*Joint Diseases and Related Surgery*

# Mid-term outcomes of hemipelvic allograft reconstruction after pelvic bone tumor resections

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Reconstruction of defects after pelvic resection is one of the most complicated and challenging issues in orthopedics tumor surgery. With the improvements in diagnostic imaging and multimodality treatment including radiation and chemotherapy, limb salvage resection, as opposed to hindquarter amputation, represents a reliable surgical option.

While pelvic tumors in the ischiopubic area can be safely resected without the need for reconstruction,[1] poor clinical results have been observed, particularly when no reconstruction has been performed in periacetabular resections. Over the last three decades, some reconstruction procedures and implants have been developed to improve functional outcomes.[2,3]

Nevertheless, none of these reconstruction techniques can be shown superior to the others. All techniques have many complications in terms of oncological disease (recurrences or metastases) and reconstruction (infection, dislocation, and loosening) itself.[4]

**ABSTRACT**

**Objectives:** This study aims to evaluate survival of patients and implants, functions, and morbidity of surgical technique of reconstruction with a fresh-frozen massive pelvic allograft following a pelvic resection.

**Patients and methods:** Between January 2009 and December 2016, a total of 19 patients (12 males, 7 females; mean age: 35.8±14.4 years; range, 10 to 53 years) who underwent reconstruction with fresh-frozen massive allograft after internal hemipelvectomy were retrospectively analyzed. Patients' age, sex, resection types, histopathology and grades, surgical margins, operative times, intraoperative blood loss, complications experienced during their treatment (infection, dislocation, implant failure, nonunion, local recurrence and metastasis), neoadjuvant and adjuvant therapies they received, and functional scores were revelaed and analyzed in 10 years period.

**Results:** According to the Enneking and Dunham classification, two (10%) patients had type I resection only, six (32%) had type I-II, one (5%) had a type II resection, one (5%) had type II-III resection, three (16%) had type I-II-III resection, one (5%) had type I-IV resection, and five (26%) had type I-II-IV resection. The resection involved the acetabulum (type II) in all, but three patients. Several complications were seen in 12 patients, although seven patients had no complication. Pelvic resections had a high mortality rate in patients with malignant tumors and reconstruction with massive allograft had a high morbidity rate with susceptibility to many complications. Prolonged surgical time was found to be directly related to blood loss. Deep infection significantly worsened functional results.

**Conclusion:** Despite the high complication rates seen in pelvic resections, massive pelvic allografts represent a valid option for reconstruction after resection of pelvic tumors, but due to the associated morbidity, patients should be carefully selected.

*Keywords:* Allograft, hemipelvectomy, pelvic bones, sarcoma, transplantation.

One of the materials for reconstructing innominate bone is the allograft. The major advantages of this material are that the bone can be shaped and customized to match the resection. This method can be combined with the hip prosthesis or applied

alone. There is no standard surgical technique due to the limited number of publications in the literature and the inadequacy of the number of patients in existing researches. As is the case with other methods, controversy still remains regarding the use of allografts due to inadequate data in the literature and high rates of infection and mechanical complications.[5,6]

In the present study, we aimed to evaluate patient and implant survival, functional outcomes, and morbidity of the surgical technique with a fresh-frozen massive pelvic allograft after a pelvic resection and to contribute to the uncertainty in the literature.

## PATIENTS AND METHODS

This single-center, retrospective study was conducted at Dr. Abdurrahman Yurtaslan Ankara Oncology Training and Research Hospital, Department of Orthopedics and Traumatology between January 2009 and December 2016. Patients who underwent hemipelvectomy with a diagnosis of pelvic tumor were retrospectively screened. Among 49 patients who underwent hemipelvectomy surgery, 19 patients (12 males, 7 females; mean age: 35.8±14.4 years; range, 10 to 53 years) who underwent reconstruction with fresh-frozen massive allograft after internal hemipelvectomy were included in the study. The topographical distribution was demonstrated in Figure 1. A written informed consent was obtained

from each patient. The study protocol was approved by the Clinical Research Ethics Committee of University of Health Sciences Turkey, Abdurrahman Yurtaslan Ankara Oncology Health Practice and Research Center (date/no: 19.10.2021/2021-136). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Surgical margins were classified according to the Musculoskeletal Tumor Society (MSTS) system[7] and resulted wide in eight patients, contaminated wide in four, marginal in five, and intralesional in two.

Four patients with Ewing sarcoma, two patients with osteosarcoma, and one patient with dedifferentiated chondrosarcoma were treated with neoadjuvant and adjuvant chemotherapy. One case of plasmacytoma and one desmoid tumor received preoperative radiotherapy. Four patients (n=1 osteosarcoma, n=1 dedifferentiated chondrosarcoma, n=1 Ewing sarcoma, n=1 malignant fibrous histiocytoma) received irradiation due to microscopic positivity of surgical margins and contaminated wide resection.

Cephalosporin and aminoglycoside were administered prophylactically, until no bacterial growth on cultures of surgical specimens was reported and drains were removed.

All operations were performed under general anesthesia, with the patient in lateral decubitus on the contralateral side. All except for one procedure
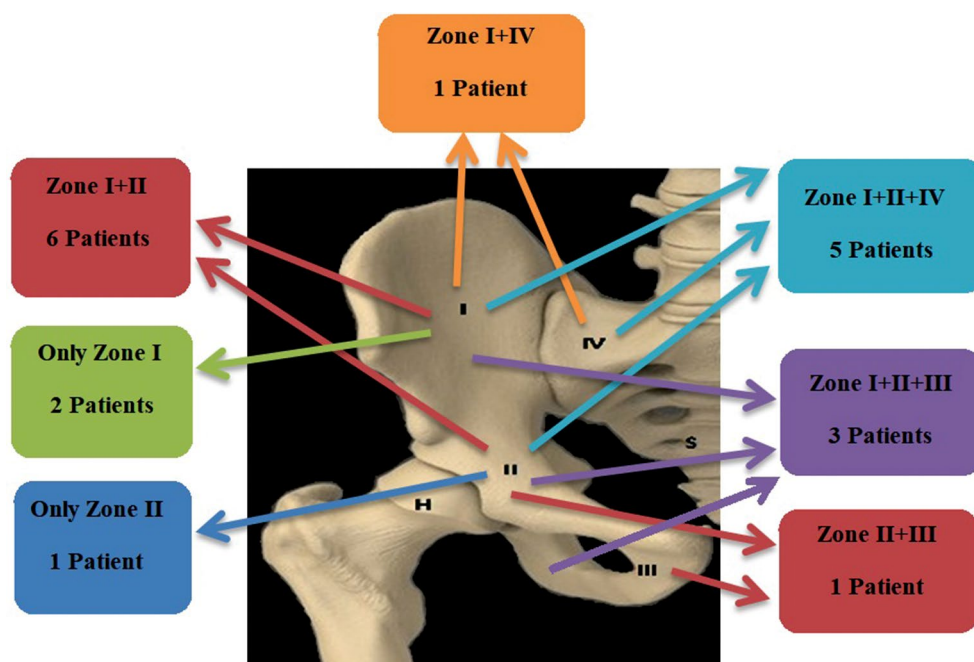


**FIGURE 1.** The topographic distribution of the pelvic resection zones.

**FIGURE 2.** Extended lateral incision with the flexible lateral decubitus position.

were performed through an extended lateral approach (Figure 2). This approach allowed extensive visualization of the inner and outer aspects of the hemipelvis. Additional suprapubic and inguinal incisions were added while placing the anterior column plate and when it was necessary to cross the symphysis pubis (Figure 3). Fresh-frozen, non-irradiated hemipelvic allografts were used for reconstruction. After all osseous resections, anatomic reconstruction was made with a pelvic allograft obtained from the internationally registered bone bank (Bone Bank Allografts, San Antonio, TX, USA) that was similar to the one that was resected (Figure 4).

