Reliability of vascularized fibula in maintaining arthrodesis following extra-articular wide excisions of malignant musculoskeletal tumors

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ABSTRACT

Objective: To evaluate the reliability of vascularized fibula transfer in maintaining arthrodesis following wide excision of malignant tumors located at the metaphyseal ends of long bones.

Methods: Fourteen patients underwent wide extra-articular excisions followed by arthrodesis with vascularized fibula and its variants at the Department of Orthopedic Surgery and Traumatology, University of Hacettepe Medical School, Ankara, Turkey, in the period from 1996 to 2003. There were 9 males and 5 females. Their mean age was 28 years (ranging 12-52 years). The mean follow-up time was 68 months (range 28-110 months). The most common diagnosis was malignant giant cell tumor (6), followed by Ewing's sarcoma (3), hemangioendothelioma (2), osteosarcoma (2) and chondrosarcoma (1). Three tumors were located at the distal end of the radius, 4 at the proximal humerus, 3 at the distal femur, one at the proximal tibia, one in distal tibia, one in distal humerus and one in proximal ulna. We used fibula as a vascularized graft in 4 patients; fibula osteoseptocutaneous flap in 4 cases; bilateral vascularized fibulae in 3; fibula with autoclaved autograft in 4 and free osteoseptocutaneous fibula in conjunction with a structural allograft and a circular external fixator in one patient.

Results. In 4 cases, implant failure developed and revision was required in 3. One case had local infection around the distal interlocking screw. In one case, clawing of first and second toes were developed at the donor side. Two patients with metastatic Ewing's sarcoma had metastatic disease. We achieved union within 9 months in 12 cases. In 2 cases with implant failure, bony consolidations were maintained at 11th and 13th months.

Conclusion: Vascularized fibula transfer is reliable to achieve arthrodesis following extra-articular excision of malignant tumors from the metaphyseal ends.

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Reconstruction of primary and secondary skeletal defects remains a challenge to reconstructive surgeons.[1] Surgical procedures designed to accomplish removal of a malignant tumor and reconstruction of the limb with acceptable oncologic, functional, and cosmetic results has become a standard approach for many musculoskeletal malignant tumors.[2] Preservation of the extremity with a useful function has many advantages. Recent developments in chemotherapy and imaging systems made surgical treatment of malignant tumors of the musculo-skeletal system easier without resorting to amputation. Nowadays, high percentage of patients with an extremity malignancy are undergoing limb-salving surgery.[2-4] When the tumor is located adjacent to a joint, extra-articular wide excision with or without adjunctive

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chemotherapy is the treatment of choice. The defects caused by extra-articular wide excision are substantial. Reconstruction of defects with implant arthroplasty, bone transport with Ilizarov techniques, arthrodesis with autogenous bone grafts, and interpositional allograft or vascularized bone transfers have different indications, advantages and complications.[5-8] The mainstay of limb sparing surgery for periarticular musculoskeletal tumors is implant arthroplasty. Stability and long-term duration of implant arthroplasty decreases in patients with large tumors. Removal of several ligaments, muscles and tendon groups jeopardize the static and dynamic stability of the joints. Despite improvements in the preparation techniques and in the methods of fixation, allograft reconstruction has overall complication rate exceeding 50%, including infection, nonunion and fractures.[7] Ilizarov's techniques are time consuming and needs patient's cooperation. The vascularized autogenous bone transfers for the reconstruction of bone defects has become popular when it was first described by McKee.[9] Vascularized fibula and its variants including osteoseptocutaneous fibular flap have been the most preferred vascular bone transfer especially for the upper extremity.[10,11] In the lower extremity, a long period of protection is needed for a functional takeover following vascularized fibula transfer. Longer periods will elapse for the compensatory hypertrophy of the transferred fibula in the lower extremity in comparison with the upper extremity, although the osteotomy sites consolidate rapidly.[12] Biologic advantages of the vascularized bone transfer may be combined with the mechanical advantages of allograft and external fixation,[13,14] to prevent the premature failure of the surgical reconstruction. Implant arthroplasty may be technically impractical due to extreme soft tissue loss following extra-articular wide excisions. Vascularized bone transfer may offer several advantages in these complicated conditions. The purpose of this study is to evaluate the clinical results in a group of 14 selected patients who underwent wide extra-articular excision followed by arthrodesis with vascularized fibula for the treatment of malignant tumors involving musculoskeletal system.

