ORTHOPAEDICS COURSE

Management of Great Vessels and Nerves in Limb-Salvage Surgery for Bone and Soft Tissue Tumors

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In recent years, limb-salvage surgery has gradually replaced amputations and become one of the main treatment strategies for patients with bone and soft tissue tumors of the extremities. The goals of tumor resection in limb-salvage surgery are to reduce the recurrence rate and preserve as much limb function as possible. However, depending on the size and specific location of the tumor, large neurovascular bundles may be involved. In addition, management of large nerves and vessels can make wide marginal resection more difficult. Sites where these problems commonly arise include the sciatic and tibial common peroneal nerve, artery and vein in the lower limbs.

Key words: Amputation; Bone and soft tissue tumors; Limb-salvage surgery

Introduction

Limb-salvage surgery has superseded amputation as the treatment of choice in patients with bone and soft tissue tumors of the extremities. One goal of tumor resection in limb-salvage surgery is to preserve as much limb function as possible. However, depending on the tumor size and location, large neurovascular bundles may be involved. Thus, management of large nerves and vessels can make adequate marginal resection difficult^{1,2}.

Resection and Reconstruction of Great Vessels

Incidence of Vascular Involvement in Tumors

Tumors of the extremities do not commonly invade the great blood vessels. However, limb-salvage surgery is difficult to perform and resection of the great vessels together with the whole tumor occurs in approximately 1% to 5% of patients with tumors of the extremities³⁻⁸. Faenza *et al.* reviewed 1650 patients with limb bone and soft tissue tumors who underwent limb-salvage surgery in the Rizzoli Hospital, Italy from 1990 to 2004; these patients included 650 with bone tumors and 1000

with soft tissue sarcomas. Of the patients with bone tumors, arteries had been resected in 10 (1.5%) and veins in 4 (0.6%), whereas of patients with soft tissue sarcomas, arteries had been resected in 32 (3%) and veins in 13 (1.3%)⁹. In a clinical trial by Schwarzbach *et al.*, of 213 adult patients who underwent limb-salvage surgery for lower limb soft tissue sarcomas, 20 arteries and 18 veins were resected in 21 (9.9%) patients¹⁰.

In the lower limbs, tumor invasion of the great blood vessels often occurs in the inguinal region, the medial region of the thigh (sartorius muscle) and the popliteal fossa, whereas in the upper limbs the most commonly involved sites are the supraclavicular, axillary and cubital fossas: in all these regions blood vessels are relatively unprotected from growing tumors and can therefore easily be invaded^{3,4}.

Schwarzbach *et al.* reported that lower-limb soft tissue sarcomas invaded the femoral vessels in 16 of 21 patients (76%) and the inguinal vessels in 5 of 21 patients (24%)¹⁰. Leggon *et al.* studied 92 patients with vascular reconstruction and limb-salvage surgery and reported vascular involvement in the thigh in 52 patients (56.5%), the external inguinal area in

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13 (14.1%), the popliteal fossa in 13 (14.1%) and the posterior tibial area in 8 (8.7%)¹¹. Nishinari *et al.* investigated 17 patients with bone and soft tissue tumors in their extremities and found vascular involvement in the thigh in seven patients, the inguinal region in four, the fibula in two, the femur in one, the popliteal fossa in one, the supraclavicular fossa in one and the cervical region in one¹². Spark *et al.* found that of nine patients with lower-limb chondrosarcomas who underwent limb-salvage surgery, the tumor involved the great vessels in the popliteal fossa in five patients and the inguinal region or the medial aspect of the thigh in four¹³.

