Complications and Risk Factors for Failure of Rotationplasty

Review of 25 Patients

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Abstract Rotationplasty is one treatment option for femoral bone sarcomas in skeletally immature patients. This procedure enables patients to avoid phantom pain, limb length discrepancy, or loosening of an endoprosthesis, and good functional outcome has been reported. However, rotationplasty is only rarely indicated and the surgical complications or risk factors for failure of the procedure that might influence choices of treatment or patient counseling have not been well described. We reviewed 25 patients who underwent rotationplasty focusing on risk factors for failure and postoperative complications. Three of 25 patients had vascular compromise resulting in amputation. All three had vascular anastomosis and were resistant to chemotherapy with less than 95% of tumor necrosis. Two of the three patients who underwent amputation had a pathologic fracture before surgery. Late complications included one patient with a tibial fracture, two with wound complications treated with skin grafts, one with nonunion,

and one with subsequent slipped capital femoral epiphysis. Rotationplasty was successfully accomplished in 22 of the 25 patients. Patients with large tumors unresponsive to chemotherapy or preoperative pathologic fracture appear at higher risk for failure of rotationplasty presumably as a result of compromise of venous drainage of the leg.

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

Introduction

Rotationplasty is one treatment option for femoral osteosarcoma and other sarcomas in skeletally immature patients. Rotationplasty is an alternative to amputation and has the advantages of avoiding phantom pain, limb length discrepancy, and loosening of an endoprosthesis. The reported functional outcomes are good [7, 13]. This procedure can also be used to save failed limb salvage procedures [3, 17, 20]. Rotationplasty is particularly favored in patients with extensive soft tissue mass, intraarticular extension of tumor, or pathologic fractures [8]. The femoral or tibial sarcoma can be resected en bloc with surrounding soft tissue without opening the knee joint. The major arteries and veins can be resected and anastomosed if soft tissue involvement by the tumor so requires. Rotationplasty only requires the ability to retain an intact sciatic nerve so this procedure can be used for patients with large femoral sarcomas who are not candidates for endoprosthesis or osteoarticular allograft reconstruction, and wide margins can be obtained.

Rotationplasty is, however, only rarely recommended because of psychological concerns resulting from the strange appearance of the rotated limb [16, 18]. Failure of rotationplasty is sufficiently rare that complications and risk

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factors for surgical failure are not well enumerated in the literature. Postoperative complications, especially vascular compromise, may be devastating and, in the worst scenario, patients require amputation for ischemia [2, 12, 17]. A recent study reported two amputations for unsalvageable arterial compromise out of 30 patients [2]. Another study of 70 patients who had rotationplasty reported seven had vascular complications and three underwent amputation [12]. Winkelmann [20] reported seven vascular complications out of 134 patients. Vessels can be resected with end-to-end anastomosis if they are involved with or too close to the tumor. Resection of the artery and vein en bloc with the tumor has the potential to achieve a wider margin and possibly reduce the local recurrence rate. Kinking of the vessels or leaving long, coiled vessels at risk for thrombosis may be reduced by vascular anastomosis; however, anastomoses can also fail [8]. Candidates for rotationplasty tend to have large sarcomas of the femur with extensive soft tissue involvement or pathologic fractures, in which case endoprosthetic or allograft reconstruction is not indicated. Extensive tumor involvement with poor response to preoperative chemotherapy or pathologic fractures could contribute to surgical failure of rotationplasty because of alternation of blood supply or drainage, although to the best of our knowledge, there is no literature that specifically focuses on surgical failure and preoperative conditions.

To confirm these rates of 5% to 10% serious complications, we ascertained the rates of success and serious early and late complications for rotationplasty. We further identified the reasons for failure and possible preoperative risk factors (poor response to chemotherapy, use of vascular anastomosis, and pathologic fractures).

Materials and Methods

We retrospectively reviewed the medical records of 25 patients who had rotationplasty between 1984 and 2007.