Methods. In the period from 1996 to 2003, 14 patients with malignant tumors of the musculoskeletal system were treated with extra-articular wide excision followed by vascularized fibula transfer and arthrodesis of the involved joint at the Department of Orthopedic Surgery and Traumatology, University of Hacettepe Medical School, Ankara, Turkey. A wide extra-articular surgical margin means the tumor has been removed en bloc, that the plane of dissection has been peripheral to the reactive zone through normal tissue. The resected specimen contains the tumor, the whole metaphyseal end of bone together with the adjacent joint and the surrounding reactive zone. There were 9 male and 5 female patients. Their average age was 28 years (range, 12-52 years). The mean follow-up time was 68 months (range, 28-110 months). The most common diagnosis was malignant giant cell tumor (6), followed by Ewing's sarcoma (3), hemangioendothelioma (2), osteosarcoma (2), and chondrosarcoma (1). Four tumors were located at the proximal humerus, one at distal humerus, one at proximal ulna, 3 at the distal end of the radius, 3 at the distal end of the femur, one at the proximal tibia and one in distal tibia. The ages, lesions, location, type of surgery, follow up periods, state of disease, complications and functional Toronto Extremity Salvage Scores are shown in **Table 1**.[15] The majority of the lesion (9/14) were located in the upper extremity. The involved joints were as follows: 4 shoulders, 4 knees, 3 wrists, 2 elbows, and one ankle. The surgical procedure was divided into 5 steps: 1. extra-articular wide excision of the lesion, 2. establishment of a stable internal or external fixation, 3. stabilization of fibula, 4. arterial and venous anastomoses, and 5. autogenous iliac bone grafting of the junctional areas. For shoulder arthrodesis the intention was to position the arm in 30 degrees abduction, 30 degrees forward flexion and 30 degrees internal rotation. A 4.5 mm pelvic reconstruction plate with a buttressing dynamic compression plate was used to improve the stability of the construct.[16] A vascularized fibula was placed between the lateral border of the scapula and the proximal stump of the humerus (**Figure 1**). Peroneal artery was anastomosed to brachial artery in an end-to-side fashion, and basilic and cephalic veins were used in an end-to-end fashion. For the elbow, arthrodesis fibula was interposed in the defect and fixed to humerus proximally and ulna distally. Peroneal artery was anastomosed to radial artery in an end-to-side fashion, and comitant and cephalic veins were used in an end-to end fashion. For the wrist, arthrodesis fibula was interposed between the distal stump of radius and distal carpal raw. A pelvic reconstruction plate was used to bridge radius and second or third metacarpus (**Figure 2**). Peroneal artery was anastomosed to radial artery in an end-to-side fashion, and comitant and cephalic veins were used in an end-to-end fashion. For the knee arthrodesis, a custom made intramedullary rod was used for fixation. Structural allograft was placed in between femur and tibia during rod insertion. Interlocking screws were placed. The fibula was placed between femur and tibia or over allograft. Peroneal artery

Table 1 - Patients, location of the lesions, tissue diagnosis, treatment modality, and follow up of patients.

