Review

Intercalary segmental reconstruction after bone tumor resection

B. Fuchs a,*, C. Ossendorf a, T. Leerapun b, F.H. Sim b

a Department of Orthopedics, Balgrist University Hospital, Forchstrasse 340, 8008 Zurich, ZH, Switzerland
b Department of Orthopedics, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA

Accepted 27 November 2007
Available online 11 January 2008

Abstract

Background/aims: Intercalary resection can be used for primary as well as metastatic tumors. Reconstruction options include vascularized fibula graft, interposition of an allograft, combination of vascularized fibula and allograft, segmental prosthesis, insertion of an extracorporeally irradiated autograft, segmental transportation, either with external fixation or by using an intramedullary rod, intercalary scaffolds augmented with growth factors, and technical refinements for the resection of tumors located close to the growth plate. The purpose of this review is to discuss the indications, limitations and pitfalls of each of these techniques.

Methods: The PubMed database was searched for articles on intercalary reconstruction after bone tumor resection and for the different reconstruction options presented in this review. Additionally, cross-referencing was used to cover articles eventually undetected by the respective search strategies. The resulting articles were then reviewed with regard to the different techniques, outcomes and complications of the reconstruction options.

Results: With the advance of imaging techniques and the use of chemotherapy for malignant bone tumors, surgical techniques can be refined. There are many techniques for the reconstruction of large intercalary defects of long bones, with which the orthopedic oncologist needs to be familiar. General oncologic principles of achieving a wide margin still need to be respected.

Conclusion: The techniques presented in this review will allow a better functional outcome of patients. It will continue to be important to carefully analyze each patient’s situation and to adapt and individualize the method of reconstruction used.

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Tumor resection; Bone defect; Intercalary; Segmental; Vascularized fibula; Allograft; Tumor prosthesis; Extracorporeal irradiation; Segmental transport

Introduction

Bone tumor therapy comprises an interdisciplinary, multimodal approach, with surgical resection, irradiation, systemic and local chemotherapy, including isolated limb perfusion therapy. In this context, surgery is the mainstay of bone tumor treatment of localized and metastatic disease, and for reconstruction. Because limb-salvage techniques do not compromise the long-term survival of patients with bone sarcoma of the extremity compared to traditional amputation,1 limb-salvage surgery is performed in 80—90% of patients with malignant bone tumors.2 A major concept in orthopedic oncology therefore is avoiding amputation without compromising cancer surgery principles. Accurate preoperative assessment of the extent of an intramedullary tumor is crucial when a limb-salvage procedure is being considered.3 Although many bone tumors are close to or involve a joint, diaphyseal, meta-diaphyseal or intraepiphyseal location is not infrequent for primary as well as metastatic disease. Intercalary resection of the femur, tibia, and humerus is particularly challenging. If an adjacent joint can be preserved, the expected function is superior; however, this requires stable reconstruction with secure fixation. Intercalary resection can be used for primary as well as metastatic tumors with a reported 10-year survival rate of 75—89%,4,5 as long as oncological principles apply. The indications for femur, tibia, and humerus reconstructions vary greatly depending on the anatomic extent and need to be individualized for each patient’s situation.

* Corresponding author. Tel.: +41 44 386 16 63; fax: +41 44 386 16 69.
E-mail address: bfuchs@research.balgrist.ch (B. Fuchs).
When an intercalary bone resection is performed, the reconstruction options include (1) a vascularized fibula graft alone or double-barreled, (2) the interposition of an allograft, (3) the combination of vascularized fibula and allograft, (4) a segmental prosthesis, (5) the insertion of an extracorporeally irradiated autograft, (6) segmental transport either with external fixation or by using an intramedullary rod, (7) innovative techniques using intercalary scaffolds augmented with growth factors (tissue engineering techniques), and (8) technical refinements for the resection of tumors located close to the growth plate. For tumors with intraepiphyseal location and those tumors close to the growth plates of patients with immature skeleton, both Capanna and Canadell have refined the technique of reconstructions for intercalary defects. The purpose of this review is to discuss the indications, techniques, limitations and problems of each of these techniques.