Diagnosis and Type of Vascular Involvement

When tumors that either originate from or invade the great vessels are diagnosed, a careful history should be taken and physical examination performed to obtain information on limb swelling, deep venous thrombosis and nerve function. Imaging examinations, including colored Doppler ultrasound, computerized tomography (CT), magnetic resonance imaging (MRI), arteriography and phlebography are even more important. Colored Doppler ultrasound can provide information on the relationship between vessels and tumors and on any changes in the shape and blood flow of involved vessels. Digital subtraction angiography can clearly display anatomic changes in arteries and veins involved by tumor. In MRI, because tumors show low to moderate signals in the T₁-weighted phase and high signals in the T₂-weighted phase and blood clots show high signals and vascular walls low signals in the T₁-weighted phase, these structures can be easily distinguished. Contrast-enhanced CT and MRI can reveal the anatomic structures of arteries and veins in all three of the following phases: the arterial-venous mixed phase, early arterial phase and delayed venous phase. However, it should be noted that the findings of these imaging examinations should be analyzed together to accurately identify the degree of great vessel involvement and also which, if any, vascular substitutions can take place.

Great vessel involvement in sarcomas of the extremities has been classified into four categories, Types I to IV, by Schwarzbach *et al.*¹⁰; these researchers also suggested treatment strategies and principles for each type. Type I (artery and vein) involves tumor invasion of both the great arteries and veins. The involved arteries and veins should be resected together with the tumor; subsequent arterial reconstruction is required. The need for venous reconstruction depends on the amount of reflow in the remaining homolateral limb veins; if there is enough venous reflow, venous reconstruction is not required. Type II (artery only) involves tumor invasion of the arteries. The involved arteries should be resected together with the tumor; arterial reconstruction is required. Type III (vein only) involves resection of veins invaded by tumors. Venous reconstruction is required if there is not enough homolateral venous reflow in the affected limb. Type IV (neither artery nor vein) is when neither the artery nor the vein has been invaded by the tumor and adequate marginal resection can be achieved without vascular resection.

Survival and Recurrence Rates after Amputation of Tumors with Vascular Involvement

When a tumor has originated from arteries or veins, the corresponding vessels require resection. When there is a thin layer of normal tissue between the tumor and the vessels and the vessels are close to, but not surrounded by, the tumor, effective additional treatments, such as radiotherapy for soft tissue sarcoma and chemotherapy for osteosarcoma, should be used to eliminate satellite tumor cells in this layer. When a tumor is close to the vessels but only invading those vessels' aponeuroses (tumor barrier), continuity of the great vessels can be preserved by removing the tumor by subadventitial separation with a wide or local marginal resection¹⁴. However, separation of the great vessels' aponeuroses cannot be avoided and may damage the vessels. In the surgical treatment of bone tumors, such as juxtacortical osteosarcoma, osteogenic sarcoma and chondrosarcoma, and of hard soft tissue sarcomas, such as malignant fibrohistiocytoma, synovial sarcoma and desmoid tumor, mechanical damage to the vessels can injure the tunica intima, thereby causing thrombosis.

Fortner *et al.* proposed that subadventitial separation is acceptable for low grade tumors that have not invaded more than 50% of the involved great vessel's diameter¹⁵. Briefly, this technique is as follows. The adventitia of the involved vessel is separated starting on the side that is furthest away from the tumor, following which the interface is separated beneath the adventitia (like "page turning"); this allows complete vascular separation. Vascular branches completely invaded by tumor are cut and ligated at their origins from the great vessel and the adventitia is left in the "tumor bed" as barrier to the tumor. The vascular aponeurosis is removed with the tumor. All removed structures should be sectioned for histological examination to verify the absence of tumor cells. The fact that there are only five reported cases in which vascular separation with subadventitial separation has been employed; (described by Fortner *et al.*¹⁵ and Bonardelli *et al.*¹⁶) suggests that the indications for this technique are limited. Although this technique preserves vascular continuity, it is associated with a high risk of tumor contamination and it is difficult to guarantee appropriate marginal resection. Vascular resection and reconstruction is a safer approach when the great vessels are involved.