The mean age at the time of surgery was 10 ± 3 years (mean $\pm$ standard deviation; range, 4–15 years). Fourteen of the 25 patients were boys and 11 patients were girls. All patients were diagnosed with osteosarcoma. Most of them had high-grade osteosarcoma and two patients had telangiectatic osteosarcoma. Our primary indication for rotationplasty is skeletally immature patients with large bone sarcomas of the femur. We did not specifically use the potential for continuing skeletal growth as a sole criterion for the procedure, however. We also took into consideration the functional and athletic desires of the child, the wishes of the family to reduce the likelihood of future operations associated with limb salvage reconstructions and the desire to avoid high thigh amputation or hip disarticulation. In our series, very large sarcomas with potential vascular involvement or tumors with pathologic fractures were not considered a contraindication if the sciatic nerve was free of tumor, and we favored rotationplasty in those patients, who did not have alternative treatment options other than amputations. This procedure can also be used in adults with similar indications or in those with failed limb salvage procedures. The minimum followup was 2 months (range, 2–270 months; average, 59 months); no patients were lost to followup prior to the 2 months visit.

The preoperative workup included routine radiographs, total body radionuclide bone scans, and recent MRI of the whole femur in addition to systemic staging studies (primarily computed tomography of the chest). MRI was used to assess the soft tissue extent of the lesion and the involvement of the neurovascular bundle (Fig. 1). The decision to resect the vessels and perform vascular anastomosis was made based on the MRI and intraoperative findings. When we believed the tumor in close proximity or potentially invading the femoral artery and vein, we excised the vessels with the tumor en bloc and performed a vascular anastomosis. The bone scan and MRI were carefully evaluated to rule out skip lesions and to help plan the site of the femoral osteotomy. Fifteen patients had

Fig. 1A–C MRI images show an example of a large osteosarcoma of the left distal femur. (A) A T1 coronal image of both femurs shows extensive soft tissue involvement of the left thigh. (B) A sagittal MRI image shows the left femur with contrast. The soft tissue mass is extensive anteriorly and posteriorly and surrounds the femur. (C) An axial T2-weighted MRI image shows the tumor compresses the hamstrings and vascular invasion of the tumor is suspected.

Fig. 2A–C This graph shows the distribution of each risk factor in the 25 patients. (A) Eighty-four percent of patients received preoperative chemotherapy. (B) Eighty percent of patients underwent vascular anastomosis during the procedure. (C) Sixty percent of patients had pathologic fractures before the surgery.

pathologic fractures at presentation or fractured their femur during chemotherapy and were treated with a cast. This is a higher rate of fracture than the general osteosarcoma population and reflects the fact that these were selected patients who were deemed more appropriate for rotation-plasty than limb salvage procedures. Twenty-one patients had preoperative chemotherapy. The other three patients were treated early in the series when neoadjuvant chemotherapy was not as routinely employed (Fig. 2). Most patients were treated with a conventional regimen of doxorubicin, cisplatin, and high-dose methotrexate [10]. Ifosfamide with or without etoposide was selectively used prior to the resection for patients with an apparent poor clinical response to chemotherapy.

Rotationplasty was the initial surgical reconstruction for all patients; in one patient, rotationplasty was performed after curettage and bone grafting for a misdiagnosis on frozen section of an aneurysmal bone cyst, finally diagnosed as telangiectatic osteosarcoma. Twenty-four patients had a tumor of the distal femur and underwent Van Nes rotationplasty [16, 17] and one had a Winkelman type B1 [20] rotationplasty for a proximal femoral osteosarcoma. The operative procedure of Van Nes-type rotationplasty was described by Merkel et al. [17]. In brief, two circumferential rhomboidal skin incisions were used proximal and distal to the tumor, and then nerves and vessels were exposed in the distal aspect of the wound. The sciatic nerve was freed along the entire length of the resection specimen. We did not attempt to preserve the saphenous nerve and did not note any phantom sensation or problems due to loss in sensation in the distribution of the saphenous nerve in our patients. If resection of a portion of the femoral artery and vein was deemed necessary, vascular anastomosis was performed by vascular surgeons after osteosynthesis. After tumor excision, the distal extremity was externally rotated and fixed with plate osteosynthesis. The sciatic nerve was coiled medially. The femoral artery and vein were also coiled if they were saved and then the wound was closed. Winkelman type B1 procedure was employed for one tumor of the proximal femur without involvement of the hip [4, 14]. In this patient the knee was rotated 180° and fixed to the pelvis where it functions as a hinge joint. First,