Allograft fixation was performed with cortical and spongious screws to stabilize the sacroiliac joint (Figure 4). A molded reconstruction plates were used to fix the residual anterior and the posterior column (Figure 5). In 16 patients, the acetabulum was resected total or subtotally and allograft was implanted together with a total hip prosthesis. Cemented acetabular components were used in five cases while uncemented components were preferred in 10 cases. In four patients, the size of
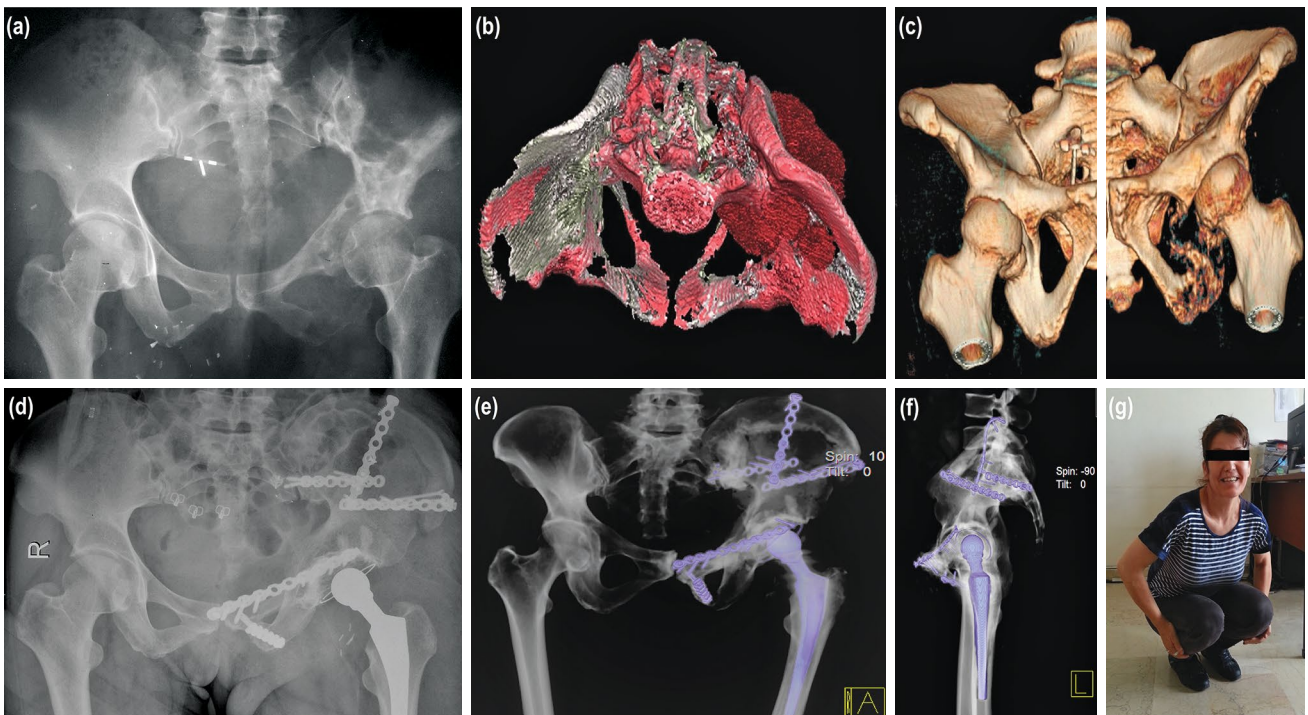


**FIGURE 3. (a)** Preoperative anteroposterior (AP) pelvis radiograph of the 42-year-old patient with recurrent malignant giant cell tumor (mGCT) involving almost the entire left hemipelvis. **(b)** 3-dimensional (3D) reconstruction on computed tomography (CT) with the soft tissue component of the recurrent tumor involving the left hemipelvis of the same patient. **(c)** 3D reconstruction on CT with only bony structures revealed the massive destruction, particularly in zone II and zone III. **(d)** Postoperative AP pelvis radiograph at 10 years. **(e)** 3D CT AP view of the patient who underwent combination of allograft and cemented arthroplasty after Zone I + II + III resection. **(f)** 3D CT lateral view of the patient who underwent combination of allograft and cemented arthroplasty after Zone I + II + III resection. **(g)** Excellent functional result was obtained with 80% musculoskeletal tumor society (MSTS) score.
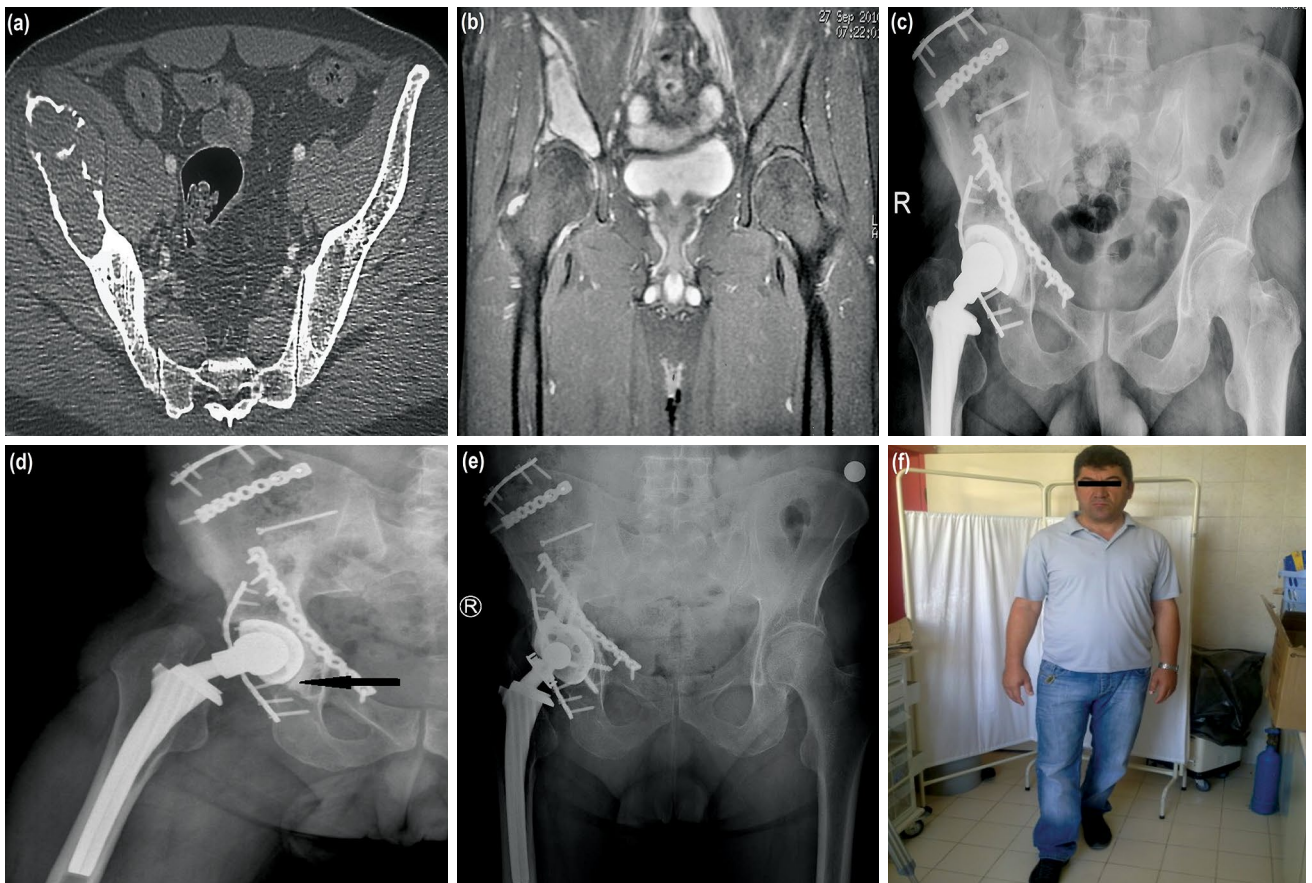
**FIGURE 4. (a)** Preoperative axial computed tomography (CT) image of our 45-year-old patient with right periacetabular osteogenic sarcoma (OGS). **(b)** Intramedullary OGS in the right periacetabular region in coronal T2 contrast-enhanced magnetic resonance images (MRI). **(c)** Postoperative anteroposterior (AP) pelvis radiograph at three years. **(d)** Aseptic loosening complication at the allograft and cement interface of hip arthroplasty in the 44th month follow-up of our patient who underwent type I + II resection. **(e)** Postoperative 10th year control AP pelvis radiography after revision with acetabular cage + cemented constraint cup. **(f)** Excellent functional result was obtained with 85% musculoskeletal tumor society (MSTS) score. He walks without any assistive device.

the acetabular component of the allograft matched the femoral head of the patient and the hip joint was restored without a prosthesis. The prosthetic femoral stem was uncemented in 13 patients, and in two cases, the proximal femur was reconstructed with a modular cemented mega prosthesis after hip extra-articular resection due to femoral tumor extension (Figure 6).