Patient	Age	Lesion	Site	Arthrodesis	Flap	Follow up	Disease	Complication	TESS
1	18	HE	Distal radius, left	Wrist	Fibula osteoseptocutaneous	110 months	Free	-	97
2	32	MGCT	Proximal humerus, right	Shoulder	Fibula + autoclaved autograft	102 months	Free	-	89
3	52	MGCT	Distal tibia, right	Ankle	Osteoseptocutaneous + structural allograft + external fixation	98 months	Free	-	97
4	39	HE	Proximal humerus, right	Shoulder	Fibula + autoclaved autograft	96 months	Free	Clawing IP fusion + extensor shift	86
5	42	CS	Proximal humerus, right	Shoulder	Fibula + autoclaved autograft	89 months	Free	-	87
6	17	OS	Femur distal, right	Knee	Fibula (bilateral)	87 months	Free	-	72
7	22	ES	Proximal humerus, right	Shoulder	Fibula + autoclaved autograft	74 months	Preop metastatic disease	-	87
8	31	MGCT	Distal femur, right	Knee	Fibula (bilateral)	62 months	Free	Implant (IM Rod) failure revision needed	81
9	12	OS	Distal femur, right	Knee	Fibula osteoseptocutaneous	58 months	Free	Implant (IM Rod) failure revision needed	70
10	34	MGCT	Proximal tibia, right	Knee	Fibula (bilateral) + allograft	44 months	Free	infection distal interlocking	80
11	13	ES	Coronoid process, right	Elbow	Fibula	36 months	Free	Implant failure (plate-screw) revision needed	84
12	34	MGCT	Distal radius, right	Wrist	Fibula osteoseptocutaneous	32 months	Free	-	89
13	24	ES	Distal humerus, right	Elbow	Fibula	30 months	Preop metastatic disease	Implant failure (plate-screw) No revision needed	83
14	35	Malignant giant cell tumor	Distal radius left	Wrist	Fibula osteoseptocutaneous	28 months	Free	-	97
Mean	29	-	-	-	-	68 month	-	-	86

TESS - Toronto Extremity Salvage Score, HE - hemangioendothelioma, MGCT - malignant giant cell tumor, CS - Chondrosarcoma, OS - osteosarcoma, ES - Ewing's sarcoma, IP - interphalangeal, IM - intramedullary

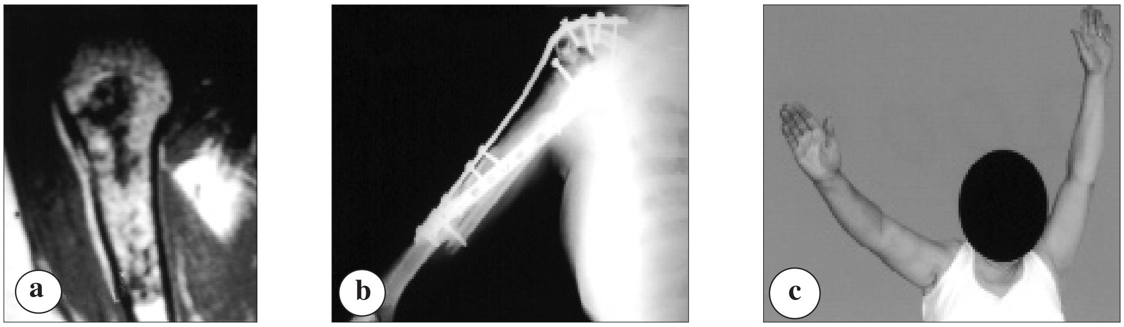

Figure 1 - Shoulder arthrodesis with vascularized fibula and autoclaved bone. **a)** A 42-year-old female presenting with chondrosarcoma of the proximal part of the right humerus. **b)** Shoulder arthrodesis with autoclaved humerus and vascularized fibula. **c)** Range of motion of the shoulder 7 years after surgery.

