The Use of Free Vascularized Fibular Grafts for Reconstruction of Segmental Bone Defects

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BACKGROUND

- Wide resection of long-bone tumors can create a large intercalary bone defect requiring reconstruction. Such defects were traditionally reconstructed with prosthetic implants, allografts, and allograft-prosthetic composites, all of which were associated with considerably high rates of complications and failure.1
- Distraction osteogenesis provides biologic reconstruction of only small to medium intercalary defects. Moreover, it is a prolonged procedure, requiring up to 2 months for an elongation of 1 cm, complications are frequent, patient compliance is critical, and large soft tissue defects cannot be addressed simultaneously.6,12 Reported experience regarding safety and efficacy in the oncologic setting is also limited.
- Since the introduction of vascularized autogenous graft for long-bone reconstruction after tumor resection in the early 1970s, the use of a free fibular flap has become a viable option for reconstructing large intercalary bone defects after tumor resection or for resection-arthrodesis.3,4,6,9–11,13,14 Its inherent advantage is based on its ability to exploit the biology of normal fracture healing rather than the creeping substitution that is fundamental to the incorporation of a nonvascularized graft.
- The fibula is an optimal vascularized graft source because of its anatomic accessibility and because removing an intercalary segment while preserving the proximal fibula and lateral malleolus would have minimal impact on knee and ankle stability and would not compromise the weight-bearing capacity and overall function of the lower extremity. It allows reconstruction of large bone defects because of its independent blood supply, which permits graft incorporation into the host bone even when the presence or viability of the surrounding soft tissue is considerably compromised because of previous surgery or radiation therapy.
- The fibular head can also be used for joint reconstruction after intracalary resection of bone tumors. Furthermore, a vascularized fibular graft has the ability to hypertrophy over time in response to continuous pressure load. As a result, vascularized fibula have shown excellent long-term durability.2,9,15
- In summary, a free fibular graft provides a durable true biologic reconstruction with accommodative and regeneration capabilities and has minimal short- and long-term complications.15 It requires a combined effort of highly trained and committed teams as well as the patient’s compliance throughout a very long, complex, and demanding rehabilitation period.

ANATOMY

- The fibula is long and narrow and therefore provides a strong cortical strut for reconstruction of long-bone defects. It has a square cross-section in its superior part and is triangular in its inferior end. In the adult, it can reach a width of 1.5 to 2 cm and a length of 35 cm, 25 to 30 cm of which can be harvested for free grafting. Its shape and length can match bone segments of the upper extremity (humerus, radius, and ulna) or can fit the medullary canal of bones of the lower extremity (femur, tibia); it therefore can be used to reconstruct bone defects at these sites.
- The fibula is circumferentially surrounded by muscle groups on its lateral, anteromedial, and posterior aspects and is also the origin of the four intermuscular septa of the leg. The blood supply and drainage of the fibular shaft are related to the peroneal vessels. The peroneal artery, together with the two peroneal venae comitantes, follow a course parallel to the fibula and lie between the flexor hallucis longus and tibialis posterior muscles (FIG 1A). The fibula is dually vascularized through its endosteal and periosteal vessels.
- The endosteal blood supply is based on the nutrient artery, which stems 6 to 14 cm from the peroneal artery bifurcation, enters the middle third of the diaphysis via the nutrient foramen, and then divides into an ascending and a descending branch. The periosteal blood supply is derived from eight or nine periosteal branches, mostly in the middle third of the diaphysis. The peroneal artery is also the source of four to six fascial vessels that pass through the posterior intercrural septum to the skin territory, lateral to the fibula. It provides numerous muscular branches as well: specifically, it supplies multiple small branches to the muscles of the anterior compartment and a few larger branches to the soleus muscle at the deep posterior compartment of the leg.
- The unique morphologic characteristics and blood supply of the fibula allow considerable versatility in the use of the fibular flap for reconstruction of skeletal, soft tissue, and growth plate defects. The fibular flap can be transferred in various configurations and compositions to suit the needs of individual cases:
  - In its straight configuration, it can be used to reconstruct a relatively narrow bone segment (FIG 1B). A longitudinal osteotomy that increases the surface area of the flap can serve as an onlay graft to augment the healing process for partial cortical defects. Based on perforating fasciocutaneous branches at the middle and distal thirds of the pedicle, a skin paddle of up to $20 \times 10$ cm can be transferred simultaneously to facilitate coverage of concomitant large soft tissue defects and to allow the patency of the pedicle anastomosis to be monitored (FIG 1C–G). Part of the soleus or the flexor hallucis longus muscles can also be included with the flap to reconstruct soft tissue defects and cover exposed bone.
The blood supply and drainage of the fibula are related to the peroneal artery and two peroneal veins, which follow a course parallel to the fibula. The fibula has a dual blood supply: endosteal and periosteal. The former is based on a nutrient artery that stems 6 to 14 cm from the peroneal bifurcation; the latter is based on multiple periosteal branches along the fibular diaphysis.