Not any brace was applied after surgery to prevent hip dislocation when the periacetabular area was reconstructed. Partial weight-bearing with fingertip contact was started at Week 3 (with walker) and gradually increased until the third month, and it was possible to give full weight-bearing at three months in some patients and at six months in some according to the fixation strength.

From admission to their final follow-up, patients' age, sex, resection types, histopathology and grades, surgical margins, operative times, intraoperative blood loss, complications experienced during their treatment (infection, dislocation, implant failure, nonunion, local recurrence and metastasis), neoadjuvant and adjuvant therapies they received, and functional scores were recorded periodically every 45 days up to the six months and every six months up to the fifth year and annually thereafter.

Functional outcome was determined using the MSTS 93' scoring system,[8] checking six parameters including pain, function, emotional acceptance, supports, walking ability, and gait. Surviving patients were analyzed at a minimum of six months postoperatively.
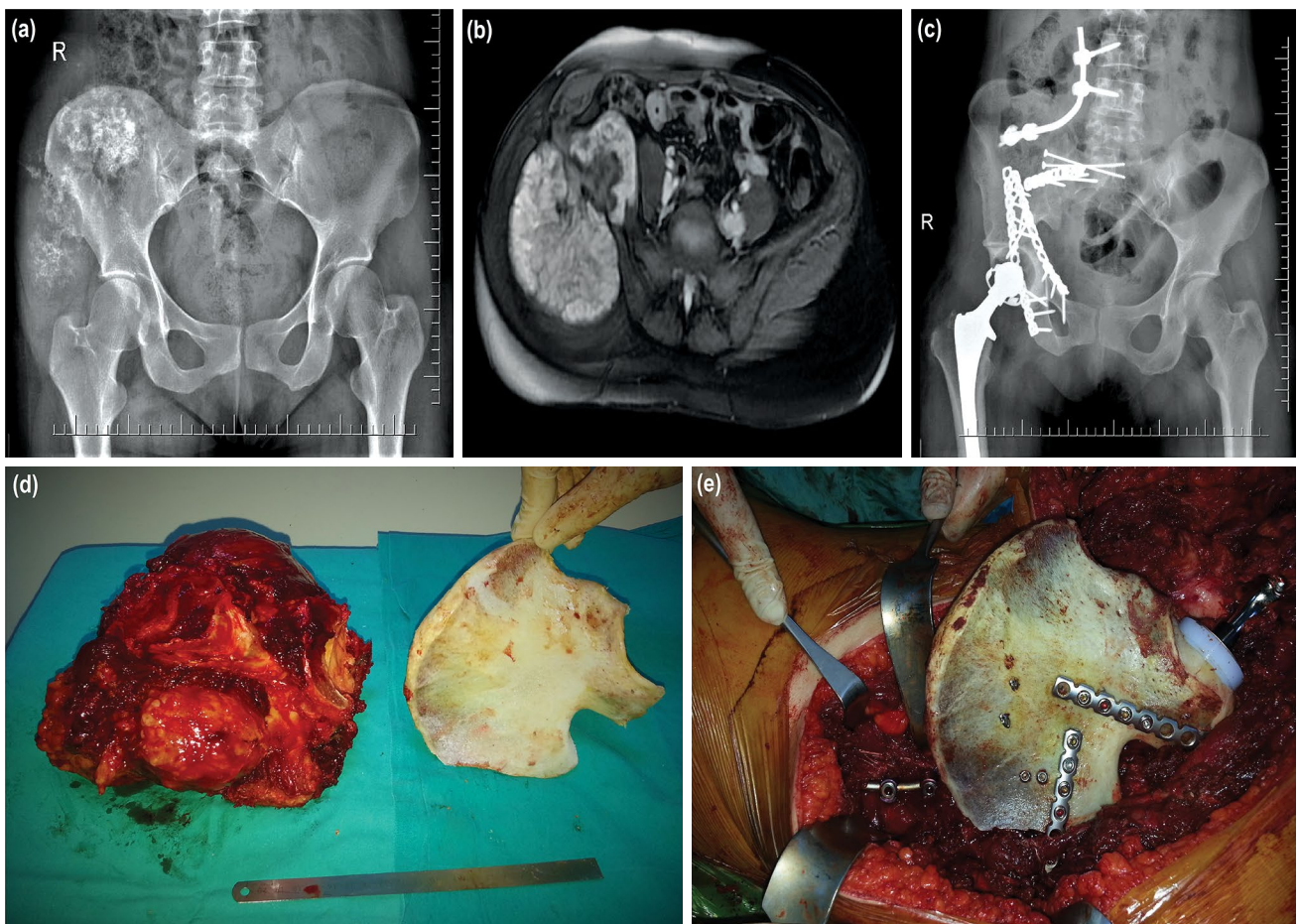
**FIGURE 5. (a)** Preoperative anteroposterior (AP) pelvis radiograph of the 35-year-old patient with high grade chondrosarcoma (CHS) involving right hemipelvis. **(b)** Intraosseous chondroid matrix mineralization and cortical destruction are seen in axial T2 contrast-enhanced magnetic resonance images (MRI) in right ileum. **(c)** Postoperative 6th year AP pelvis radiography. Excellent functional result was obtained with 80% musculoskeletal tumor society (MSTS) score. She walks without any assistive device. **(d)** It was possible to remove the tumor *en bloc* by performing wide resection with the surrounding gluteus maximus and iliacus muscle. **(e)** Allograft was placed anatomically between the pubic, ischium and residual crescent bone fragments, and the graft was supported vertically with lumbopelvic stabilization in addition to the combination of cemented constraint hip arthroplasty.

## Statistical analysis

Statistical analysis was performed using the SPSS version 12.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The Mann-Whitney U test was used to compare two unpaired subgroups of patients according to a grouping variable such as the spinopelvic stabilization. These subsets were compared concerning the duration of surgery, the blood loss, and the MSTS score. Relationships between two sets of parameters were analyzed using the Spearman rank-order correlation coefficient. A *p* value of <0.05 was considered statistically significant.