a circumferential incision was made just proximal to the popliteal fossa of the attached limb. A longitudinal extension was made anterolaterally between the iliac crest and the great trochanter and the sciatic nerve was exposed. The limb was detached at the level of distal femoral incision except the sciatic nerve and proximal femoral sarcoma was removed. Anastomosis of femoral and popliteal vessels was performed in this case because the vessels had to be excised with tumor. The knee was externally rotated and brought to the acetabulum and attached to the pelvis. Following bone fixation, the muscles of the leg were attached to the resected thigh muscles. A drain was left in place and the subcutaneous tissues and skin were closed [14]. In both procedures, uninvolved (normal) skin, subcutaneous tissue, and muscle were preserved to the extent possible given the location of the tumor and/or fracture hematoma to avoid tight closure, which may cause compression of neurovascular bundles. If skin closure was expected to be tight, additional hemi-cylindrical osteotomy of the proximal tibia was employed to bury the distal femur further in the tibial metaphysis to relieve the tension on the soft tissue closure. This had the additional benefit of greater surface area for healing of the osteotomy. Because skin, subcutaneous tissue, and muscle are resected except for around the sciatic nerve, all tissues involved with the hematoma of a pathological fracture are resected. Twenty patients had resection of the femoral vessels and anastomosis of the femoral artery and vein to the popliteal vessels (Fig. 2). Drains were placed in all cases to prevent blood collection and hematoma. Wide surgical margins were achieved in all patients.

All specimens were evaluated by experienced pathologists (AR, AP-A). The response to chemotherapy was determined based on percent tumor necrosis as determined by the system that existed at the time. Most of these patients were on protocols of the Pediatric Oncology Group (now the Children's Oncology Group) [9, 11]. More than 95% tumor necrosis was considered a good response to chemotherapy and less than 95% was considered a poor response.

Patients were observed in the intensive care unit postoperatively and arterial pulse, skin color, and sciatic nerve function were monitored closely. The ultrasonic Doppler flow detector was used to monitor arterial pulse. Once patients became hemodynamically stable and tolerated pain and diet, they were discharged about 5 to 7 days postoperatively. We followed up in 2 weeks for wound check and postoperative chemotherapy was started when the wound was cleared. We followed up every 2 to 4 weeks until the patients were familiarized with their prosthesis (up to around 3 months postoperatively). Patients without complications are followed up every 6 months up to 5 years. If patients are disease free for 5 years, they are followed up annually.

We identified from the records early and late complications. Early serious complications resulted in failure of rotationplasty and amputation. The rates of amputation and pre- and postoperative risk factors for failure such as pathologic fracture, response to chemotherapy, and anastomosis during the procedure were reviewed. Late complications such as fractures and wound complications were also evaluated.

Results

Rotationplasty was successfully accomplished in 22 patients (88%) with large femoral osteosarcomas. In 21 patients who received preoperative chemotherapy, 10 had more than 95% necrosis of the tumor and 11 had a poor histologic response to chemotherapy (Fig. 3). Three patients (12%) had vascular compromise postoperatively, which resulted in amputation. Above knee amputation at the level of osteotomy was employed for Van Nes rotationplasty and hip disarticulation was performed for the Winkelman B1 procedure. In one patient, poor venous drainage and continuous bleeding around the anastomosis with associated platelet consumption could not be corrected despite multiple intraoperative attempts regardless of the placement of the drain, reexploration of the anastomoses, or platelet transfusion. This ultimately compromised the arterial anastomosis and resulted in poor arterial perfusion. In the second patient, considerable venous drainage continued for the first postoperative day and the hematoma compressed the sciatic nerve as well as

the anastomosis. In both cases, anastomosis was apparently successful without leak and an arterial pulse was transiently reestablished during exploration in the operating room. In the third case, venous perfusion was not established during the procedure. Embolectomy catheters were passed through the posterior tibial artery, but it was not possible to get a posterior tibial or dorsalis pedis pulse by Doppler. It appeared that the vascular system of the leg had been compromised by the months of immobilization in a cast and thrombosis of the popliteal vein due to compression of the large tumor mass. In all three cases, the failure to establish blood flow through the anastomoses appeared to be on the venous, not the arterial side.

One patient had a sciatic nerve palsy immediately after the operation as a result of tight closure and compression of the nerve by excessive muscle tissue retained at time of closure. This patient had immediate surgical exploration of the wound with resection of excess muscle and decompression of the nerve in the operating room. The nerve function recovered immediately after the procedure. We believe that unless there is an obvious explanation for a nerve palsy, immediate exploration of the nerve is indicated since sciatic nerve function is essential to making this procedure successful. Kinking or compression of the nerve is possible during the closure and easily remedied if noted early.