Vascularized fibular graft

Vascularized autogenous grafts for long bone reconstruction after tumor resection were first described in the late 1970s. Since then, the fibular-free flap has become very popular for limb sparing surgery after tumor resection. This flap is used in three major types of reconstructive combinations, whereas the surgeon can use the assistance of an algorithm to select the preferred method of reconstruction: vascularized fibular flap as a sole bone replacement; vascularized double-barreled fibula; and vascularized fibula flap combined with an allograft (discussed later). The main advantage of such a reconstruction includes the improved biological properties due to its independent vascularity and short fusion time. In case a longer pedicle and more volume to fill a defect is needed, an osteocutaneous flap can be combined with an omental flap. Large intercalary resections can be easily bridged with such a vascularized fibula flap. However, the fibula is narrow and weaker than the originally resected long bone, especially the femur. To functionally replace a fibular graft, a long period of non-weight-bearing is necessary. During this period, the osteotomy sites will unite and a longer period will elapse for the fibula to undergo hypertrophy through processes of pressure transport, microfractures, and callous formation. Single vascularized fibula flaps are therefore mainly used for intercalary reconstructions of the humerus. However, although bony union is achieved in the majority of cases, the fracture rate of this graft even in the upper non-weight-bearing extremity is more than 30–50%. As an alternative, a free double-barreled fibula flap can be chosen for a resection site with intermediate stress loads. This provides a strong and stable reconstruction by transferring twice the volume of a fibular bone to a given length of defect without increasing the number of microvascular anastomosis. A double-barreled fibula flap may be indicated for intercalary resection of the femur or the pelvis. When augmented with a stable osteosynthesis bridging the whole defect, it may result in a durable construct.

Intercalary allograft reconstruction

The introduction of intercalary allografts for the reconstruction of large segmental defects was an important innovation. The allograft enables the repair of long osseous defects while maintaining native bone stock, potentially without a durable reconstruction. Ortiz-Cruz et al. in the largest series on intercalary allografts to date comprising 104 allograft procedures, concluded that the transplantation of allografts for the treatment of intercalary defects has a high rate of success and usually results in a functional limb. Allografts can survive for decades, but intercalary allografts seem to have the best record. However, the complication rate is considerable and usually occurs within the first 3–4 years, whereas after that the graft appears to become a relatively competent, stable system. Current technical advances to minimize nonunion include improved fixation of the allograft to the host bone with locked compression plates and stronger intramedullary devices. The chances of bone resorption and immunologic reactions can be lessened by careful tissue matching and allograft processing. Conversely, allograft failures are mostly related to local recurrences, allograft infections, fractures and nonunions. Ortiz-Cruz et al. found a 12% incidence of infection in their series. In another multicenter study, a 14% incidence of infection in 113 patients was found. The reported prevalence of allograft fractures has ranged from 9 to 19%, whereby this increased incidence was reported in relation to screw holes, suggesting that allografts are very sensitive to stress-concentrating defects. Therefore, by spanning the entire allograft with a long plate to provide extracortical support may further diminish fracture risk. The incidence of allograft host junction nonunion is considered to be between 17 and 50%. Hornicek et al. suggested that in patients who received chemotherapy, the nonunion rate is higher than in patients who did not receive adjuvant therapy. Others analyzed the effect of internal fixation on healing of large allografts. In one study, there was no significant difference between the rate of nonunion after fixation with a plate and after intramedullary fixation, whereas others found that patients having plate fixation had a lower number of nonunions (22 vs. 8%). Gerrand et al. suggested to fill the entire intramedullary canal with pressurized cement in addition to using plates to span the entire length of the allograft. They had no fracture in 27 intercalary allografts. In addition, they supplement the allograft host junction with cancellous autograft to maximize the potential for union at the first procedure which, however, is still more than 17%. Moore et al. combined an intercalary allograft and retrograde intramedullary fixation for the treatment of distal intra-articular tibial tumors and reported outcomes similar to previously published techniques.
Combined fibula allograft reconstruction