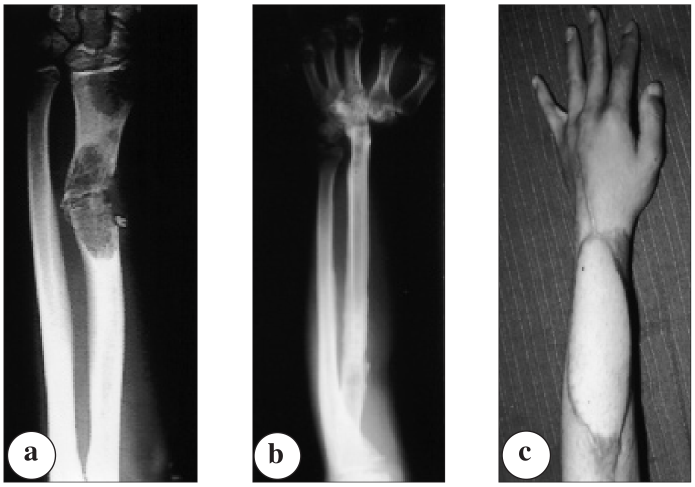

Figure 2 - Case one presenting with a pathological fracture of his left radius **a)** A 18-year-old male presenting hemangioendothelioma of the distal half of his left humerus. **b)** Wrist arthrodesis with osteoseptocutaneous vascularized fibula transfer. **c)** Nine years after surgery.

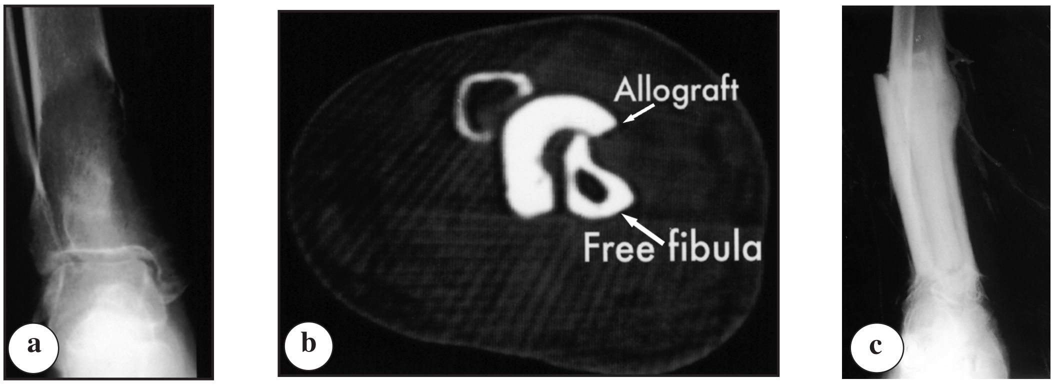

Figure 3 - Case 3 **a)** A 52-year-old male presenting with malignant giant cell tumor of the distal part of his right tibia. **b)** Ankle arthrodesis using allograft femur, osteoseptocutaneous vascularized fibula and circular external fixation. **c)** Eight years after surgery.