In the three patients who underwent amputation, two had undergone Van Nes-type and one Winkelman-type rotationplasty. We assumed poor response to chemotherapy, vascular anastomosis, and pathologic fractures as risk factors for rotationplasty. All three patients with unsuccessful rotationplasties had a poor histologic response to chemotherapy and had vascular anastomosis. Two had pathologic fractures preoperatively (Fig. 3).

One patient had a distal tibial fracture 11 months after rotationplasty and underwent internal fixation. Two had wound complications; one underwent split-skin grafting for wound necrosis 4 months after the initial operation and the other had a *Pseudomonas* infection and underwent skin grafting 2 months postoperatively. One patient had non-union of the osteosynthesis and underwent revision with a bone graft. One had a slipped capital femoral epiphysis 2 months after rotationplasty and was surgically treated (Table 1). All of these patients recovered fully and functioned similar to those without complications once they were adequately treated for their complication.

Fig. 3A–C The relationship between risk factors and amputation is demonstrated. (A) All amputees showed a poor response to preoperative chemotherapy. (B) All patients with unsuccessful rotationplasty had vascular anastomosis. (C) Two patients with unsuccessful procedures had pathologic fractures before the surgery.

Discussion

Rotationplasty is one treatment option for femoral bone sarcomas in skeletally immature patients and can be used in adults with large tumors or failed limb salvage procedures.

Table 1. Early and late complications after rotationplasty

Time of complication	Age at procedure/gender	Type of rotationplasty	Complications	Duration between surgery and development of complications	Resolution
Early	10/F	Winkelmann B1	Vascular compromise	8 hours	Hip disarticulation
	11/M	Van Nes	Vascular compromise	2 days	Above knee amputation
	14/M	Van Nes	Vascular compromise	During surgery	Above knee amputation
	7/F	Van Nes	Sciatic nerve palsy	Immediately after procedure	Removal of hematoma, nerve function recovered
Late	14/M	Van Nes	Distal tibial fracture	11 months	Open reduction and internal fixation
	10/F	Van Nes	Wound complications	4 months	Skin graft
	13/M	Van Nes	Wound complications	2 months	Skin graft
	13/M	Van Nes	Slipped capital femoral epiphysis	2 months	Internal fixation with pinning
	6/M	Van Nes	Nonunion of osteosynthesis	41 months	Revision with bone graft

This procedure enables patients to avoid phantom pain because the sciatic nerve or its branches are not divided as they are in amputation. It also avoids issues of limb length discrepancy or loosening of an endoprosthesis, and good functional outcome has been reported; however, rotationplasty is only rarely indicated and surgical complications or risk factors for failure of the procedure have not been well reported [7, 13]. We reviewed 25 patients with rotationplasty focusing on risk factors for failure and postoperative complications. We observed that rotationplasty is a relatively successful procedure with a low amputation rate and that those patients whose rotationplasties result in amputation have risk factors such as pathologic fractures, poor response to chemotherapy, or vascular anastomosis.

Our study is limited by the small number of patients precluding clear statistical identification of preoperative factors predicting complications; however, because rotationplasty is rarely indicated, we believe our observations important because of their serious nature and the fact that we may never have sufficient cases, i.e., the power to statistically validate them. A few patients were followed up for a relatively short-term period of up to 2 months. Some of our patients came from outside the country for surgical treatment, and once their postoperative conditions were stabilized they returned to their homes, so we were unable to achieve long-term followup for all patients. Two months is sufficient, however, to evaluate the early complications we focused on in this study.

In our series, rotationplasty was successfully accomplished in 88% of the patients. In those that were successful, good function was achieved and phantom pain was avoided. However, three of the 25 procedures resulted in an amputation due to vascular compromise within 2 days of the rotationplasty.

One report suggests poor response to chemotherapy is associated with a greater risk of local recurrence as well as

decreased disease-free and overall survival [5]; however, the relationship between chemotherapy response and outcome of surgical procedures has not been discussed. Good response to chemotherapy may result in a decrease in the size of the soft tissue mass and edema or at least prohibit the tumor from enlarging dramatically in the induction phase. Chemotherapeutic regimens changed over the course of this study and most of the patients were on protocols of the Pediatric Oncology Group (now the Children's Oncology Group) [9, 11]. As a result, there was a lack of uniformity in the drug regimens used for these patients and there were 16% of patients who did not receive preoperative chemotherapy because at the time it was not in standard use. In our series, all patients with unsuccessful rotationplasties were unresponsive to chemotherapy with less than 95% of tumor necrosis. Poor response to chemotherapy associated with an increase in tumor size was noted; this might have resulted in compromise of the venous drainage in the leg after the anastomosis. We hypothesize but cannot prove these large tumors compress the draining veins and lead to thrombosis and poor venous drainage of the leg, making the likelihood of a successful anastomosis low. Whether amputation could have been avoided by preserving the vessels in these three cases is not known, but it was not considered possible to safely resect the tumor and preserve the femoral vessels for these patients.