Both allograft and vascularized fibula reconstruction for segmental defects are associated with specific complications when used alone. Vascularized fibula transfer in combination with an allograft for segmental defects immediately after bone resection has also been advocated. For using an allograft with a vascularized bone flap is to combine the mechanical strength of the allograft with the biological activity of the vascularized bone flap. Also, the vascularized bone flap facilitates the host allograft to union at the level of the osteotomy. It has been reported that the bone flap will undergo progressive hypertrophy and osteointegration with the allograft, perhaps, using revascularization of the allograft’s intercalary segment. The vascularized fibula can be assembled with the allograft using either an intramedullary or an on-lay technique. The intramedullary technique is considered for femur and tibia reconstructions, where the vascularized fibula is inserted through a trochanter opened up in the anterolateral cortex of the allograft. Damaging the flap pedicle while inserting into the allograft has to be avoided, and the edges as well as any sharp bone spurs need to be eliminated. Ideally, the length of the vascularized fibula needs to be 5 cm longer than the segmental defect, so that at least 2 cm of vascularized bone can be inserted into both host ends. If the intramedullary canal of the allograft does not allow a fibula to be inserted, the on-lay technique may be considered, which may be more easily performed in the femur than in the tibia because of soft tissue coverage. Due to the irregular contour of the allograft and the host bone, optimal bone-to-bone contact may not be achieved with the on-lay technique. Thus, the intramedullary technique is preferred over the on-lay technique.

Segmental prosthesis

A segmental prosthesis to reconstruct an intercalary defect is far less popular than other methods, but it was described for primary tumors as well as metastatic disease. The indications for its use include metastatic disease, myeloma, or lymphoma in patients with severe pain or instability. Adequate cortical bone stock subsequent to resection is required to circumferentially accept the seating portion of the body of the prosthesis at each end of the bond. Approximately 5 cm of intramedullary canal must remain at each end to accept a standard stem. The longer the stem, the more stress shielding of the surrounding bone will occur, resulting in a higher risk of aseptic loosening. In patients with limited life expectancy, the use of a segmental prosthesis as opposed to the locked intramedullary nail in segmentally destroyed humera is indicated, because of the need for immediate stability by cementation, without having to wait for healing. The biomechanical analysis of a prosthetic intercalary spacer, intercalary allograft and a locked humeral nail combined with methyl methacrylate was performed with low risk of mechanical failure. It was found that reconstruction with a prosthetic intercalary spacer provides significantly greater immediate stability than interlocked intramedullary nail fixation supplemented with cementation or intercalary allograft reconstruction. Alternatively, the cementation technique, extracortical bone bridging and ingrowth fixation with a porous coating over the shoulder region of the implant, and augmentation by autogenous bone grafting were used for inter- or segmental reconstructions of long bones after primary tumor resection. Osteointegration was satisfactory, and there were no complications in five patients at the mean follow-up of 16 years.

Extracorporally irradiated autograft

In Asian countries, the concept of bone donation is not widely accepted, therefore pasteurized or irradiated autogenous bone graft are commonly used as an alternative to allograft. The advantages of such autografts for large defects are ease of procurement, absence of problems which are associated with storage and obtaining grafts of suitable dimensions, ensured stability, and probable avoidance of an immunological response. The optimal dose of irradiation will need to be determined. Uyttendaele et al. irradiated the resected specimen with a dosage of 30,000 rads and reported only one recurrence. The disadvantage of autoclaved bone is that it takes a long time for it to revascularize and incorporate into surrounding bone, and that the bone itself is bridle. Interestingly, bone-inducing activity can be reasonably preserved despite heat-treatment, although this finding is temperature dependent. The complication rate is up to 52%. Potential complications include nonunion, fracture, infection, bone resorption, and necrosis of the graft. The nonunion rate was 4–32%, the fracture rate varied between 10 and 17%, whereas the infection rate was 0–29%. The risk of bone resorption has been reported with 8%. Necrosis of the graft was reported in a single case. Rate of integration of the graft was between 50 and 86%. Taken together, the risks and complications of extracorporally irradiated autografts are comparable to other reports of intercalary reconstruction allografts.