Previously, great vessel involvement was considered a contraindication to radical tumor resection without amputation because limb-salvage surgery could adversely affect local recurrence and long-term survival rates and result in perioperative complications in such cases. In recent years, the development of vascular resection and reconstruction techniques has made it possible for surgeons to achieve adequate marginal resection of tumors that are invading great vessels by performing limb-salvage surgery with vascular reconstruction. Leggon *et al.* described 92 patients who had undergone vascular reconstruction and limb-salvage surgery, including 75 previously published cases and 17 enrolled in a study¹¹. The surgery was successful in most (90%) of the 17 patients enrolled in their study: 76% retained functional limbs and 15% had local tumor recurrence. Tumor recurrence occurred

in 3% of patients who had undergone extensive resection and 20% of those who had undergone intracapsular resection. These results suggest that limb-salvage surgery for tumors with great vessel invasion is not associated with an increase in rate of local tumor recurrence. Williard *et al.* compared patients with great vessel involvement who underwent either amputation or limb-salvage surgery in combination with compartmentectomy and found the two groups had a similar long-term survival rate¹⁷. Karakousis *et al.* reported a 5-year survival rate of 28% in patients who underwent amputation and 52% in patients who underwent limb-salvage surgery, and a local recurrence rate of 0% in the amputees and 9% in patients whose limbs had been salvaged; the differences between the two groups were not statistically significant¹⁸. Hohenberger *et al.* found no difference in 5-year local recurrence and survival rates between tumors with or without great vessel involvement¹⁹. Thus, local recurrence survival rates were comparable for patients who underwent the limb-salvage surgery with or without vascular reconstruction.

Selection of Materials for Vascular Reconstruction

Various materials can be used for vascular grafting and reconstruction, including autogenic vessels (great saphenous, femoral, cephalic and jugular veins), allogeneic vessels (arteries and veins) and artificial blood vessels (polytetrafluoroethylene [PTFE] and Dacron). The contralateral great saphenous vein, which is the most commonly used material for vascular grafting, is very effective for reconstructing arteries and veins proximal and distal to the limb. The femoral vein can also be used to reconstruct blood vessels with large diameters. McKay *et al.* used the femoral vein to reconstruct a resected vein and reported that benefits of using this vein include that it is autogenic material, has a large diameter and has the ability to resist infection, torsion and clot formation²⁰. Schulman *et al.* investigated 42 patients undergoing vascular reconstruction using the femoral vein²¹. The patency rate in the first 2 years was higher for patients who underwent vascular reconstruction using the femoral vein than in those in whom the great saphenous vein was used: the 3-year patency rate was 80% for patients with femoral vein reconstruction and 67% for those with great saphenous vein reconstruction. However, the patency rate was low when the grafted vein was more than 1.3 cm in diameter or situated distal to the inguinal region; thus, use of large diameter femoral veins as reconstructive grafts should be avoided in the inguinal region²².

Artificial vessels can shorten the surgical time and prevent injuries and complications due to autogenic vessel sampling. Artificial vessels can also be used if no satisfactory autogenic vessel is available because of vascular disease, vessels having been cut or the vein to be reconstructed having too large a diameter. However, use of artificial vessels is associated with a high infection rate. In a study of 92 patients undergoing limb-salvage surgery with vascular reconstruction, the infection rate was 26% for artificial vessels, but only 3% for autogenic vessels⁹. Muramatsu *et al.* performed comprehensive sarcoma resection in combination with femoral

arterial reconstruction in 14 patients, 12 of whom received contralateral great saphenous vein grafts and 2 of whom received expanded PTFE grafts²³. They concluded that great saphenous vein grafts produced better outcomes than did prosthetic grafts. Bonardelli *et al.* suggested that the position of the vessel's distal stoma is the chief determinant for selection of arterial reconstruction material¹⁶. Autogenic and artificial vessels are both acceptable for reconstructing vessels in the iliofemoral and femoropopliteal areas proximal to the knee joint because of the large vessel diameters, whereas autogenic vessels are more suitable for vessel reconstruction distal to the knee joint because of their relatively small diameters.

Benefits of using allogeneic vessels include that they are easy to obtain, save time and can more easily be matched to the required vessel diameter; allogeneic vessels can be used as both arterial and venous grafts. Faenza *et al.* implanted seven allogeneic vessels (five arteries and two veins) obtained from a tissue bank into 16 patients undergoing arterial reconstruction, and implanted five allogeneic vessels (three veins and two arteries) obtained from a tissue bank into 13 patients undergoing venous reconstruction, with a low incidence of complications⁹.