Vascular anastomosis has been suggested as a risk factor for vascular compromise as a result of potential for anastomosis failure [12]. In our study, 20 patients (80%) had resection of the femoral vessels, with successful anastomosis of the femoral artery and vein to the popliteal vessels in 17 of them. The high rate of anastomosis in this series was the result of the selection of this procedure for patients who had large femoral osteosarcomas involving the femoral artery and vein or sufficiently close that we did not consider them salvageable. There was also a bias early in

the series that it was better to resect and anastomose the vessels rather than preserve and coil them. We believe the primary indications for rotationplasty are in patients with very large osteosarcomas with potential vascular involvement or in very young patients, and the ability to resect the vessels at times is useful in achieving adequate tumor margins. Of note, the reason for vascular compromise in our patients was not a failed vascular anastomosis, but rather an initially successful anastomosis was compromised by what appeared to be poor venous drainage and bleeding with subsequent hematoma formation in at least two patients. Thus, we believe venous drainage had a critical role for failure of rotationplasty.

One report suggests pathologic fracture in an osteosarcoma a poor prognostic factor [19], and another recommends immediate amputation for these patients [6]. The role of pathologic fracture as a risk factor for failed rotationplasty has not been reported. The majority of our patients had pathologic fractures, whereas the reported prevalence of pathologic fracture either at diagnosis or during preoperative chemotherapy is relatively uncommon (between 5% and 10% [1, 15]). This is likely attributable to our philosophy of reserving rotationplasty primarily for patients with higher risk of local recurrence such as those with pathologic fracture. Because rotationplasty is in effect an “intercalary amputation” and the tumor can be resected with surrounding soft tissue, including the major arteries and veins, our primary indication for rotationplasty was patients with large femoral osteosarcoma, whom we deemed inappropriate candidates for endoprosthetic or osteoarticular allograft reconstruction. Patients with osteosarcoma who present with a pathologic fracture or sustain one during preoperative chemotherapy have an increased risk of local recurrence and a decreased rate of survival compared with patients without pathologic fracture [19]. The fracture results in a local hematoma with possible dissemination of tumor cells into the adjacent tissue and perhaps into the vasculature and adjacent joints [1]. These are often large tumors and the fracture may alter the vascular supply and drainage of the leg, which we suggest could result in vascular compromise and subsequent failure of the rotationplasty.

We had only one Winkelmann rotationplasty that resulted in amputation. This procedure is more technically demanding than the Van Nes rotationplasty [4]. Three of the six patients who underwent Type B1 Winkelmann rotationplasty had vascular complications with thrombosis of the venous anastomosis or embolism of the femoral artery in a previous report [14]. Extreme caution must be taken to avoid obstructing the blood flow and avoiding irreversible limb ischemia with the Winkelmann procedure.

We did not routinely employ arteriograms, nor did we use venograms, MR angiograms or venograms, or

ultrasound to assess the vascular integrity of the distal limb in our patients. It is possible that these studies might have predicted poor arterial circulation or venous thrombosis, but we cannot confirm that in this group of patients.

We found rotationplasty successful in 88% of the patients with femoral osteosarcoma. Patients with large tumors and poor response to chemotherapy or pathologic fracture appeared to have a higher risk for failure of rotationplasty that we believe results from compromise of venous drainage of the leg, although we do not have a sufficient numbers of patients to have the power to statistically prove this contention. Patients with pathologic fractures or sarcomas with soft tissue masses may be at increased risk for an unsuccessful result after rotationplasty. Although probably not a contraindication to the procedure, the surgeon should be aware of the higher potential risk of failure and proceed with caution in patients with these risk factors.