was anastomosed to femoral artery in an end-to-side fashion, and comitant and saphenous veins were used in an end-to-end fashion. For the ankle fusion, circular external fixation was placed fixing forefoot, midfoot, hindfoot and proximal part of the tibia to preserve the alignment of the lower extremity during excision. Extra-articular wide ankle excision was performed after the circular external fixator frame was completed. A femoral allograft and osteoseptocutaneous free fibula flap was inserted in the defect (**Figure 3**). Peroneal artery was anastomosed to tibialis posterior artery in an end-to-side fashion, and comitant and saphenous veins were used in an end-to-end fashion. Tumor excision and primary reconstruction were performed at the same session in 10 patients. In 4 patients, excision and secondary reconstruction were performed in different sessions. The free vascularized fibula was used in 9 patients. Of these, 2 patients used a single strut, 4 with autoclaved autograft, and 3 both ipsilateral and contralateral fibula. In 2 of these last patients, extra-articular knee excisions were reconstructed with intramedullary rod fixation and bilateral vascularized fibula interposition. In one patient, bilateral fibula were used at the proximal and distal osteotomy sites to augment consolidation of the interposition allograft over the intramedullary nail. Free osteoseptocutaneous vascularized fibula was used in 5 patients. Wide extra-articular excision of the wrist, followed by fibular interposition was applied (**Figure 2**). In one patient, malignant giant cell tumor of the distal tibia invading the articular surface was excised extra-articularly. An external fixation was constructed bridging the tibia and the foot. A structural allograft was interposed between tibia and talus. Osteoseptocutaneous free fibula was placed between the allograft and normal fibula. Immediate weight bearing was allowed. Consolidation was very rapid (**Figure 3**). Patient 2 with recurrent malignant giant cell tumor of the proximal humerus was treated with wide excision and shoulder arthrodesis. Patient 6 has implant site infection in his knee. Removal of the implant and debridement followed by bilateral free fibula transfer to obtain knee fusion were applied in this case. In patient 9, previous attempt of reconstruction of the distal femur with allograft interposition and intramedullary rod fixation, which was ended with infected nonunion knee stiffness. Osteoseptocutaneous vascularized fibula was used to replace the scar of the previous operation. Knee arthrodesis was added at the same session and a custom-made intramedullary rod was used for fixation. Staging studies included direct x-ray evaluation of the lesion, bone survey, MRI investigation of the lesion, bone scintigraphy, computed tomography of the chest, abdomen and pelvis.[17,18] In all patients preoperative angiographic evaluation of the tumor was performed. All anastomoses were performed using interrupted 9-0 or 10-0 nylon sutures. All patients were monitored for vital signs and flap viability (for osteoseptocutaneous flaps) intensively during the postoperative 3 days. Hemoglobin levels were kept above 9 g/ml. For the first 48 hours continuous heparin perfusion was given to all patients keeping the activated partial thromboplastin time between 1.5 to 2 times the normal. After the second day heparin perfusion was stopped and aspirin was administered 300 mg/day, until normal activities of daily living regained. In all patients ^{99m}Tc-methylene diphosphonate bone scintigraphy was performed within 4-5 days after surgery to evaluate the bone viability. In all specimens the surgeon specifically indicated the critical anatomic locations for pathologic studies of tumoral contamination. In patients 4, 7, 9, 11 and 13 both neoadjuvant and adjuvant chemotherapy were given, while in patient one only adjuvant chemotherapy was administered. After the patients discharged, they were followed up at outpatient clinics regularly. At the last follow-up visit functional assessments were performed. Overall satisfaction, use of analgesics, objective and subjective assessment of function according to Toronto extremity salvage score (TESS) were determined.[15]

Results. Macroscopic and microscopic evaluations of all specimens showed no contamination in the surgical bed. Two patients in this study group (patients 7 and 13; both with Ewing's sarcoma) had soft tissue and lung metastases before the reconstructive procedure. At the last follow up visit, there was no local recurrence or metastasis. ^{99m}Tc-methylene diphosphonate bone scan performed within 4-5 days after surgery was compatible with transferred vital bone in all patients. In 5 patients in which osteoseptocutaneous flap was used, viability of the overlying skin probably reflected the viability of the fibula. Signs of bony consolidation were evaluated radiologically with 2 months intervals with plain radiography. Differentiation of the cortex and medulla at the osteotomy site was accepted as the sign of consolidation. The average time to bony union was 4 months in the upper and 6 months in the lower extremity. Primary union was obtained in 11 patients (78%). Implant failures were developed in 4 patients. Revision with intramedullary rod exchange and autogenous grafting were needed in patients 8 and 9. In patient 11, plate and screws were replaced and autogenous grafting was carried out. The secondary treatment resulted in fusion. In patient 13, plate fracture was asymptomatic and there was no abnormal movement. No revision was carried out in this patient. Immobilization in a plaster cast for 2-3 months was applied for wrist and elbow arthrodesis. Shoulder, knee and ankle arthrodeses were not supported externally longer than 3 weeks. All 9 patients with upper extremity involvement resumed their activities of daily living within 2 months. Gait analysis revealed no abnormalities in this group. The study on the results of gait analysis using a hardware developed by the Department of Mechanical Engineering, Middle East Technical University following post-oncologic surgery reconstruction is underway and due to be published shortly. In patient 3, in whom ankle fusion was carried out with allograft, fibula and circular external fixation combination, postoperative course was uneventful and osseous consolidation developed very rapidly. Early partial weight bearing was allowed postoperatively. External fixator was removed at the 8th month.