Vascular Reconstruction

Arterial reconstruction is necessary after resecting a tumor and the corresponding great artery en bloc. If arterial reconstruction is not performed, the limb will become ischemic, resulting in a high amputation rate for this type of surgery. Thus, blood vessels should be reassessed during surgery. If vessels are determined to be either within the tumor or too close to the tumor to be spared, the vessel(s) and tumor should both be resected to ensure complete tumor removal. Following complete tumor resection, the arteries should be clamped and severed to reduce ischemic time and avoid venous stasis in the limb.

The long-term patency rate of arterial reconstruction is 60% to 100%, which is higher than that for venous reconstruction. Schwarzbach *et al.* recruited 21 patients undergoing tumor removal with vascular resection, nine of whom (43%) had vascular infiltration as determined by postoperative pathological examination¹⁰. Arterial resection and reconstructive surgery were performed in 20 patients, using the autogenic great saphenous vein as a graft in eight patients and artificial arterial grafts in twelve. Following reconstructive surgery, three patients (37.5%) with autogenic vein grafts and four (33.3%) with artificial arteries developed thrombi and were managed by arterial reconstruction and revision (two patients), reconstruction and replacement (three), surgical exploration (one), and conservative therapy (one) 16 months after surgery because of asymptomatic arterial occlusion. The 2-year and 5-year patency rates for reconstructed arteries were both 78.3%.

Nishinari *et al.* conducted a prospective follow-up study on 17 patients who underwent vascular reconstruction as a component of surgical management of tumors involving major limb vessels¹². Vascular reconstruction was performed in nine patients: simple arterial reconstruction in six and simple

venous reconstruction in two. Because infections are more likely to occur after artificial vascular reconstruction and the great saphenous vein and limb vessels were well matched in diameter, the contralateral great saphenous vein was used for arterial reconstruction in 12 of these patients, artificial vessels being used in only three of them. Those three patients received artificial vessels for the following reasons: one had an artificial vessel used to replace an end-to-side anastomosis outside a cervical-subclavian artery surgical field, one had previously had the great saphenous veins resected bilaterally and the in the third the great saphenous vein diameter was poorly matched. In one patient with no previous femoral or popliteal arterial obstruction, the grafted great saphenous vein ruptured because of a wound infection. The ruptured vessel was ligated, after which a good collateral circulation formed, possibly as a result of compensatory blood flow following graft ligation and healing of the incision. Considering that the collateral circulation had been resected prior to surgery and that this situation occurred in only one patient, these researchers advised that arterial stump ligation during tumor resection is dangerous even when a collateral circulation has formed prior to surgery.

Leggon *et al.* reported that 4 of 16 patients (25%) with vascular invasion who underwent limb-salvage surgery followed by vascular reconstruction developed thrombi; two of these underwent arterial reconstruction 5 days after surgery and resection of thrombus in the reconstructed vessel 3 months after surgery, one underwent limb amputation and one developed a posterior tibial arterial thrombus 5 months after surgery with no associated adverse effects¹¹. These authors also reviewed eight studies published from 1977 to 1996 that included 92 patients who had undergone vascular reconstruction and limb-salvage surgery; venous reconstruction had been performed in 9% of patients, arterial reconstruction in 36% and arterial and venous reconstruction in 55%. Among the patients who underwent vascular laboratory examinations, the long-term arterial and venous patency rates were 87% and 64%, respectively. Additionally, there were no significant differences between autogenic and artificial vessels in patency rate; which was 88% for arterial and 75% for venous artificial vessels and 83% for arterial and 56% for venous autogenic vessels. Vascular occlusion necessitating amputation occurred in 3% (3/92) of the patients.

Venous Reconstruction

Venous reconstruction following great vein resection remains controversial because some veins become occluded shortly after reconstruction. Fortner *et al.* advised that arteries and veins should be reconstructed following tumor and great vessel resection to avoid early severe intractable swelling¹⁵. McKay *et al.* resected both the tumor and the vein to achieve an acceptable negative resection margin in seven patients, of whom six underwent venous reconstruction²⁰. In one of these patients, the grafted vein became occluded but conservative therapy (anticoagulant therapy and compressive stockings) was implemented and deep venous thrombosis did not occur.