A diaphyseal fibular graft used to reconstruct intercalary bone defects. If a long segment is required and the osteotomy is close to the lateral malleolus, screw fixation to the tibia is advised to prevent valgus deformity and ankle instability. A skin paddle can be transferred simultaneously to facilitate coverage of concomitant large soft tissue defects and to allow patency of the pedicle anastomosis to be monitored. A proximal fibular graft that includes the proximal fibular epiphysis and is based on the anterior tibial vascular pedicle may be used for joint reconstruction and preservation of longitudinal growth in children after intra-articular resection of bone tumors.
Transverse osteotomies can be made through the mid-diaphysis to produce two or more cortical struts on a single pedicle (double or triple barrel) to reconstruct a wide bone segment. When the periosteal vessels are transected, the bone survives on its endosteal system.

The proximal epiphysis may be included in the flap for joint reconstruction and preservation of longitudinal growth potential (in pediatric patients) after intra-articular resection of bone tumors. This flap is based on the anterior tibial vascular flap or the descending geniculate artery and is most commonly used for reconstructions after resections of the proximal humerus and distal radius.

**INDICATIONS**
- Segmental bone defects larger than 5 cm after resection due to tumor, radiation-induced bone necrosis, or osteomyelitis
- In high-grade sarcomas of bone, we generally use spacers for immediate reconstruction after tumor resection rather than performing the definitive reconstruction with vascularized fibula. The latter is carried out 2 years after tumor resection if there has been no tumor recurrence or lung metastases.

**CONTRAINDICATIONS**
- Systemic and General Conditions
  - Cardiovascular, surgical, or hematologic diseases that may affect peripheral blood flow
  - Poor compliance, or if the patient’s physical or psychological state would not allow a prolonged non-weight-bearing period and rehabilitation
  - Poor general health
- Donor Site Considerations
  - Fibular deformity after previous injury to the lower extremity
  - Vascular injury or compromise after previous trauma to the leg
  - Vascular anomalies of the leg or plantar arches (eg, single-vessel foot)
- Recipient Site Considerations
  - Infection around the recipient site
  - Suspected tumor recurrence

**IMAGING AND OTHER STAGING STUDIES**
- Detailed preoperative evaluation of both the recipient and donor sites is mandatory. Imaging of the recipient site should provide information about the dimensions of bone (length and diameter) and soft tissue defects remaining after tumor resection, thus allowing the selection of the appropriate type and size of fibular flap to be used. Imaging of the donor site should include the entire leg and is aimed at excluding fibular deformity and determining maximal flap length. The surgeon should verify adequate pulses in both posterior tibial and dorsalis pedis arteries.
- The deep and superficial plantar vascular arches are evaluated using an equivalent to the palmar Allen’s test, confirmed by Doppler ultrasound examination. If those studies are inconclusive, angiography or magnetic resonance angiography is performed.

**Recipient Site**
- Plain radiography
- Computed tomography (CT)
- Magnetic resonance imaging (MRI)

**Donor Site**
- Plain radiography
- Magnetic resonance angiography
- Angiography
- Doppler ultrasound

**SURGICAL MANAGEMENT**

**Positioning**
- For treating a bone defect of the lower extremity, the patient is placed supine on the operating table with the thighs spread. The hip and knee of the donor extremity are flexed. The first team, which is responsible for tumor resection (blue team), is positioned along the medial or lateral side of the recipient extremity. If tumor resection is done from the medial side of the extremity, a surgeon can be positioned at that aspect. A second (red) team, responsible for the harvest of the fibular flap from the donor extremity, is positioned along its lateral aspect (Fig 2).
To minimize the duration of surgery, if the patient’s position on the operating table permits, the fibular flap is harvested as the recipient site is being prepared, a procedure that may include resection of the primary bone tumor or removal of a spacer that had been used in a previous surgery for reconstructive purposes.