## RESULTS

Table I lists the demographic characteristics of patients, types of resection and reconstruction, and oncological data. There were 15 primary malignant bone tumors, three recurrent aggressive lesions, and one hydatic cyst. Osteosarcoma and Ewing sarcoma were the most predominant lesions. According to the Enneking and Dunham classification,[9] two patients (10%) had type I resection only, six (32%) had type I-II, one (5%) had a type II resection, one (5%) had type II-III resection, three (16%) had a type I-II-III resection, one (5%) had a type I-IV resection and five (26%) had a type I-II-IV resection. The resection involved the acetabular area (type II) in all, but three patients.
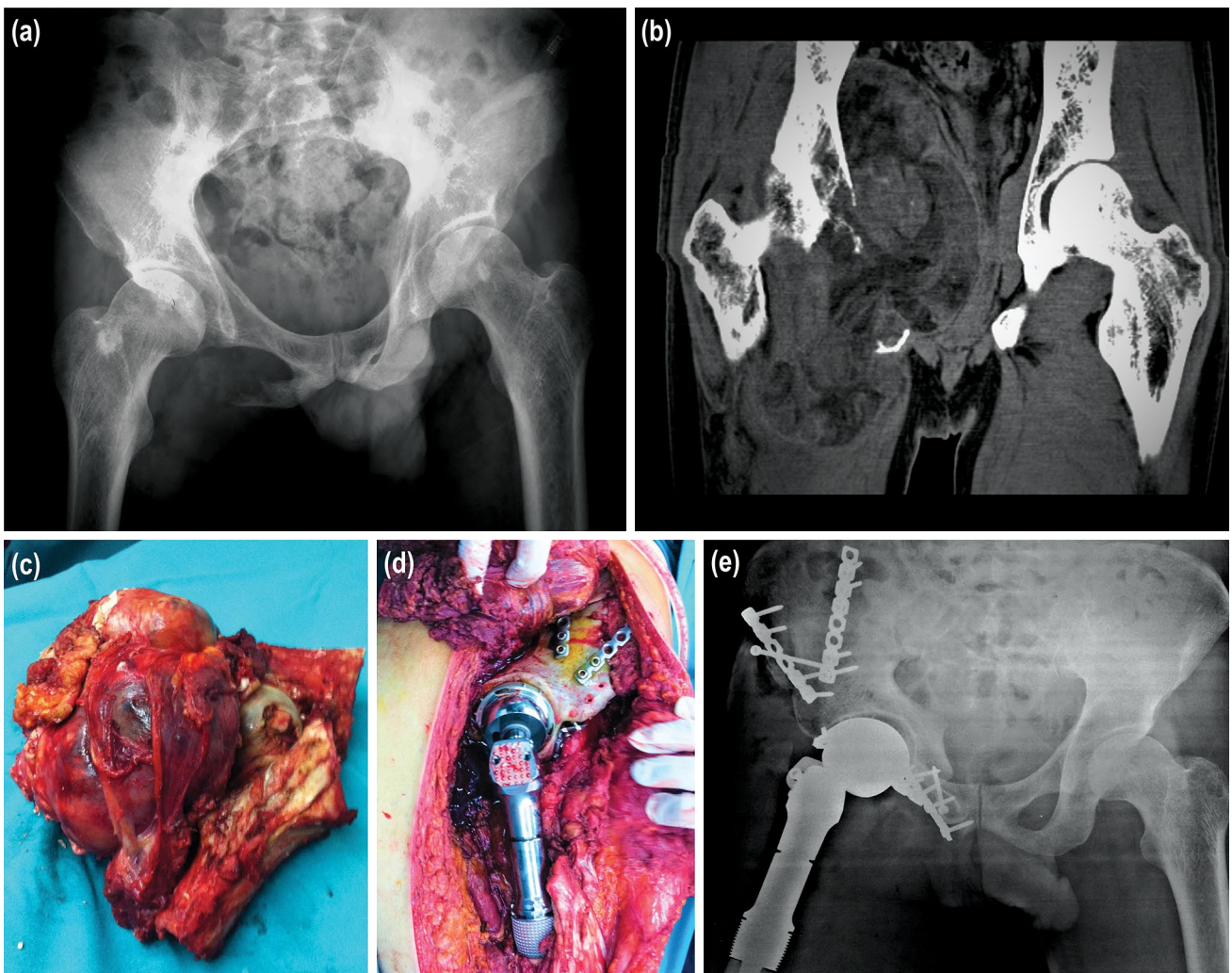
**FIGURE 6. (a)** Preoperative anteroposterior (AP) pelvis radiograph of the 43-year-old patient with giant high grade MMT causing destruction of the right hemipelvis **(b)** Coronal CT images showed how much the soft tissue component pushes the visceral organs to the contralateral side, and destruction of the tumor, especially in the periacetabular area and ischium. **(c)** Considering that the large tumor even crossed the midline medially, only marginal resection could be made, as can be understood from the specimen. **(d)** Osteosynthesis with reconstruction plates between the residual ileum and pubic bone and the perfectly cut allograft. Hip joint restoration with large-head proximal femur resection prosthesis for stability. **(e)** Postoperative 5th months AP pelvis radiography. This patient died of lung metastasis with deep infection before local recurrence was observed in the 6th postoperative month. Poor functional result with the MSTS score of 26% and could only be mobilized with 2 crutches.

At the time of the final follow-up visit, 10 patients were alive and nine of them were free of disease. The mean follow-up of surviving patients was 97±19.6 (range, 63 to 124) months. Eight patients died of metastatic disease and one died of another cause.

The surgical resection was wide in eight patients, contaminated wide in four, marginal in five, and intralesional in two. Four patients with Ewing sarcoma, four patients with osteosarcoma, and one patient with dedifferentiated chondrosarcoma were treated with neoadjuvant and adjuvant chemotherapy. One case of plasmacytoma and two recurrent desmoid tumors received preoperative radiotherapy. Four patients (one osteosarcoma, one dedifferentiated chondrosarcoma, one Ewing sarcoma) received irradiation due to microscopic positivity.

The mean operative time was 317±63.7 (range, 240 to 420) min and the mean amount of blood loss was 2,431±1,284.6 (range, 700 to 5,300) mL. There was no significant relationship between functional outcomes and duration of surgery and blood loss (p>0.05). However, as expected, there

**TABLE I**
Patient characteristics

| Patient number | Age (year) | Diagnosis | Grade | Stage | Follow-up (months) | Resection type | Surgical margine | Osteosynthesis | Hip artroplasty | Lumbopelvic stabilization | Complications | Neoadjuvant | Adjuvant | Oncological outcome | Status | Functional outcome MSTS score % | Operative time (minutes) | Estimated blood loss (mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Reconstruction | | | | | | | | | |
| 1 | 45 | OGS | Low | Ia | 124 | I-II | W | 4 plates 2 sacral screws | Cemented | No | Acetabular Loosening | - | - | 0 | NOD | 85 | 370 | 2,000 |
| 2 | 20 | Ewing | High | IIb | 6 | I-II-IV | M | 2 plates 2 sacral screws | Cementless | Yes | Dislocation Neurological Deficit Deep Infection | CT | CT, RT | Metastasis | DOD | 30 | 420 | 5,300 |
| 3 | 42 | GCT | - | III | 121 | I-II-III | M | 5 plates | Cemented | Yes | Neurological Deficit Superficial Infection | - | CT | 0 | NOD | 80 | 360 | 3,000 |
| 4 | 53 | OGS | High | IIb | 42 | I-II-IV | WC | 2 plates | Cementless | Yes | Deep Infection | - | CT, RT | Metastasis | DOD | 40 | 390 | 4,300 |
| 5 | 23 | Desmoid tumor | - | II | 108 | II-III | M | 3 plates | Cementless | No | Deep Infection Nonunion | RT | - | 0 | NOD | 65 | 300 | 2,200 |
| 6 | 43 | OGS | High | IIb | 4 | I-II-IV | I | 2 plates 2 sacral screws | Cementless | Yes | Superficial Infection | CT | CT | Metastasis LR | DOD | - | 420 | 3,700 |
| 7 | 43 | MMT | High | IIb | 6 | I-II-III | M | 4 plates | Cementless | No | Deep Infection | - | CT, RT | Metastasis | DOD | 26 | 400 | 1,700 |
| 8 | 31 | Plasmacytoma | - | II | 107 | I-II-III | W | 3 plates | Cementless | No | - | RT | CT | 0 | NOD | 70 | 260 | 1,200 |
| 9 | 49 | MFH | High | IIb | 105 | I-II-IV | WC | 4 plates 2 sacral screws | Cementless | Yes | Deep Infection Acetabular Loosening | - | CT, RT | LR | AWD | 55 | 360 | 3,500 |
| 10 | 53 | Hydatic cyst | - | - | 99 | II | M | 3 plates | Cementless | No | - | - | - | 0 | NOD | 85 | 255 | 800 |
| 11 | 57 | MMT | High | IIb | 7 | I-II | WC | 3 plates | Cementless | No | - | - | - | Metastasis | DOC | 50 | 255 | 1,250 |
| 12 | 10 | Ewing | High | IIb | 6 | I-II | W | 4 plates 2 sacral screws | - | No | - | CT | CT | Metastasis | DOD | 73 | 240 | 700 |
| 13 | 31 | CHS | High | Ib | 24 | I-II-IV | I | 2 plates 3 sacral screws | Cementless | Yes | Dislocation Deep Infection | CT | CT, RT | Metastasis LR | DOD | 25 | 330 | 2,500 |
| 14 | 51 | CHS | High | IIb | 22 | I-IV | W | 2 plates 2 sacral screws | - | Yes | - | - | - | Metastasis LR | DOD | 66 | 275 | 1,700 |
| 15 | 14 | Ewing | High | III | 2 | I | WC | 4 plates 2 sacral screws | - | No | - | CT | CT | Metastasis LR | DOD | - | 330 | 2,350 |
| 16 | 34 | Desmoid tumor | - | II | 85 | I-II | W | 5 plates 1 sacral screw | Cemented | Yes | Superficial Infection | - | - | 0 | NOD | 80 | 275 | 4,000 |
| 17 | 35 | CHS | High | Ib | 80 | I-II | W | 3 plates 2 sacral screws | Cemented | Yes | - | - | - | 0 | NOD | 80 | 300 | 3,000 |
| 18 | 15 | Ewing | High | IIb | 80 | I | W | 3 plates 2 sacral screws | - | Yes | Deep Infection | CT | CT | 0 | NOD | 60 | 240 | 1,000 |
| 19 | 33 | OGS | High | IIb | 63 | I-II | W | 5 plates | Cemented | No | Dislocation | CT | CT | 0 | NOD | 75 | 240 | 2,000 |
| Mean | 35.8 | | | | | | | | | | | | | | | 60-73.5 | 317 | 2,431 |