Overall TESS score was 86% (range 70-97). Average TESS score for shoulder fusion was 87 (range, 86-89), wrist fusion 94 (range 89-97), knee fusion 76 (range 70-81), elbow fusion 83.5 (83-84) and ankle fusion was 97. Pain was not a limiting factor in none of the patients. Holding the arm over head was limited in shoulder arthrodesis group. The most difficult postoperative course was observed in patients with knee arthrodesis. Although partial weight bearing and self-ambulation were allowed as tolerated, the quality of life was not high these patients (17, 22, 31, 34) Going in and out of car was especially difficult for these patients. Six of 14 patients (43%) had complications; 5 require another surgical procedure. Running was impossible due to the stiffness of the big and second toes in patient 4. The result of the IP fusion and extensor shift was satisfactory for this patient. Patient 10 developed pseudomonas infection at the distal interlocking screw of the intramedullary rod at the 23rd postoperative month. Although débrided twice it was still draining. Internal fixation material was removed. From the time when the hardware removed no drainage was reported by the patient. In patients 8, 9 and 11 implant failed and needed to be changed. In patient 13, the implant failed but the stability of the fusion site was not affected.

Discussion. Reconstruction of the defects following oncologic orthopedic surgery is a challenging task. A limb worth saving needs an acceptable degree of function and cosmetic appearance with a minimal amount of pain. The method of reconstruction must be tailored to each individual patient. Grade of the tumor, the compartments contaminated, prognosis and the expected result of the oncologic treatment should be considered in surgical planning. Increasing success of chemotherapy makes long-term durability of the reconstruction. The basis of a limb salvage procedure is a complete excision of the tumor with a dissection through normal tissues to obtain an adequate margin, although what constitutes an adequate margin in any particular patient may remain controversial. Most of the malignant tumors of the musculoskeletal system are located adjacent to major joints. Patients with high-grade tumors may present with nearby joint invasion. When a joint is contaminated with a malignant tumor, all of its appendages and neighboring muscles, tendons and skin must be excised in order to obtain a safe surgical margin. For shoulder, aside from glenohumeral joint, most of the rotator cuff muscles are partly sacrificed. For the elbow, aside from the elbow joint, the origins of the flexor-pronator and extensor groups and the insertions of the elbow flexors are sacrificed. For the wrist, distal radio-ulnar joint and the proximal carpal raw are sacrificed if the radio-carpal joint is contaminated. For the knee, suprapatellar recess, the head of the fibula, the insertions of the hamstring muscles, the origins of collateral and cruciate ligaments are sacrificed.[19] Stability and function of implant arthroplasty is closely related to the condition of the soft tissues around the involved joint following surgical excision. The extension of the surgery is related to the dimensions and anatomic location of the tumor. In patient presenting with small tumors, a stable and functional implant arthroplasty may be possible and quality of life may be better in these patients. Implant arthroplasty has become the main procedure of limb salvage surgery, especially in the hip, knee, shoulder, and elbow joints.[20] In patients presenting with larger tumors, excision may include functionally vital structures such as big muscles and tendon groups. Soft tissue coverage may not be possible and the muscles necessary for the movement of the artificial joint may be lost following a wide excision. Relatively, faster mechanical wear of joint surfaces and modular parts of megaprotheses is the major disadvantage of prosthetic replacement following oncologic surgery. Reattachment of tendons and ligaments is often unsatisfactory and motor power and range of motion usually remains restricted.[21,22] In this difficult condition arthrodesis appears to be a viable alternative. Mostly, movements exerted by the involved joint disappear, there may be some advantages of this procedure. The risk of postoperative complications is probably lower with arthrodesis. There is no need to produce a custom made prosthesis. The need for custom-made prosthesis may sometimes delay the excision. The number of operations in the postoperative course is probably lower in arthrodesis. Implant arthroplasty and arthrodesis have their own advantages and disadvantages. Local and systemic conditions of the patient determine the most appropriate surgical procedure. Free vascularized fibula may be harvested in 3 major different methods. It may be dissected for bone reconstruction, or it may be dissected with its septocutaneous perforators and the skin overlying it. It may also be divided in the middle over the peroneal pedicle and a double barrel construct may be prepared. External support with external fixators and internal support with internal fixation materials or allografts may also be preferred depending on the planned reconstruction method. For upper extremity and in children younger than 10 years, in the reconstruction of the defects caused by extra-articular wide excisions, vascularized fibula transfer is probably the most effective treatment.[23] In the lower extremity and more for adults, combination of the fibula with an allograft is the most preferred approaches described by Capanna et al[13] In this method, early axial stability supported by allograft is combined with late biologic advantages of the vascularized bone. In the reconstruction of large osseous defects about a joint resulting from excision of a tumor, there are limited treatment options other than arthrodesis.[24] Patients who have wide extra-articular excisions may have deep infection, soft tissue defects and compromised circulation due to previous operations. Arthrodesis in the presence of a large periarticular defect may be more complicated due to infection and soft tissue defects. Reconstruction of the bony and associated soft tissue defect is usually necessary. As pointed out in the literature, the complication rate of vascularized fibula transfer is high.[23] Despite the major complications, overall result was reported to be satisfactory in previous publications.[25-26] In this small series of patients, fusion was achieved in all of the patients with relatively lower complication rate. Although technically demanding, the use of free vascularized fibula graft allows restoration of large periarticular defects, especially in the upper extremity.[27]