As a rule, a vascularized fibula in its straight and simple configuration is sufficient for reconstructing bone defects of the upper extremity because of the relatively narrow cross-sectional diameter of the latter. Reconstruction of such defects of the lower extremity requires graft material of a larger diameter because of the additional mechanical support needed. A double-barrel fibular flap can be used to reconstruct femoral and tibial defects of up to 13 cm.

Longer defects may require the support of an allograft, which provides the initial stability required for bone healing, graft incorporation, and subsequent fibular hypertrophy. Furthermore, in cases of failed vascular anastomosis, the combined fibular–allograft construct is still comparable to multiple cortical allogenic struts with a relatively good chance of success, especially if reliable fixation is achieved.

The technique of combined reconstruction with an allograft and the vascularized fibula, as described by Capanna and colleagues, provides such stability and is the preferred method of reconstruction that we use for long intercalary defects of the lower extremities.1,2

### INTERCALARY RESECTIONS

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### RESECTION OF BONE TUMOR

- The bone tumor is removed according to the standard techniques, and the length and diameter of the intercalary bone defect are measured (TECH FIG 1).

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**TECH FIG 1** • A. Diaphyseal tumor is resected with wide margins, leaving a long intercalary bone defect. B. Plain radiograph of the tibia showing a large diaphyseal low-grade osteosarcoma. C. Intraoperative photograph of the tumor. D. Large intercalary defect remaining after wide tumor resection. E. Plain radiograph of the arm showing considerable bone loss and pathologic fracture associated with acute osteomyelitis of the humeral diaphysis. F. After tissue sampling and cultures, administration of intravenous antibiotics, and resolution of acute manifestations of infection, the patient underwent resection of the infected bone tissue, leaving a long intercalary bone defect.
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**TECHNIQUES**

**HARVEST OF A FIBULAR FLAP**
- Using an anterolateral incision at the contralateral leg, an intercalary fibular segment that is 6 cm longer than the bone defect is harvested, together with its nutrient vessels and its periosteal cuff (TECH FIG 2A,B). If a large skin defect is anticipated at the tumor resection site, the fibular flap is harvested with an overlying skin island supplied by the same peroneal artery, which allows tension-free skin closure as well as early detection of compromised viability of the flap: arterial or venous compromise would instantly be expressed by ischemic or congestive changes of the skin island (TECH FIG 2C).
- If a long bony segment is required and the osteotomy is close to the lateral malleolus, screw fixation to the tibia is advised to prevent valgus deformity and ankle instability (see Fig 18). A skin graft, usually taken from the thigh of the donor extremity, is used to cover the skin defect in that leg. The peroneal tendons should be well covered by muscle bulk to enable a safe skin graft take.

![Tech Fig 2](image1.png)
**TECH FIG 2 • Removal of fibular graft.** A. An anterolateral leg incision is used for harvesting of the fibular graft. B. An intercalary fibular segment, 6 cm longer from the bone defect, is removed with its nutrient vessels and its periosteal cuff. C. If a large skin defect is anticipated at the tumor resection site, the fibular graft is removed with an overlying skin island, which is used to cover that defect and to monitor flap viability.

**PREPARATION OF THE ALLOGRAFT**
- The allograft is cut to the same length as the bone defect and a groove is opened longitudinally by removing as much cortical and cancellous bone as needed to allow insertion of the fibular flap into it.