Schwarzbach *et al.* reported that 12 of 18 patients (66%) who underwent venous resection also underwent venous reconstruction; the reconstructed vein remained patent in seven of these patients (58.3%) and became occluded in five (41.7%). The 2-year and 5-year venous patency rates in these patients were both 54.9% and the average duration of venous thrombosis was 12 months¹⁰. Thrombi were not treated surgically or by invasive therapy, were generally well tolerated, and were asymptomatic. In a study by Faenza *et al.*, four patients whose bone tumors were resected underwent venous reconstruction (three with artificial vessels and one with an autogenic vein). Only one reconstructed vessel remained patent 3 months after surgery. Thirteen patients whose soft tissue sarcomas were resected also underwent venous reconstruction; two of these patients received artificial vessels and eleven biological materials (autogenic veins in six patients, allogeneic veins in three and allogeneic arteries in two)⁹. One of the patients who received artificial vessels developed an arterio-venous fistula and, in patients who had received autogenic or allogeneic grafts, only three vessels remained patent by 6 months after surgery. One of the latter patients developed a small pulmonary embolism.

Most patients who undergo vessel resection survive for more than five years. In patients who have not undergone venous reconstruction, blood flow congestion may appear several years after surgery. To assess the long-term outcomes of venous resection without vessel reconstruction, Matsushita *et al.* reviewed 13 patients with malignant limb or aggressive retroperitoneal tumors that had infiltrated the great vessels and required limb-salvage surgery with complete vessel resection²⁴. The surgeons had reconstructed these patients' great arteries but not their veins. All patients were followed up for an average of four years; ten patients survived beyond four years and completed the assessment. The patients developed severe swelling and intermittent venous claudication and, as a result, required compression stockings while walking. One patient complained of pain and pruritus in a pigmented area that appeared five years after surgery on the anteromedial leg; however, there was no ulcer formation. The above results were analyzed using short-term outcome data. However, long-term outcome data suggested that venous reconstruction should be evaluated individually for each patient. In conclusion, venous reconstruction depends on the venous return status prior to surgery bilaterally and on the residual venous return post-resection. Limb-salvage surgery for lower-limb tumors is associated with a high risk of chronic venous disease when the great arteries, veins, surrounding muscles, and other sources of collateral veins have been resected.

Resection and Reconstruction of Major Nerves

Sciatic Nerve

A current indication for amputation is multi-point involvement of major neurovascular bundles, also known as the "three kings", which include vessels, nerves and bone. Sciatic nerve

resection as a component of surgical management of soft tissue sarcoma was first reported in 1984²⁵; the theoretical basis for resecting the sciatic nerve was that wearing braces to support the foot and ankle that lacked sensation would result in better leg function than would hip disarticulation. Dorsi *et al.* reported removal of approximately 15 cm of the sciatic nerve proximal to the popliteal fossa because of tumor infiltration²⁶. Eight years after surgery, the patient was able to walk with an ankle-foot orthosis brace on the right leg. There was complete absence of tibial and peroneal sensory and motor nerve function below the knee. The patient had no neuropathic pain. Serial MRIs of the thigh had shown no evidence of local recurrence. There are many medical centers in which amputation is not performed even when the sciatic nerve is infiltrated by tumor, although such infiltration is usually an indication for resection²⁷.

Bickels *et al.* studied 15 patients with malignant tumors surrounding the sciatic nerve who underwent limb-salvage surgery with sciatic nerve resection²⁸. At the completion of follow-up, 14 of these patients were able to walk, seven with the assistance of a crutch or a cane, and only one required a wheelchair. Although all patients had complete loss of foot sensation, none developed pain, burning pain or skin ulcers in the affected limb and none required additional amputation. Postoperative function in the affected limb was dependent on the level of resection of the sciatic nerve: for the pelvic level it was excellent in four, less excellent in two and poor in two; for the buttock level it was less excellent in one; and for the thigh level it was less excellent in nine and less excellent in one. The motor branch that supplies the hamstring muscles branches off from the sciatic nerve quite high. Resection of the sciatic nerve inferior to this branch retains motor function of the hamstring muscles, thus allowing retention of extension and flexion of the knee joint. This explains why more desirable results, including retention of motor function, are obtained when the sciatic nerve is resected more inferiorly. Because short-term postoperative function was excellent in these patients, these authors suggested that complete tumor and sciatic nerve resection is not an indication for amputation, although amputation was previously considered necessary in patients requiring sciatic nerve resection.

