13]. One of the most important factors affecting the choice of the reconstruction after periacetabular resections is the involvement of the iliac wing; ilium reconstruction has been associated with a higher incidence of postoperative infections [12]. Thus, in this clinical scenario, a hip transposition without reconstruction may represent a reasonable option, particularly in patients treated with perioperative chemotherapy and/or radiotherapy. On the contrary, in Type II and II-III resections, the incidence of infection in our study seemed to be lower compared with prosthetic reconstructions (either custom-made or stemmed prostheses) besides a lower dislocation rate [4, 5, 12, 13]. These findings could be related to the solid soft tissue attachment to the graft, which occurs within the first months after surgery and involves almost the whole graft surface [8]. This is different from a metal smooth prosthesis in which the attachment of surrounding soft tissue does not occur, leaving a "dead space" around the implant, which might explain the low proportion of late infections in our study.

Interestingly, we observed no nonunions or graft fractures, even though these complications have been reported by other authors to be rare [3, 4, 6, 7, 13]. This could be related not only to the accurate contact between host bone and allograft cortices that was achieved through a progressive and meticulous shaping of the pelvic graft, although navigation or cutting guides were not used, but also to the good vascular supply of innominate bone, which enhances graft union potential, and to the adoption of different fixation methods with the aim of achieving a compression between osteotomies. Moreover, the frequent use of acetabular cages as spanning fixation could have shielded the graft from fractures. One of the major advantages of using an allograft-prosthesis composite over a prosthesis is the restoration of bone stock once union is achieved, in particular in patients who survive long term and who are at high risk of further revisions. In our study, three patients underwent revision for a cup loosening with acetabular component replacement preserving the periacetabular allograft. Further studies focused on investigating the comparison between the long-term failure rate of periacetabular allograft-prosthesis composites and other reconstructive options should be performed.

The reconstruction of periacetabular bone defects with a massive allograft combined with a THA has some drawbacks. One drawback is that compared with prosthetic reconstructions, surgical time is longer, which is likely related to the complexity of the reconstruction and graft shaping. This difficulty could be reduced through 3D planning and the use of navigation or patient- and allograft-specific cutting guides. In our patients, these osteotomies were made freehand without navigation or cutting guides. Moreover, the procedure requires the availability of a well-functioning bone bank program, and religious or ethical concerns could exist in some countries.

Outcome Scores for Pain and Function

The mean MSTS score was 23, and all patients returned to walking after surgery, although more than one-half of patients used a single cane or crutches, with a mean MSTS score of 25 points in the patients who retained their graft at last follow-up despite further procedures for minor or major complications. These functional results are comparable to those reported by other authors either for prosthetic or biologic reconstructions [3, 4, 6, 7, 13] and when considering long-term results [12, 15]. In our study, functional results were better in patients treated for a conventional chondrosarcoma, in those who underwent a periacetabular resection with complete or partial preservation of the iliac wing, and in patients whose hip abductors were preserved.

Survivorship of Pelvic Grafts

The cumulative incidence of graft removal was 8% (95% CI 3% to 18%) at 5 and 10 years and 12% (95% CI 4 to 24%) at 15 years; graft removal was undertaken in 10% (5) of patients after a mean of 47 months. Among the 47% (23) of patients who were alive at last follow-up, 83% (19 of 23) had retained their original graft at a mean of 167 months from primary surgery. Periacetabular reconstructions after tumor resection are burdened by a high complication rate [4, 13], but few studies [2, 7, 12, 15] discuss long-term results. Promising results have been published with a modular prosthesis in resection preserving part of or the whole iliac wing [1, 16] with a low incidence of major complications and implant removal, but given the relatively short follow-up time—on average, no longer than 70 months—these results should be confirmed in the long term. Currently, custom-made prostheses are probably the most adopted reconstruction option after periacetabular tumor resection [13]. In a series of 96 3D-printed custom hemipelvic endoprostheses with a porous surface, Hu et al. [14] reported a complication rate of 13.5%, with only one implant removed for infection, although the follow-up time was relatively short, ranging between 6 and 76 months. These excellent results could be related to several key factors: precise reconstruction through a custom-made design that ensured an anatomically precise fit; secure fixation, which is crucial for effective osteointegration; complete pelvic ring reconstruction, which allows for natural stress distribution; and reduced surgical time. However, these results have not been confirmed by long-term results. Recent findings have demonstrated an incidence of major complications that reached 60%, an incidence of infection of approximately 30%, and a risk of subsequent implant removal of between 12% and 47% [2, 12, 15]; these differences may be related to different prosthetic designs and manufacturing. Considering other types of biological reconstructions, the use of recycled autograft, in addition to a high risk of complications, is hampered by the lack of material for histologic examination of chemotherapy-induced necrosis and surgical margins [12, 19]. Finally, despite the hypometria and cosmetic concerns, hip transposition without reconstruction offers good functional results with a very low complication rate, which makes it a particularly good indication for patients expected to be at high risk of major complications [2, 12].

Reconstruction of periacetabular bone defects with allograft-prosthesis composite represents a challenging option that requires a well-experienced orthopaedic team, but we believe that the restoration of bone stock once union is achieved is a major advantage, in particular for patients who are expected to survive long term and who are at risk for further revisions. Most failures were dislocations and infections that occurred within the first postoperative year. Once union of the graft and soft tissue healing were achieved, the complication rate was low, confirming that an allograft-prosthesis composite reconstruction could still have a role after periacetabular resection for primary bone tumors of the pelvis.