MSTS score: Musculoskeletal tumor society score; W: Wide resection; NOD: No evidence of disease; I: Intralesional resection; M: Marginal resection; CT: Chemotherapy; RT: Radiation therapy; DOD: Dead of disease; GCT: Giant cell tumor; OGS: Osteogenic sarcoma; WC: Wide contaminated resection; LR: Local recurrence; AWD: Alive with disease; DOC: Dead of other cause; CHS: Chondrosarcoma; MMT: Malignant mesenchymal tumor; MFH: Malignant fibrous histiocytoma;

| TABLE II |
| --- |
| Comparison of data between operation statistics (time and blood loss) and functional results |

| | Functional results (MSTS scores) | Operative time (min) | Blood loss (mL) |
| --- | --- | --- | --- |
| **Functional results (MSTS scores)** | | | |
| r | 1,000 | -0,372 | -0,199 |
| p | | 0,141 | 0,444 |
| n | 17 | 17 | 17 |
| **Operative time (min)** | | | |
| r | | 1,000 | 0,711 |
| p | | | **0,001** |
| n | | 19 | 19 |
| **Blood loss (mL)** | | | |
| r | | | 1,000 |
| p | | | |
| n | | | 19 |

MSTS: Musculoskeletal tumor society.

was a positive, strong, and significant relationship between duration of surgery and blood loss (p<0.05) (Table II).

Functional results (MSTS scores), duration of surgery, and blood loss did not significantly differ according to the number of complications; however, the duration of surgery and blood loss were higher in patients with complications than in those without (Table III). In addition, deep infection, which is one of the most serious complications, significantly affected patient functions and negatively correlated with the MSTS scores (Table IV).

According to spinopelvic stabilization, spinopelvic stabilization increased the duration of surgery by

approximately half an hour and the amount of bleeding twice. However, lumbopelvic stabilization had no effect on the functional scores of the patients (Table V).

Several complications were seen in 12 patients, although seven patients had no complication. Five patients (33% of malignant lesions, 27% of tumoral lesions) had a local recurrence. Neurological deficits were present in two patients (11%), and three had a transient superficial infection (16%) and six had a deep infection (32%). Hip dislocation occurred in three patients (16%). Nonunion was observed in one of the 19 allografts that could be evaluated (5%). Neither graft fracture nor lysis was observed.

| TABLE III |
| --- |
| Comparison of data between surgical statistics (time and blood loss) and functional outcomes with the increasing number of complications |

| | Number of complications | n | Mean rank | $\chi^2$ | p |
| --- | --- | --- | --- | --- | --- |
| Functional results (MSTS scores) | No complication | 6 | 10.83 | | |
| | 1 complication | 6 | 9.42 | **2,278** | **0.320** |
| | 2 or more complication | 5 | 6.30 | | |
| Operative time (min) | No complication | 7 | 6.50 | | |
| | 1 complication | 7 | 11.14 | **4,758** | **0.093** |
| | 2 or more complication | 5 | 13.30 | | |
| Blood loss (mL) | No complication | 7 | 6.14 | | |
| | 1 complication | 7 | 11.07 | **5,960** | **0.051** |
| | 2 or more complication | 5 | 13.90 | | |

MSTS: Musculoskeletal tumor society.

| TABLE IV | | | | |
|---|---|---|---|---|
| Correlation between deep infection and functional outcomes | | | | |
| | Deep infection | n | Mean rank | Sum of ranks |
| Functional results (MSTS scores)*** | 0 | 10 | 12,20 | 122,00 |
| | 1 | 7 | 4,43 | 31,00 |
| | Total | 17 | | |
| | Test statistics (Mann-Whitney U test) | | | |
| | Function | Operative time | Blood loss | |
| Mann-Whitney U | 3,000 | 24,000 | 28,500 | |
| Wilcoxon W | 31,000 | 102,000 | 106,500 | |
| Z | -3,134 | -1,528 | -1,142 | |
| Asymp. Sig. (2-tailed) | **0.002*** | 0.127 | 0.253 | |
| Exact Sig. [2*(1-tailed Sig.)] | 0.001 | 0.142 | 0.261 | |
| p=0.002*** | | | | |

| TABLE V | | | | |
|---|---|---|---|---|
| Comparison of functional outcomes and surgical statistics (time and blood loss) in patients with and without spinopelvic fixation | | | | |
| | Spinopelvic stabilization | n | Mean rank | Sum of ranks |
| Functional results (MSTS scores) | 0 | 8 | 9,88 | 79,00 |
| | 1 | 9 | 8,22 | 74,00 |
| | Total | 17 | | |
| Operative time (min) | 0 | 9 | 8,00 | 72,00 |
| | 1 | 10 | 11,80 | 118,00 |
| | Total | 19 | | |
| Blood loss (mL)*** | 0 | 9 | 6,28 | 56,50 |
| | 1 | 10 | 13,35 | 133,50 |
| | Total | 19 | | |
| | Test statistics (Mann-Whitney U Test) | | | |
| | Function | Operative time | Blood loss | |
| Mann-Whitney U | 29,000 | 27,000 | 11,500 | |
| Wilcoxon W | 74,000 | 72,000 | 56,500 | |
| Z | -0.676 | -1,476 | -2,739 | |
| Asymp. Sig. (2-tailed) | 0.499 | 0.140 | **0.006*** | |
| Exact Sig. [2*(1-tailed Sig.)] | 0.541 | 0.156 | 0.004 | |
| *** p=0.006. | | | | |

Twelve patients underwent surgical revision, with three of these revisions related to the reconstruction. The average revision surgery rate was 1.9 in patients with complications. Of 10 patients who were alive and passed postoperative sixth months, five of them walked without any assistive device and four had normal function with no or only a slight limp with the assistance of one crutch. The patient who had local recurrence and sciatic palsy was unable to walk without support. When all patients who completed the postoperative six-month follow-up were analyzed, the MSTS score was 60% of the maximum possible score at six months. The MSTS score in the last follow-up of our 10 patients who were still alive was 73.5% of the maximum possible score.

## DISCUSSION

The most important result of this study is that pelvic resections had a high mortality rate, particularly in patients with malignant tumors and reconstruction with massive allograft had high morbidity, and susceptible to many complications. As expected, prolonged surgical time was found to be directly related to blood loss. Additionally, deep infection, which is the most serious complications, significantly worsened functional results.

Reconstructions of pelvic bone defects are one of the most complex subjects of orthopedic surgery. The type of surgery to be selected may vary depending on the anatomy of the pelvis, etiology of the pelvic defect, the reconstruction technique to be used, the physiological condition and age of the patient, and the expected survival. The morbidity of pelvic reconstruction is very high and should only be performed in the presence of adequate technical and physical equipment and an experienced team. Despite advances in limb-sparing surgery in patients with musculoskeletal tumors, pelvic reconstruction still has complex, complicated, and serious consequences for patient function.