Brooks *et al.* summarized the data of 1505 patients with lower-limb soft tissue sarcomas who had been treated at the Memorial Sloan Kettering Cancer Center and found that 18 (1.2%) had undergone sciatic, tibial or common peroneal nerve resection; 11 of these patients completely or partially completed postoperative assessment²⁹. None of these patients developed a skin ulcer on the denervated foot, only one needed a cane, and six needed to wear a brace. Overall, the patients had good mobility and quality of life. Fuchs *et al.* analyzed 20 patients with thigh tumors involving the sciatic nerves bilaterally. Ten of them had Toronto extremity salvage scores (TESS) of more than 74%, suggesting good postoperative function³⁰. One patient developed a recurrent foot ulcer and underwent amputation six years after the original surgery. Hence, although such limb-salvage surgery is associated with a high

level of postoperative function, patients should be informed preoperatively of the potential for functional loss following their surgery.

Nerve reconstruction prolongs the duration of surgery and there is no guarantee that function will be preserved; thus, the sciatic nerve should not be reconstructed after completion of the initial resection. Nevertheless, sciatic nerve preservation remains one important objective in limb-salvage surgery. Clarkson *et al.* used an epineural dissection technique to preserve the sciatic nerve when it was in close proximity to the tumor surface³¹. Of 43 patients with negative tumor margins analyzed, three (6.8%) had tumor recurrence. Comparison of 94 patients showed that the local recurrence rate and functional outcomes were comparable in patients who had undergone sciatic nerve dissection and in those who had undergone sciatic nerve resection; however, patients who had undergone sciatic nerve dissection had superior function. These authors suggest that the sciatic nerve should be resected when completely surrounded by tumor³¹.

Grafting of autogenic nerves is the gold standard for nerve reconstruction. Melendez *et al.* reported outcomes of autogenic nerve reconstruction following sciatic nerve and tumor resection³². Of 619 patients with lower-limb sarcoma, five with thigh tumors that required removal of the sciatic nerve underwent homolateral autogenic common peroneal reconstruction, in two of these five patients, the sural nerve was also used. The average length of the nerve defect was 13 cm and one to four nerve grafts were employed. The goal of sciatic nerve reconstruction is recovery of metatarsal sensation³². All five of the patients recovered metatarsal sensation, one patient recovering from 1/5 strephenopodia and regaining the ability to flex the toes. All patients were able to walk with the aid of an ankle joint brace.

Femoral Nerve

The femoral nerve originates from the lumbar plexus, passes through the deep inguinal ligament and travels lateral to the femoral artery. This nerve has multiple branches within a short distance. Femoral nerve stem resection induces quadriceps femoris paralysis, which affects the straightening motion of the knee joint and causes over-activity of the patella. The knee joint is still able to extend slightly because of the compensatory effect of the tensor muscle of the fascia lata.

To assess the clinical efficacy of complete femoral nerve resection, Jones *et al.* assessed 10 patients with tumors in the thigh, inguinal region, and pelvis who had undergone removal of the femoral nerve and tumor³³. During long-term follow-up, six of these ten patients developed eight fall-related fractures because loss of function in their legs had caused them to fall. By the final follow-up visit, six patients needed a crutch or cane to walk and five needed a knee brace. Jones *et al.* compared these six patients with nine who had undergone sciatic nerve resection at the thigh level and found no difference in TESS with femoral nerve resection³³. Results of this study suggest a better outcome than expected for patients who have undergone sciatic nerve resection and a poorer outcome

than expected for those who have undergone femoral nerve resection. It is important to protect metatarsal sensation, which is controlled by the sciatic nerve, in order to protect the foot and maintain its function. The cutaneous branch of the femoral nerve, which relays information about sensations in the anterior thigh and medial leg, can be sacrificed. However, outcomes induced by loss of motor control due to femoral nerve resection are worse than expected. Falling is a common complication of femoral nerve resection and can often cause fractures that require surgery. Most fractures occur after several months rather than in the early perioperative period, suggesting that the risk of falling increases over time.