In conclusion, arthrodesis with vascularized fibula flap and its variants is a reliable reconstructive option in the reconstruction of extra-articular wide excision of malignant musculoskeletal tumors, with a 78% primary and 22% secondary fusion rate.

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References

1. Malizos KN, Zalavras CG, Soucacos PN, Beris AE, Urbaniak JR. Free vascularized fibular grafts for reconstruction of skeletal defects. ***J Am Acad Orthop Surg*** 2004; 5; 360-369.
2. Malawer M, Sugarbaker PH. Musculoskeletal Cancer Surgery: Treatment of Sarcoma and Allied Diseases. Dordrecht; Kluwer Academic Publishers. 2001.
3. Simon MA, Aschliman MA, Tomas N, Mankin HJ. Limb-salvage treatment versus amputation for osteosarcoma of the distal end of the femur. ***J Bone Joint Surg*** 1986; 68-A; 1331-1337.
4. Kropej D, Schiller C, Ritschl P, Salzer-Kunt M, Rainer K. The management of IIB osteosarcoma: Experience from 1976 to 1985. ***Clin Orthop*** 1991; 270; 40-44.
5. Capanna R, Morris HG, Campanacci D, Del Ben M, Campanacci M. Modular uncemented prosthetic reconstruction after resection of tumours of the distal femur. ***J Bone Joint Surg*** 1994; 76-B: 178-183,
6. Muschler GF, Ihara K, Lane JM, Healey JH, Levine MJ, Otis JC, et al. A custom distal femoral prosthesis for reconstruction of large defects following wide excision for sarcoma: results and prognostic factors. ***Orthopedics*** 1995; 18: 527-538.
7. Gebhardt MC, Flugsted DI, Springfield DS, Mankin HJ. The use of bone allografts for limb salvage in high-grade sarcomas. ***Clin Orthop*** 1991; 270: 181-196.
8. Zaretski A, Amir A, Meller I, Leshem D, Kollender Y, Barnea Y, et al. Free fibula long bone reconstruction in orthopedic oncology: a surgical algorithm for reconstructive options. ***Plast Reconstr Surg*** 2005; 113: 1989-2000.
9. McKee DM. Microvascular bone transplantation. ***Clin Plast Surg*** 1978; 5: 283-292.
10. Wei FC, Chen HC, Chuang CC, Noordhof MS. Fibula osteoseptocutaneous flap: anatomic study and clinical application. ***Plast Reconst Surg*** 1986; 78: 191-200.
11. Schusterman MA, Rees GP, Miller MJ, Harris S. The osteoseptocutaneous flap: Is the skin paddle reliable? ***Plast Reconst Surg*** 1992; 90: 787-793.
12. Ceruso M, Falcone C, Innocenti M, Delcroix L, Capanna R, Manfrini M. Skeletal reconstruction with a free vascularized fibula graft associated to bone allograft after resection of malignant bone tumor of limbs. ***Handchir Mikrochir Plast Chir*** 2001; 133: 277-282.
13. Capanna R, Bufalini C, Campanacci M. A new technique for reconstruction of large metadiaphyseal bone defects: A combined graft (allograft shell plus vascularized fibula). ***Operat Orthop Traumatol*** 1993; 2: 159-177.
14. Kocialkowski A, Wallace A, Harvey L. Fate of frozen intercalary allograft at one year after implantation with adjuvant chemotherapy treatment: A case report. ***Clin Orthop*** 1991; 272: 146-151.
15. Davis AM, Wright JG, Williams JI, Bombardier C, Griffin A, Bell RS. Development of a measure of physical function for patients with bone and soft tissue sarcoma. ***Qual Life Res*** 1996; 5: 508–516.
16. Clare DJ, Wirth MA, Groh GI, Rockwood Jr CA. Shoulder arthrodesis. ***J Bone Joint Surg*** 2001; 83-A: 593–600.
17. Massengill AD, Seeger LL, Eckardt JJ. The role of plain radiography, computed tomography, and magnetic resonance imaging in sarcoma evaluation. ***Hematol Oncol Clin North Am*** 1995; 9: 571-604.
18. Wolf RE, Enneking WF. The staging and surgery of musculoskeletal neoplasms. ***Orthop Clin North Am*** 1996; 27: 473-481.