Pelvic resections and reconstructions in the same session are associated with long operative times and severe blood loss, even for experienced surgeons. In the literature, the average surgical time varies between 5 and 10 h depending on the type of reconstruction, and the average amount of blood loss varies between 2,500 and 8,000 mL.[5,10-14] In this study, the mean duration of surgery was calculated as 317±63.7 (range, 240 to 420) min. The mean duration was 337±63.3 min in 10 patients who underwent spinopelvic reconstruction and 294±59.5 min in nine patients who did not. The mean amount of blood lost was 2,431±1284.6 (range, 700 to 5,300) mL in 19 patients. This amount was 3,200±1,258 mL in 10 patients who underwent spinopelvic reconstruction and 1,577±610 mL in nine patients who did not. Based on these data, spinopelvic stabilization increases the duration of surgery by approximately half an hour and the amount of bleeding twice. In addition, despite the stability we attempted to increase by spinopelvic stabilization, a significant increase in functional results could not be achieved. Nevertheless, the duration of surgery and blood loss was significantly lower than the literature. This may be as all surgical procedures are performed by the same incision, by the same surgical team, without the need for additional assistance for any intraoperative complication (general surgeon, plastic surgeon, spinal surgeon, vascular surgeon) and serious attention to hemostasis. At the same time, good preoperative planning, mastery of the anatomy, sequential surgical procedure and the use of easy-to-use quality materials may be the reason for the good results of our operation statistics from the literature.

Many reconstruction options have been discussed after resection of pelvic tumors; however, a standard reconstruction technique has not been established to date. Many authors have achieved better MSTS functional scores in patients with stable and reconstructed pelvic tumors than those without reconstruction.[6,15] In the reconstruction of pelvic defects; iliofemoral and ischiofemoral arthrodesis, massive allografts, custom made pelvic prostheses, saddle-type or modular pelvic prostheses, ice-cream cone prosthesis are performed by various methods;[5,9,16-19] however, all of these methods have reported serious early and late complications. While early complications such as infection and dislocation may delay adjuvant therapies in some patients and affect patient prognosis, septic or aseptic loosening and mechanical failure from late complications may result in additional revisions, progressive bone loss, and reduced functional capacity. Another reconstruction option is to rotate the autologous proximal femur around the vascular pedicle and place it in the defect between the residual ileum and pubis and combine it with a cemented hip prosthesis.[20] Recently, custom made implants produced with three-dimensional printers are gaining importance in the literature and this technology can be used in pelvic discontinuity after hip revision arthroplasties or tumoral resections.[21] However, the long-term results of this new methods are not yet available. Reconstruction with pelvic massive allografts, which is the subject of this study, provides complete restoration of the anatomical architecture of the pelvis, preserves bone stock and limb length, and is successful in achieving satisfactory functional results when combined with hip replacement in acetabular resections.[6,10,19]

The prognosis for primary malignant tumors of the pelvis is worse than for the appendicular skeleton and is associated with surgical margin quality, response to adjuvant therapies, and grade of the tumor.[20,22] The primary aim of surgical treatment of pelvic sarcomas is to perform tumor-free surgical resection. It is difficult to reach wide surgical margins in cases where the proximity of pelvic tumors to major neurovascular and visceral structures and the presence of tumors crossing the sacroiliac joints. In the literature, local recurrence rates range from 9.6 to 33%.[6,10,15,19,23]

In this study, local recurrence was detected in five patients. In addition, 15 of our 19 patients were diagnosed with malignant tumors (79%), while there was no recurrence in benign tumors, and the local recurrence rate among malignant tumors was 33%. Although it is high, our recurrence rates are similar to the literature. Wide resection was achieved in eight of our patients, and marginal resection was achieved in five patients. Large, but contaminated resection was possible in four patients, and intralesional surgery was possible in two patients. One of the recurrent cases is chondrosarcoma for which intralesional surgery could be performed, while the other is Ewing sarcoma in which the response to neoadjuvant therapy is not as good as expected, in which contaminated wide resection can be performed. One osteosarcoma case, whose surgical margin was intralesional, died in the postoperative fourth month due to lung metastasis without recurrence. In other cases resulting in marginal resection and wide contaminated resection (poor quality surgical margins), the reason why we did not see local recurrence despite long follow-up periods may be due to the adjuvant treatments they received.

Regardless of the type of reconstruction, infection is the most important and most common complication in all pelvic resections. The reconstruction itself is described by Angelini et al.[24] who found it to be an independent risk factor in a study of 270 cases. While Zeifang et al.[25] reported higher infection rates after biological reconstructions, Hillman et al.[26] found similar infection rates in biological and endoprosthetic reconstructions (38%).

Infection is one of the most problematic complications in pelvic tumors undergoing reconstruction with allograft.[6,22,27,28] Although there is no comparative study with other types of reconstruction methods, infection rates after reconstruction with massive pelvic allografts ranged from 12.5 to 38.5% in five different series ranging from 13 to 59 patients.[6,10,16,24,26]

The effect of chemotherapy and radiotherapy, one of the risk factors for infection, investigated in the literature, remains unclear. In the series of 62 cases, Gebert et al.[23] examined the subgroup analysis of 45 patients who underwent only hip transposition after pelvic resection, to exclude the reconstruction itself, as a known risk factor, no relationship between clinical-stage, surgical procedure, chemotherapy, radiotherapy, and postoperative infection and other complications was found. In the same study, age (>50 years) was found to be a significant factor for complications.

In addition, in a series of 26 cases consisting of patients with Ewing sarcoma, a chemosensitive and radiosensitive tumor, in which all patients received chemotherapy and/or radiotherapy, infection rates were similar at 19 to 31%.[29] Also, the infection was not statistically significantly related to the pelvic resection zone (acetabulum, ileum, pubis).[11,25]

In this study, superficial infection was observed in three (16%) patients, and deep infection complication was observed in six (33%) patients. While two of the patients with superficial wound problems were completely cured with antibiotherapy and early surgical debridement, tissue integrity could not be achieved in one patient, despite additional plastic surgery after flap necrosis. The wound problem continued until the postoperative fourth month, when the patient died due to metastasis. Four of our six patients with deep infections are still alive and followed with a chronic infection that drains from time to time despite surgical debridements. We do not have a patient whose allograft had to be removed. All of our patients with deep infections received adjuvant treatments such as radiotherapy and/or chemotherapy, but some patients did not have an infection despite receiving adjuvant therapy. The lack of a sufficient number of patients to conduct statistical studies prevents us from comparing the relationship between adjuvant therapy and infection rates. In addition, although there are contradictions in the literature regarding the duration of surgery, the amount of intraoperative bleeding,[24] and the relationship between reconstruction types and infection, no significant relationship was found between these factors and infection in our study. The deep infection rate (33%) revealed in this study is similar to the literature (12.5 to 38.5%). The functional results of our patients with deep infections were statistically significantly lower than the others.

Acetabular reconstruction with allograft has been used for both oncological and revision hip operations. Implant survival rates are higher in isolated type II allograft reconstructions compared to other resection zones of the pelvis.[30,31] Allograft fracture and nonunion is a known complication of allografts and irradiated bone autografts.[10,16,32,33] In a series of 24 patients performed by Delloye et al.,[6] nonunion complication was found in three young and active patients with more interfragmentary cavities and the authors argued that deficiency can be overcome by using computer-assisted surgical method both in resection and in allograft shaping. In a study of 35 cases by Donati et al.,[19] six patients (17%) had nonunion and five patients (14%) had a

long-term acetabular fracture in the allograft, but there was no significant difference in functional scores of nonunion patients. In this study, nonunion at the supra-acetabular junction was detected in one young and active patient (5%), and consolidation was achieved after three months with autogenous bone grafting. A complication such as graft lysis resulting from allograft resorption or allograft fracture was not observed in any of our patients, despite our long follow-up periods and massive reconstruction.