Additionally, an important difference between bone and soft tissue tumors is that the bone defect following bone tumor resection is usually repaired by using an artificial joint prosthesis. The resulting slight over-extension at this joint increases the patient's standing stability when the knee joint is inactive. Hence, the tolerance for complete femoral nerve resection may be slightly better in patients who have undergone bone tumor resection and artificial joint replacement. Because of the difficulty walking and high incidence of fractures resulting from falls following femoral nerve resection, nerve reconstruction should be considered or the locations of the biceps femoris, semitendinosus and quadriceps femoris tendons shifted to redistribute the extension force at the knee joint.

References

1. Ghosh J, Bhowmick A, Baguneid M. Oncovascular surgery. *Eur J Surg Oncol*, 2011, 37: 1017–1024.
2. Yu XC, Xu M, Song RX, Xu SF. Marginal resection for osteosarcoma with effective preoperative chemotherapy. *Orthop Surg*, 2009, 1: 196–202.
3. Yu XC, Xu M, Song RX, Fu ZH, Liu XP. Long-term outcome of giant cell tumors of bone around the knee treated by en bloc resection of tumor and reconstruction with prosthesis. *Orthop Surg*, 2010, 2: 211–217.
4. Ghert MA, Davis AM, Griffin AM, et al. The surgical and functional outcome of limb-salvage surgery with vascular reconstruction for soft tissue sarcoma of the extremity. *Ann Surg Oncol*, 2005, 12: 1102–1110.
5. Ma XJ, Dong Y, Zhang CL, Zeng BF. Recurrence analysis in 66 cases with grade I and grade II chondrosarcomas in the extremities. *Orthop Surg*, 2009, 1: 132–136.
6. Sternheim A, Bickels J, Ben-Tov T, Malawer MM. Space sarcomas: extra compartmental soft tissue tumors of the lower extremities a systematic approach to sarcomas of the femoral triangle, sartorial canal, and popliteal space. *J Surg Oncol*, 2009, 99: 281–291.
7. Tsukushi S, Nishida Y, Sugiura H, Nakashima H, Ishiguro N. Results of limb-salvage surgery with vascular reconstruction for soft tissue sarcoma in the lower extremity: comparison between only arterial and arteriovenous reconstruction. *J Surg Oncol*, 2008, 97: 216–220.
8. Hu YC, Lun DX. Application of artificial prosthesis reconstruction techniques in malignant tumors around the knee joint. *Orthop Surg*, 2012, 4: 1–10.
9. Faenza A, Ferraro A, Gigli M, De Paolis M, Errani C, Mercuri M. Vascular homografts for vessel substitution in skeletal and soft tissue sarcomas of the limbs. *Transplant Proc*, 2005, 37: 2692–2693.
10. Schwarzbach MH, Hormann Y, Hinz U, et al. Results of limb-sparing surgery with vascular replacement for soft tissue sarcoma in the lower extremity. *J Vasc Surg*, 2005, 42: 88–97.
11. Leggon RE, Huber TS, Scarborough MT. Limb salvage surgery with vascular reconstruction. *Clin Orthop Relat Res*, 2001, 387: 207–216.
12. Nishinari K, Wolosker N, Yazbek G, et al. Vascular reconstruction in limbs associated with resection of tumors. *Ann Vasc Surg*, 2003, 17: 411–416.
13. Spark JI, Charalabidis P, Laws P, Seben R, Clayner M. Vascular reconstruction in lower limb musculoskeletal tumours. *ANZ J Surg*, 2009, 79: 619–623.
14. Wang Z, Guo Z, Li J, Li XD, Sang HX. Functional outcomes and complications of reconstruction of the proximal humerus after intra-articular tumor resection. *Orthop Surg*, 2010, 2: 19–26.