Segmental transport

Tsuchiya et al. introduced limb-salvage surgery using distraction osteogenesis for 19 patients with skeletal tumors. They proposed three methods of reconstruction: I: conventional bone transport, II: shortening distraction, and III: bone transport after insertion of a bone cylinder obtained from the diaphysis combined with bone grafts to reconstruct the segmental bone defect. Intramedullary nailing was used as the initial fixation in patients operated on by method II. External fixator and early weight bearing was used in methods I and III, when after completion of bone
transport, delayed intramedullary nailing replaced external fixation. Gradual distraction starts 1—2 weeks after the operation at a rate of 1 mm per day. In Tsuchiya’s experience, the segmental defect should not exceed 15 cm. Distrac-
tion osteogenesis was shown to regenerate living bone to sufficient strength and, being biological, it can be expected to remain permanent once it is found. This seems to be true even in the case when chemotherapy needs to be administered. Jarka et al. as well as Subasi et al. analyzed the effects of methotrexate, doxorubicine, cyclophospha-
die and dactinomicine on distraction osteogenesis and found no adverse effects on bone forming. Interestingly, Minematsu et al. showed that whereas chemotherapy decreased the regional blood-flow to the area of the tumor, distraction osteogenesis kept the regional blood-flow within the normal range or higher.

Tissue engineering strategies

Tissue engineering strategies for bone regeneration offer an alternative strategy of healing segmental bone defects by utilizing the body’s natural biological response to tissue damage in conjunction with engineering principles. Osteo-
cenic cells, growth factors, and biomaterial scaffolds form the foundation of numerous bone tissue engineering strategies. An ideal biomaterial scaffold provides mechanical support locally and, in addition, delivers growth factors such as BMPs and cells into the defect to support tissue growth. Ideally, the biomaterial degrades in a controlled manner without causing loss of mechanical support and a significant inflammatory response. However, further pre-clinical and clinical work is necessary to establish the safety of these implants before they are adopted for wide-
spread clinical use.

Technical refinements for the resection of tumors located close to the growth plate

In children and adolescents, malignant bone tumors are located close to the growth plate in 75% of cases. Although the growth plate may represent a barrier, vascular reaction induces early calcification and the growth plate is tres-
passed by the tumor in up to 84% of cases. MRI has proven to be very reliable in detecting physeal or ephi-
physeal involvement by the tumor. For this reason, Canadell et al. described a physeal distraction at the epiphyseal plate adjacent to the tumor followed by tumoral resection and di-
aphyseal osteotomy. This technique is not a lengthening procedure, but a simple ephyseolysis, where the growth plate is broken through the degenerative layers of cells. The majority of the growth plate remains together with the epiphysis. The functional results are very good and lo-
cal recurrences are not seen. Alternatively, or in case when the tumor trespasses the growth plate, intraepiphyseal re-
section can be performed. Capanna first described the tech-
nique of intraepiphyseal intercalary resection leaving an epiphyseal bone segment that measured 2 cm in thickness. Even a segment of 5 mm thickness may survive and grow to the end of skeletal maturity, although the distal part of the epiphysis including the entire growth plate is surgically re-
oved. The reconstructed epiphysis may still grow and increase in size. Reconstruction is performed using a vascu-
larized fibula autograft in combination with a massive bone allograft. The proximal epiphyseal osteosynthesis is fixed by small fragment screws. Limb length discrepancy was no greater than 3.5 cm, and the recurrence rate is compar-
able to other reconstructive methods.

Conclusion

With the advance of imaging techniques and the use of chemotherapy for malignant bone tumors, surgical tech-
niques can be refined. There are many techniques for the reconstruction of large intercalary defects of long 

bones, with which the orthopedic oncologist needs to be familiar. General oncologic principles of achieving a wide margin still need to be respected; however, these improved techniques will allow a better functional out-
come of patients treated for such a disease. It will con-
tinue to be important to carefully analyze each patient’s 
situation and to adapt and individualize the method of re-
construction used.

Conflict of interest

The authors have no conflict of interest.

References


23. Cara JA, Lacleriga A, Canadell J. Intercalary bone allografts. 23