There is no literature specific for long-term hip joint complications in allograft prosthetic composites. However, in various studies with a follow-up period of 41 to 96 months, acetabular complications have been reported at a rate of 0 to 67%.[6,10,16,19,34] Acetabular loosening can be reduced by preserving subchondral bone in the graft as much as possible, as suggested by Bell et al.[16] To reduce this complication, Donati et al.[19] recommended the use of stemmed cups in some cases, even if they caused the allograft fractures.

The literature on cup selection related to the combination of massive structural allograft and hip prosthesis has been discussed in hip revision surgery rather than the tumor. While there is controversy regarding the long-term success of massive structural allografts, most authors agree that if more than 50% of the acetabular cup is in contact with the structural graft, the failure rate increases.[35,36] Garbuz et al.[36] reported only a 55% survival rate at seven years after major column allograft reconstruction and advocated the reinforcement with the construction ring and cemented cups to improve success, particularly when the graft supported more than 50% of the cup. In this study, different from the literature, 10 of 14 patients who underwent hip joint restoration were operated with non-cemented porous and hydroxyapatite-coated cups, and four with constraint and unconstraint cemented cups. In particular, in some of our first cases, when resection in the periacetabular area, non-cemented cups were preferred due to the cup contact with the intact bone from the non-resected parts of the anterior and posterior column of the host bone, and no early complications were observed. However, since half of our cases who were reconstructed with cementless cups died within the first year due to oncological complications, it is not possible to talk about the middle and long-term results of this reconstruction preference. Our first mechanical complication occurred in a cemented cup in a young active and overweight patient who developed aseptic loosening in the postoperative 44th month and was revised with cemented constraint cup and acetabular cage. The second complication was seen in the postoperative 14th month in our patient with a non-cemented metal cup with septic loosening and deep infection. Likewise, constraint cup revision was performed with debridement and antibiotic cemented cement. Our acetabular loosening complication rate of 11% is consistent with the literature; however, since the results may change as the follow-up period prolongs, it may be misleading to make a clear inference about the type of hip replacement to be used.

Hip joint dislocation after acetabular reconstructions is common in prostheses and allografts. As the tumor invades the hip joint capsule and gluteal muscles, resection of these structures increases the risk of dislocation. In addition, malposition of the allograft, excessive anteversion of the acetabulum, retroversion, and vertical inclusion increase the susceptibility to dislocation. The fact that the pelvic allografts match the pelvis of the patient provides complete anatomical reconstruction and reduces the possibility of dislocation. Complications of hip joint dislocation have been reported in the literature at a rate of 0 to 20%.[6,10,19,28,37] In this study, a total of 11% of hip dislocation complications were observed in two patients (1st patient on postoperative Day 2 and 2nd patient at postoperative third month). The first patient was treated with open reduction when closed reduction could not be achieved in the early postoperative period, and our other patient was treated with constraint hip revision when the dislocation recurred despite two closed reductions. Artificial ligaments and support methods with polyethylene mesh have been proposed in the literature to reduce the incidence of dislocations. Although no support material to increase primary stability with polyethylene mesh or artificial ligament was used in our series, our dislocation complication rate is consistent with the literature.

Neurological problems are the most common complications and are more common particularly after type II resections.[6] In the study performed by Campanacci and Capanna[38] especially sciatic nerve symptoms were more common in iliac resections where the greater sciatic notch was irritated. In the literature, 3 to 30% of nerve complications have been reported.[13,32] In this study, two neurological complications (11%), one femoral and one sciatic nerve were affected. In Case 2 with femoral nerve injury, when the open reduction was performed due to early dislocation, the femoral nerve was seen to be intact, and it was thought that neuropraxia developed due to excessive retraction. Although there was a partial recovery in this patient, he died of metastasis in the postoperative sixth month before neurological deficit

was fully recovered. Our patient with sciatic nerve deficit was already a recurrent aggressive giant cell tumor case that completely invaded the sciatic nerve and the sciatic nerve had to be sacrificed. Unlike other studies, in nine of 18 patients in our series, most of the two-level unilateral spinopelvic stabilization was performed in addition to sacroiliac joint stabilization. Our 11% neurological damage rate is compatible with the literature.

Pelvic resection and reconstruction, regardless of the method, have high complication rates and inadequate functional results. Good functional outcomes depend on the stability of the reconstruction and the function of the muscles around the hip. Satisfactory functional results have been achieved in reconstructions when a good abductor, flexor, and extensor force can be achieved in the hip.[6,30] An anatomical reconstruction after pelvic resections is a good opportunity for better functional outcomes compared to palliative reconstructions. Initial studies have published good functional results, despite high mechanical failure and infection rates. In the literature, among the publications reporting results according to the MSTS scoring system, functional scores varying from 48 to 73%, including pelvic allografts, pelvic prostheses, and hip transposition.[6,10,15,19,22,23] Considering the functional scores in allograft reconstructed series, MSTS scores were published as 62% in 17 cases of Bell et al.,[16] 73% in 24 cases of Delloye et al.,[6] and 72% in 35 cases of Donati et al.[19]

Of 10 patients who were alive and died in the postoperative sixth month, five of them walked without any assistive device and four of them had normal function with no or only a slight limp with the assistance of one crutch. The patient who had local recurrence and sciatic palsy was unable to walk without support. The MSTS score at the last follow-up was 60% of the maximum possible score, when all patients who completed the postoperative six-month follow-up were included. The MSTS score in the last follow-up of our 10 patients who were still alive was 73.5% of the maximum possible score. Our functional results are also similar to the literature mentioned above. The poor functional results despite a stable pelvic continuity and hip joint restoration may be due to the following reasons. Although the iliopsoas muscle can be preserved in most of our cases, the abductor mechanism had to be sacrificed due to tumor invasion in many of our cases. In the literature, there are no specific studies involving functional comparisons based on the tumor size of patients and, thus, the sacrifice of functional structures such as the

abductor mechanism and iliopsoas muscles with wide resection. In addition, 13 of 19 patients in this study received adjuvant chemotherapy and/or radiotherapy. The adjuvant therapies that the patients receive also affect their emotional state, functional capacity, and thus their MSTS scores, regardless of reconstruction. In the literature, it has been shown that patients in the younger age group have better functional results than the elderly.[6] In this study, most cases of Ewing sarcoma in the younger age group died in the early postoperative period due to metastatic disease, which may have caused the average functional scores to be lower than we expected. In addition, while there was no change in functional results in proportion to the increasing number of complications, deep infection complications alone directly affected functional results negatively. Similar to our study, Fujiwara et al.[39] in the pelvic sarcoma series of 18 cases, although the number of reconstructions with allograft was low, deep infection and dislocation, particularly in endoprosthetic reconstruction patients, was shown to negatively affect functional results.

Although the main strengths of this study include the relatively long follow-up, there are some limitations to mention. The data belongs to a single-center and written in a retrospective manner. There are not many studies on reconstruction with allograft after pelvic tumor resection in the literature. It is not possible to make a valid comparison between the literature due to differences in tumor types and sizes, resection and reconstruction methods, and follow-up periods in studies, but this problem is always present regarding the relatively rare surgeries. Independent variables such as the inherently different behavior of the tumor and the specific differences in reconstruction from patient to patient have a constant and uniquely confounding effect on dependent variables such as survival and function. The difficulty of separating these two variables from each other limits the internal validity of this study, as in many studies of this type. Although reconstructions with allografts, which are only a narrowly defined subset of all pelvic reconstructions performed in our institution, were included, it was not possible to create a homogeneous group and many uncontrolled variables still exist.[40] These include tumor grade, size and extent, and adjuvant and neoadjuvant therapies and response to these treatments, patient age, preoperative functional status, body mass index, and others. Finally, this main study could serve as a kernel to expand the scope of our efforts to perform larger, multi-center, studies on pelvic sarcoma resection and reconstructions.

In conclusion, the results of this study support the literature in terms of postoperative complications, oncological and functional results and show that reconstruction with fresh-frozen massive allograft after pelvic resections is a method that allows full restoration of the bone anatomy, thereby obtaining satisfactory functional outcomes. Since pelvic tumors are not very common, all of the studies on this subject are small case series in the literature. There is a need for comparative analysis with more patients and longer follow-up periods and further studies that would identify the exact risk factors that may affect complications and functional outcomes. Despite the high complication rates seen in all pelvic resections, fresh-frozen massive pelvic allografts represent a valid option for reconstruction after resection of pelvic tumors, but due to the associated morbidity, patients should be carefully selected.