15. Fortner JG, Kim DK, Shiu MH. Limb-preserving vascular surgery for malignant tumors of the lower extremity. *Arch Surg*, 1977, 112: 391–394.
16. Bonardelli S, Nodari F, Maffei R, et al. Limb salvage in lower-extremity sarcomas and technical details about vascular reconstruction. *J Orthop Sci*, 2000, 5: 555–560.
17. Williard WC, Hajdu SI, Casper ES, Brennan MF. Comparison of amputation with limb-sparing operations for adult soft tissue sarcoma of the extremity. *Ann Surg*, 1992, 215: 269–275.
18. Karakousis CP, Karpaliotis C, Driscoll DL. Major vessel resection during limb-preserving surgery for soft tissue sarcomas. *World J Surg*, 1996, 20: 345–350.
19. Hohenberger P, Allenberg JR, Schlag PM, Reichardt P. Results of surgery and multimodal therapy for patients with soft tissue sarcoma invading to vascular structures. *Cancer*, 1999, 85: 396–408.
20. McKay A, Motamedi M, Temple W, Mack L, Moore R. Vascular reconstruction with the superficial femoral vein following major oncologic resection. *J Surg Oncol*, 2007, 96: 151–159.
21. Schulman ML, Badhey MR, Yatco R. Superficial femoral-popliteal veins and reversed saphenous veins as primary femoropopliteal bypass grafts: a randomized comparative study. *J Vasc Surg*, 1987, 6: 1–10.
22. Ghosh J, Naik J, Chandrasekar C, Yin Q, Vallabhaneni SR. Use of a superficial femoral artery autograft as a femoral vein replacement during en bloc sarcoma resection. *Vasc Endovascular Surg*, 2011, 45: 665–667.
23. Muramatsu K, Ihara K, Miyoshi T, Yoshida K, Taguchi T. Clinical outcome of limb-salvage surgery after wide resection of sarcoma and femoral vessel reconstruction. *Ann Vasc Surg*, 2011, 25: 1070–1077.
24. Matsushita M, Kuzuya A, Mano N, et al. Sequelae after limb-sparing surgery with major vascular resection for tumor of the lower extremity. *J Vasc Surg*, 2001, 33: 694–699.
25. Nambisan RN, Rao U, Moore R, Karakousis CP. Malignant soft tissue tumors of nerve sheath origin. *J Surg Oncol*, 1984, 25: 268–272.
26. Dorsi MJ, Zwagil ZS, Hsu W, Belzberg AJ. Epithelioid sarcoma of the tibial portion of the sciatic nerve. *Clin Neurol Neurosurg*, 2011, 113: 506–508.
27. Brennan MF. Soft tissue sarcoma involving the sciatic nerve. *Br J Surg*, 2000, 87: 983.
28. Bickels J, Wittig JC, Kollender Y, Kellar-Graney K, Malawer MM, Meller I. Sciatic nerve resection: is that truly an indication for amputation? *Clin Orthop Relat Res*, 2002, 399: 201–204.
29. Brooks AD, Gold JS, Graham D, et al. Resection of the sciatic, peroneal, or tibial nerves: assessment of functional status. *Ann Surg Oncol*, 2002, 9: 41–47.
30. Fuchs B, Davis AM, Wunder JS, et al. Sciatic nerve resection in the thigh: a functional evaluation. *Clin Orthop Relat Res*, 2001, 382: 34–41.
31. Clarkson PW, Griffin AM, Catton CN, et al. Epineural dissection is a safe technique that facilitates limb salvage surgery. *Clin Orthop Relat Res*, 2005, 438: 92–96.
32. Melendez M, Brandt K, Evans GR. Sciatic nerve reconstruction: limb preservation after sarcoma resection. *Ann Plast Surg*, 2001, 46: 375–381.
33. Jones KB, Ferguson PC, Dehesi B, et al. Complete femoral nerve resection with soft tissue sarcoma: functional outcomes. *Ann Surg Oncol*, 2010, 17: 401–406.