19. Bozkurt M, Erkan Y, Atlihan D, Tekdemir I, Havitcioglu H, Gunal I. The proximal tibiofibular joint: an anatomical study. ***Clin Orthop*** 2003; 406: 136-140.
20. Kulkarni A, Fiorenza F, Grimer RJ, Carter SR, Tilmann RM. The results of endoprosthetic replacement for tumors of the distal humerus. ***J Bone Joint Surg*** 2003; 85-B: 240-243.
21. Malawer MM. Chapter 17. Distal femoral resection for sarcomas of bone. In: Sugarbaker PH, Malawer MM, editors. Musculoskeletal surgery for cancer. New York (NY): Thieme Medical Publishers. 1992. p. 243-259.
22. Malawer MM. Chapter 19. Limb-sparing surgery for malignant tumors of the proximal tibia. In: Sugarbaker PH, Malawer MM, editors. Musculoskeletal surgery for cancer. New York (NY): Thieme Medical Publishers. 1992. p. 270-281.
23. Fuchs B, O'Connor MI, Padgett DJ, Kaufman KR, Sim FH. Arthrodesis of the shoulder after tumor resection. ***Clin Orthop*** 2005; 436: 202-207.
24. Bishop AT, Wood MB, Sheetz KK. Arthrodesis of the ankle with a free vascularized autogenous bone graft. ***J Bone Joint Surg*** 1995; 77-A: 1867-1875.
25. Cierny G, Cook WG, Mader JT. Ankle arthrodesis in the presence of ongoing sepsis. Indications, methods, and results. ***Orthop Clin North Am*** 1989; 20: 1052-1062.
26. Wood BM, Cooney WP, Irons GB. Lower extremity salvage and reconstruction by free-tissue transfer. Analysis of results. ***Clin Orthop*** 1985; 201: 151-161.
27. Gao YH, Ketch LL, Eladoumikdachi F, Netscher DT. Upper limb salvage with microvascular bone transfer for major long-bone segmental tumor resections. ***Ann Plast Surg*** 2001; 47: 240-246.