**RECONSTRUCTION OF THE RECIPIENT SITE**
- The allograft is inserted to fill the bone defect and is fixed to its proximal and distal edges with a side plate and screws (TECH FIG 3A,B). An intramedullary nail is also used if the allograft medullary canal is wide enough to contain both the nail and the fibular graft. Using a high-speed burr, a defect is created in the allograft cortex at the appropriate level to allow the passage of the fibular vascular pedicle toward the vascular bundle of the recipient extremity while avoiding traction on the vascular anastomosis (Tech Fig 3A,B).
- The fibular graft is inserted 2 to 3 cm into the medullary canal at both ends and fixed with screws (TECH FIG 3C-E). Care is taken to prevent damage to the nutrient vessels of the fibula by those screws. The fibula can be placed in an intramedullary location, inside the allograft or parallel to it. In both options, the fibular osteotomy sites should lie close to the native long-bone resected edges.
- After vascular anastomoses are completed, autologous bone graft, taken from the fibular flap remnants or the ipsilateral iliac crest, is used to reinforce the interface between the fibula and the recipient bone.
TECH FIG 3 • Preparation and fixation of allograft. A. The allograft is cut to the same length as the bone defect, and a groove is opened longitudinally by removing as much cortical and cancellous bone as needed to allow insertion of the fibular graft into it. It is then inserted to fill the bone defect and is fixed to its proximal and distal edges with a side plate and screws. B. A defect is created in the allograft cortex to allow the passage of the fibular vascular pedicle. C. Plain radiograph showing an osteosarcoma of the proximal tibia. Tumor extent allowed an intercalary resection sparing the proximal epiphysis to be performed. D. Reconstruction of the bone defect with an allograft, fixed with side plate and screws. E. Plain radiograph showing the fibular graft, inserted into the allograft's medullary canal and fixed with screws.

INTRA-ARTICULAR RESECTIONS

- The proximal fibular epiphysis, with variable lengths of the diaphysis and with the anterior tibial vessels as the vascular pedicle, or alternatively the inferior geniculate artery, is used to reconstruct defects that include one side of the articular surface. After removal of the fibular flap the lateral collateral ligament is secured to the medial tibial metaphysis with a metal staple to preserve lateral knee joint stability (TECH FIG 4A).
- The proximal aspect of the fibular flap is fixed to the radial or humeral diaphysis with a side plate and screws, and the biceps tendon stump is used for attachment to the opposing articular surface soft tissue envelope (TECH FIG 4B-E).
**TECH FIG 4** • A. After removal of a proximal fibular graft, the stump of the lateral collateral ligament is secured to the lateral tibial metaphysis to restore lateral knee joint stability. B. Reconstruction of proximal fibular graft to the remaining radial diaphysis. C. Coronal CT reconstruction of the distal forearm showing an osteosarcoma of the distal radius. D,E. Anteroposterior and lateral plain radiographs showing reconstruction of the intracalary bone defect with a proximal fibular graft.

**POSTOPERATIVE CARE**
- All patients must be treated and monitored postoperatively according to a strict and constant protocol. They are admitted to the intensive care unit for the first 5 days after surgery, where they are monitored for vital signs and flap viability. A high volume of lactated Ringer solution (1.5 times maintenance) is given to ensure high flow through the anastomosis and prevent thrombus formation. The high volume of fluids is maintained for a total of 3 days, with gradual reduction to normal maintenance volume in the ensuing 2 days.
- Enoxaparin is given to prevent deep vein thromboses. Blood samples are drawn twice daily for blood count and electrolytes. Hemoglobin levels are kept at 9 to 10 g/mL to minimize blood viscosity and further decrease the likelihood of anastomotic thrombus. A technetium methylene diphosphonate bone scan with single-photon emission computed tomography is performed 10 days after surgery to evaluate flap viability.
- Recipient extremities are immobilized for 3 months (upper extremity by a brace, lower extremity by a plaster cast), after which gradual passive range-of-motion exercises are practiced.
- Signs of bone union are evaluated radiologically by serial plain radiographs. Bone unions are usually seen after 4 to 5 months in the upper extremity and after 5 to 7 months in the lower extremity. Partial weight bearing is allowed upon detection of radiologic evidence of bone union. Gradual physical loads on the limb are recommended until full weight bearing is achieved.

**OUTCOMES**
- Solid bony unions, associated with fibular hypertrophy, full weight bearing, and mechanical load capacities, are achieved in the vast majority of patients. Fibular hypertrophy occurs over years and is the result of pressure transport, microfractures, and callus formation.
- Mild to moderate decreases in range of motion are common and are similar to those seen after other types of reconstructive surgeries. Such decreases result from the extent of resection of bone and soft tissues rather than the mode of reconstruction.
- Deep infections are rare, as is hardware failure requiring revision surgery.

**COMPLICATIONS**

**Recipient Site**
- Anastomotic thrombosis and loss of flap viability
- Nonunion
- Infection
- Hardware failure and breakage

**Donor Site**
- Valgus ankle deformity
- Ankle joint instability
■ Transient or permanent peroneal palsy
■ Transient or permanent peroneal distribution area sensory deficit
■ Skin graft failure and tendon exposure
■ Transient or permanent great toe flexion impairment

REFERENCES