## REFERENCES

1. Öztürk R, Ulucaköy C, Atalay İB, Yapar A, Karakoç Y. Management and retrospective analysis of pelvic ramus tumors and tumor-like lesions: Evaluation with 31 cases. Jt Dis Relat Surg 2020;31:184-92.

2. Cottias P, Jeanrot C, Vinh TS, Tomeno B, Anract P. Complications and functional evaluation of 17 saddle prostheses for resection of periacetabular tumors. J Surg Oncol 2001;78:90-100.

3. Zang J, Guo W, Yang Y, Xie L. Reconstruction of the hemipelvis with a modular prosthesis after resection of a primary malignant peri-acetabular tumour involving the sacroiliac joint. Bone Joint J 2014;96-B:399-405.

4. Angelini A, Calabrò T, Pala E, Trovarelli G, Maraldi M, Ruggieri P. Resection and reconstruction of pelvic bone tumors. Orthopedics 2015;38:87-93.

5. Ozaki T, Hillmann A, Bettin D, Wuisman P, Winkelmann W. High complication rates with pelvic allografts. Experience of 22 sarcoma resections. Acta Orthop Scand 1996;67:333-8.

6. Delloye C, Banse X, Brichard B, Docquier PL, Cornu O. Pelvic reconstruction with a structural pelvic allograft after resection of a malignant bone tumor. J Bone Joint Surg [Am] 2007;89:579-87.

7. Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop Relat Res 1980;(153):106-20.

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):241-6.

9. Enneking WF, Dunham WK. Resection and reconstruction for primary neoplasms involving the innominate bone. J Bone Joint Surg [Am] 1978;60:731-46.

10. Langlais F, Lambotte JC, Thomazeau H. Long-term results of hemipelvis reconstruction with allografts. Clin Orthop Relat Res 2001;(388):178-86.

11. O'Connor MI, Sim FH. Salvage of the limb in the treatment of malignant pelvic tumors. J Bone Joint Surg [Am] 1989;71:481-94.

12. Aboulafia AJ, Buch R, Mathews J, Li W, Malawer MM. Reconstruction using the saddle prosthesis following excision of primary and metastatic periacetabular tumors. Clin Orthop Relat Res 1995;(314):203-13.

13. Yuen A, Ek ET, Choong PF. Research: Is resection of tumours involving the pelvic ring justified?: A review of 49 consecutive cases. Int Semin Surg Oncol 2005;2:9.

14. Satcher RL Jr, O'Donnell RJ, Johnston JO. Reconstruction of the pelvis after resection of tumors about the acetabulum. Clin Orthop Relat Res 2003;(409):209-17.

15. Guo W, Li D, Tang X, Yang Y, Ji T. Reconstruction with modular hemipelvic prostheses for periacetabular tumor. Clin Orthop Relat Res 2007;461:180-8.

16. 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;79:1663-74.

17. Renard AJ, Veth RP, Schreuder HW, Pruszczynski M, Keller A, van Hoesel Q, et al. The saddle prosthesis in pelvic primary and secondary musculoskeletal tumors: Functional results at several postoperative intervals. Arch Orthop Trauma Surg 2000;120:188-94.

18. Çolak TS, Kekeç AF. Adolescent pelvic chondrosarcoma, surgical treatment, and unusual reconstruction with pedestal conic cup (LUMiC®): A case report. Jt Dis Relat Surg 2020;31:648-52.

19. 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;469:1450-8.

20. Biau DJ, Thévenin F, Dumaine V, Babinet A, Tomeno B, Anract P. Ipsilateral femoral autograft reconstruction after resection of a pelvic tumor. J Bone Joint Surg [Am] 2009;91:142-51.

21. Ertürk C, Ayyıldız S, Erdöl C. Orthopedics and 3D technology in Turkey: A preliminary report. Jt Dis Relat Surg 2021;32:279-89.

22. Jaiswal PK, Aston WJ, Grimer RJ, Abudu A, Carter S, Blunn G, et al. Peri-acetabular resection and endoprosthetic reconstruction for tumours of the acetabulum. J Bone Joint Surg [Br] 2008;90:1222-7.

23. Gebert C, Wessling M, Hoffmann C, Roedl R, Winkelmann W, Gosheger G, et al. Hip transposition as a limb salvage procedure following the resection of periacetabular tumors. J Surg Oncol 2011;103:269-75.

24. 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;472:349-59.

25. Zeifang F, Buchner M, Zahlten-Hinguranage A, Bernd L, Sabo D. Complications following operative treatment of primary malignant bone tumours in the pelvis. Eur J Surg Oncol 2004;30:893-9.

26. Hillmann A, Hoffmann C, Gosheger G, Rödl R, Winkelmann W, Ozaki T. Tumors of the pelvis: Complications after reconstruction. Arch Orthop Trauma Surg 2003;123:340-4.

27. Fisher NE, Patton JT, Grimer RJ, Porter D, Jeys L, Tillman RM, et al. Ice-cream cone reconstruction of the pelvis: A new type of pelvic replacement: Early results. J Bone Joint Surg [Br] 2011;93:684-8.

28. Yoshida Y, Osaka S, Mankin HJ. Hemipelvic allograft reconstruction after periacetabular bone tumor resection. J Orthop Sci 2000;5:198-204.

29. Puri A, Gulia A, Jambhekar NA, Laskar S. Results of surgical resection in pelvic Ewing's sarcoma. J Surg Oncol 2012;106:417-22.

30. Beadel GP, McLaughlin CE, Wunder JS, Griffin AM, Ferguson PC, Bell RS. Outcome in two groups of patients with allograft-prosthetic reconstruction of pelvic tumor defects. Clin Orthop Relat Res 2005;438:30-5.

31. Piriou P, Sagnet F, Norton MR, de Loubresse CG, Judet T. Acetabular component revision with frozen massive structural pelvic allograft: Average 5-year follow-up. J Arthroplasty 2003;18:562-9.

32. Schwameis E, Dominkus M, Krepler P, Dorotka R, Lang S, Windhager R, et al. Reconstruction of the pelvis after tumor resection in children and adolescents. Clin Orthop Relat Res 2002;(402):220-35.

33. Sys G, Uyttendaele D, Poffyn B, Verdonk R, Verstraete L. Extracorporeally irradiated autografts in pelvic reconstruction after malignant tumour resection. Int Orthop 2002;26:174-8.

34. Ozaki T, Hoffmann C, Hillmann A, Gosheger G, Lindner N, Winkelmann W. Implantation of hemipelvic prosthesis after resection of sarcoma. Clin Orthop Relat Res 2002;(396):197-205.

35. Traina F, Giardina F, De Clerico M, Toni A. Structural allograft and primary press-fit cup for severe acetabular deficiency. A minimum 6-year follow-up study. Int Orthop 2005;29:135-9.

36. Garbuz D, Morsi E, Gross AE. Revision of the acetabular component of a total hip arthroplasty with a massive structural allograft. Study with a minimum five-year follow-up. J Bone Joint Surg [Am] 1996;78:693-7.

37. Campanacci D, Chacon S, Mondanelli N, Beltrami G, Scoccianti G, Caff G, et al. Pelvic massive allograft reconstruction after bone tumour resection. Int Orthop 2012;36:2529-36.

38. Campanacci M, Capanna R. Pelvic resections: The Rizzoli Institute experience. Orthop Clin North Am 1991;22:65-86.

39. Fujiwara T, Ogura K, Kobayashi E, Tanzawa Y, Nakatani F, Chuman H, et al. Clinical outcomes of surgical treatments for primary malignant bone tumors arising in the acetabulum. Sarcoma 2015;2015:430576.

40. Öztürk R, Arıkan ŞM, Bulut EK, Kekeç AF, Çelebi F, Güngör BŞ. Distribution and evaluation of bone and soft tissue tumors operated in a tertiary care center. Acta Orthop Traumatol Turc 2019;53:189-94.