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References

1. Abudu A, Sferopoulos NK, Tillman RM, Carter SR, Grimer RJ. The surgical treatment and outcome of pathological fractures in localised osteosarcoma. *J Bone Joint Surg Br.* 1996;78:694–698.
2. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Rotationplasty for bone tumors: is there still a role? *Clin Orthop Relat Res.* 2007;459:76–81.
3. Brigman BE, Kumagai SG, McGuire MH. Rotationplasty after failed limb-sparing tumor surgery: a report of two cases. *Clin Orthop Relat Res.* 2003;415:254–260.
4. Brown KL. Resection, rotationplasty, and femoropelvic arthrodesis in severe congenital femoral deficiency. A report of the surgical technique and three cases. *J Bone Joint Surg Am.* 2001;83:78–85.
5. Ferguson WS, Goorin AM. Current treatment of osteosarcoma. *Cancer Invest.* 2001;19:292–315.
6. Finn HA, Simon MA. Limb-salvage surgery in the treatment of osteosarcoma in skeletally immature individuals. *Clin Orthop Relat Res.* 1991;262:108–118.
7. Fuchs B, Kotajarvi BR, Kaufman KR, Sim FH. Functional outcome of patients with rotationplasty about the knee. *Clin Orthop Relat Res.* 2003;415:52–58.
8. Fuchs B, Sim FH. Rotationplasty about the knee: surgical technique and anatomical considerations. *Clin Anat.* 2004;17:345–353.
9. Goorin AM, Harris MB, Bernstein M, Ferguson W, Devidas M, Siegal GP, Gebhardt MC, Schwartz CL, Link M, Grier HE. Phase II/III trial of etoposide and high-dose ifosfamide in newly diagnosed metastatic osteosarcoma: a pediatric oncology group trial. *J Clin Oncol.* 2002;20:426–433.
10. Goorin AM, Perez-Atayde A, Gebhardt M, Andersen JW, Wilkinson RH, Delorey MJ, Watts H, Link M, Jaffe N, Frei E 3rd, et al. Weekly high-dose methotrexate and doxorubicin for osteosarcoma: the Dana-Farber Cancer Institute/the Children's Hospital—study III. *J Clin Oncol.* 1987;5:1178–1184.

11. Goorin AM, Schwartzentruber DJ, Devidas M, Gebhardt MC, Ayala AG, Harris MB, Helman LJ, Grier HE, Link MP; Pediatric Oncology Group. Presurgical chemotherapy compared with immediate surgery and adjuvant chemotherapy for nonmetastatic osteosarcoma: Pediatric Oncology Group Study POG-8651. *J Clin Oncol*. 2003;21:1574–1580.
12. Gottsauner-Wolf F, Kotz R, Knahr K, Kristen H, Ritschl P, Salzer M. Rotationplasty for limb salvage in the treatment of malignant tumors at the knee. A follow-up study of seventy patients. *J Bone Joint Surg Am*. 1991;73:1365–1375.
13. Hanlon M, Krajchich JJ. Rotationplasty in skeletally immature patients. Long-term followup results. *Clin Orthop Relat Res*. 1999;358:75–82.
14. Harges J, Gosheger G, Vachtsevanos L, Hoffmann C, Ahrens H, Winkelmann W. Rotationplasty type BI versus type BIIIa in children under the age of ten years. Should the knee be preserved? *J Bone Joint Surg Br*. 2005;87:395–400.
15. Jaffe N, Spears R, Eftekhari F, Robertson R, Cangir A, Takaue Y, Carrasco H, Wallace S, Ayala A, Raymond K, et al. Pathologic fracture in osteosarcoma. Impact of chemotherapy on primary tumor and survival. *Cancer*. 1987;59:701–709.
16. Kotz R. Rotationplasty. *Semin Surg Oncol*. 1997;13:34–40.
17. Merkel KD, Gebhardt M, Springfield DS. Rotationplasty as a reconstructive operation after tumor resection. *Clin Orthop Relat Res*. 1991;270:231–236.
18. Rodl RW, Pohlmann U, Gosheger G, Lindner NJ, Winkelmann W. Rotationplasty—quality of life after 10 years in 22 patients. *Acta Orthop Scand*. 2002;73:85–88.
19. Scully SP, Ghert MA, Zurakowski D, Thompson RC, Gebhardt MC. Pathologic fracture in osteosarcoma: prognostic importance and treatment implications. *J Bone Joint Surg Am*. 2002;84:49–57.
20. Winkelmann WW. Rotationplasty. *Orthop Clin North Am*. 1996;27:503–523.