Conclusion

Allograft-prosthesis composites represent an effective reconstructive approach after periacetabular resection for primary bone tumors, and we believe they still have a role, especially in patients with long life expectancy who have been treated for tumors that were not managed with chemotherapy or radiotherapy, where production of custom-made endoprostheses might delay surgery, and in whom the iliac wing is fully or partially preserved. By contrast, our findings suggest that allograft-prosthesis composites should be avoided in elderly patients, in patients with bone metastasis, or in primary bone tumors that could benefit from perioperative radiotherapy. We observed no allograft fractures in our patients that might be attributed to using stable spanning fixation with an acetabular ring. Acetabular aseptic loosening might be reduced when cementing the cup onto an acetabular ring or using a stemmed cup. Functional results improved in patients with longer time since the initial resection and reconstruction, and they were better when the hip abductors were preserved. Larger studies comparing periacetabular allograft-prosthesis composite with other reconstruction options such as modular and custom-made endoprostheses, as well as recycled autograft-prosthesis composites, are warranted to assess the potential benefits of one technique over the other. In conclusion, we believe that allograft-prosthesis composite could still have a role in reconstructing a functional lower extremity after periacetabular resections for primary bone tumors in selected patients, providing a long-lasting durable reconstruction with good functional results.

References

1. Abdel MP, von Roth P, Perry KI, Rose PS, Lewallen DG, Sim FH. Early results of acetabular reconstruction after wide periacetabular oncologic resection. *J Bone Joint Surg Am*. 2017;99:e9.
2. Angelini A, Drago G, Trovarelli G, Calabrò T, Ruggieri P. Infection after surgical resection for pelvic bone tumors: an analysis of 270 patients from one institution. *Clin Orthop Relat Res*. 2014;472:349-359.
3. Bell RS, Davis AM, Wunder JS, Buconjic T, McGoveran B, Gross AE. Allograft reconstruction of the acetabulum after resection of stage-IIB sarcoma. Intermediate-term results. *J Bone Joint Surg Am*. 1997;79:1663-1674.
4. Brown TS, Salib CG, Rose PS, Sim FH, Lewallen DG, Abdel MP. Reconstruction of the hip after resection of periacetabular oncological lesions: a systematic review. *Bone Joint J*. 2018;100:22-30.
5. Bus MP, Szafranski A, Sellevold S, et al. LUMiC® endoprosthetic reconstruction after periacetabular tumor resection: short-term results. *Clin Orthop Relat Res*. 2017;475:686-695.
6. Campanacci D, Chacon S, Mondanelli N, et al. Pelvic massive allograft reconstruction after bone tumour resection. *Int Orthop*. 2012;36:2529-2536.
7. Donati D, Di Bella C, Frisoni T, Cevolani L, DeGroot H. Alloprosthetic composite is a suitable reconstruction after periacetabular tumor resection. *Clin Orthop Relat Res*. 2011;469:1450-1458.
8. Enneking WF, Campanacci DA. Retrieved human allografts: a clinicopathological study. *J Bone Joint Surg Am*. 2001;83:971-986.
9. 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.
10. Enneking WF, Dunham WK. Resection and reconstruction for primary neoplasms involving the innominate bone. *J Bone Joint Surg Am*. 1978;60:731-746.
11. Enneking WF. A system of staging musculoskeletal neoplasms. *Clin Orthop Relat Res*. 1986;204:9-24.
12. Fujiwara T, Medellin Rincon MR, Sambri A, et al. Limb-salvage reconstruction following resection of pelvic bone sarcomas involving the acetabulum. *Bone Joint J*. 2021;103:795-803.
13. Fujiwara T, Ogura K, Christ A, et al. Periacetabular reconstruction following limb-salvage surgery for pelvic sarcomas. *J Bone Oncol*. 2021;31:100396.
14. Hu X, Lu M, Wang Y, et al. Advanced pelvic girdle reconstruction with three dimensional-printed custom hemipelvic endoprostheses following pelvic tumour resection. *Int Orthop*. 2024;48:2217-2231.
15. Jaiswal PK, Aston WJ, Grimer RJ, et al. Peri-acetabular resection and endoprosthetic reconstruction for tumours of the acetabulum. *J Bone Joint Surg Br*. 2008;90:1222-1227.
16. Ji T, Yang Y, Tang X, et al. 3D-printed modular hemipelvic endoprosthetic reconstruction following periacetabular tumor resection: early results of 80 consecutive cases. *J Bone Joint Surg Am*. 2020;102:1530-1541.
17. Qu H, Mou H, Wang K, et al. Risk factor investigation for hip dislocation after periacetabular tumour resection and endoprosthetic reconstruction via thin-slice CT-based 3D model. *Bone Joint J*. 2022;104:1180-1188.
18. Ratasvuori M, Wedin R, Keller J, et al. Insight opinion to surgically treated metastatic bone disease: Scandinavian sarcoma group skeletal metastasis registry report of 1195 operated skeletal metastasis. *Surg Oncol*. 2013;22:132-138.
19. Vahabi A, Kaya H, Tosyalı HK, Keçeci B, Sabah D. Composite reconstruction with irradiated autograft plus total hip replacement after type II pelvic resections for tumors is feasible but fraught with complications. *Clin Orthop Relat Res*. 2024;482:1825-1835.
20. Wang H, Tang X, Ji T, Yan T, Yang R, Guo W. Risk factors for early dislocation of the hip after periacetabular tumour resection and endoprosthetic reconstruction of the hemipelvis. *Bone Joint J*. 2021;103:382-390.