Free Vascularized Fibula Grafting: Principles, Techniques, and Applications in Pediatric Orthopaedics

Donald S. Bae, MD and Peter M. Waters, MD
Children's Hospital

INTRODUCTION

Bone grafts are commonly used in all specialties of orthopaedic surgery, and an understanding of the principles and techniques of bone grafting is critical to the care of traumatic, developmental, and reconstructive musculoskeletal conditions. While most orthopaedic surgeons are familiar with the utilization of non-vascularized bone graft and bone graft substitutes, the applications of vascularized bone grafts --and free vascular fibula grafts in particular—are often less well understood. The purpose of this article is to review the principles and technique of free vascularized fibula grafting, with particular attention to its applications in pediatric orthopaedic surgery.

Type of Graft	Osteoconduction	Osteoinduction	Osteogenesis	Mechanical strength	Vascularity
Bone Marrow	+/-	+	++	-	-
Cancellous autograft	++	+	++	+	-
Cortical autograft	+	+/-	+	++	-
Vascularized	++	+	++	++	++

Table 1. Properties of bone grafts

THE RATIONALE FOR VASCULARIZED BONE GRAFTS

Bone grafts and bone graft substitutes have a number of inherent properties which allow them to initiate, stimulate, and facilitate bony healing.(1,2) (Table 1) Osteoconduction refers to the process by which the graft provides a scaffold for the ordered 3-D ingrowth of capillaries, perivascular tissue, and osteoprogenitor cells. Osteoinduction refers to the recruitment of osteoprogenitor cells from surrounding tissue. Osteogenesis refers to the formation of new bone from either the host or graft tissue. In addition to these three properties, it is important to consider the mechanical strength and vascularity of the bone graft material.

Autogenous and allogenic cortical and cancellous bone grafts are all, to varying degrees, osteoconductive, osteoinductive, and osteogenic. For these reasons, non-vascularized bone grafts are effective in facilitating bony healing. When appropriately utilized, non-vascularized bone grafts may be incorporated into the adjacent host bone through the process of "creeping substitution." The bone graft material, through the invasion of capillaries, perivascular tissue, and inflammatory cells, is gradually revascularized and ultimately resorbed, allowing for the formation of new living bone which is incorporated and remodeled into the host skeleton. However, this process takes time, during which the structural integrity and mechanical strength of the bone graft and host bone may be compromised.(1)

Vascularized bone grafts, by definition, are placed with their vascularity intact, and thus are immediately viable. As a result, vascularized bone grafts obviate the need for incorporation by creeping substitution and may instead incorporate into the adjacent host bone via primary (or secondary) bone healing. This process allow allows for the mechanical strength and structural integrity of the vascularized graft to be preserved, which may confer greater strength and more immediate stability to the recipient site.

FREE VASCULARIZED FIBULA GRAFTS

The fibula has been long recognized as an attractive choice for vascularized bone grafting procedures.(3,4) Biomechanically, the fibula bears only 15 percent of the axial load across the ankle, allowing for its use as an autogenous bone graft with minimal biomechanical consequences on the weight-bearing status of the lower limb.(5) As the distal fibula also plays an important role in conferring rotational stability and restraint against lateral translation of the talus, efforts are made to preserve the distal fibula during graft harvest to avoid subsequent ankle deformity or instability.(6,7,9)

Furthermore, the vascular supply to the fibula has been well established.(4,9) The endosteal blood supply to the fibula is provided by a nutrient artery which typically enters the pos-

Dr. Bae is and Instructor in Orthopedic Surgery at Harvard Medical School.
Dr. Waters is a Professor of Orthopedic Surgery at Harvard Medical School.

Address correspondence to:

Dr. Donald Bae
Children's Hospital
300 Longwood Ave. A2
Boston, MA 02115

terior fibular cortex at the junction of the proximal one-third and distal two-thirds. This nutrient artery is a branch of the peroneal artery, which runs along the posterior aspect of the fibular diaphysis. In addition to this nutrient vessel, the fibula receives additional vascularity via a number of segmental musculo-periosteal vessels which also emanate from the peroneal artery. Based upon this understanding of the vascularity of the fibula, techniques of vascularized fibula graft harvest have been developed which preserve both the nutrient artery and the rich periosteal blood supply.

Vascularized fibular grafting also has a number of additional theoretical advantages over conventional, non-vascularized bone grafting techniques. Given the length of fibular diaphysis that may be harvested, free fibular grafts are well suited for the reconstruction of segmental defects of the long bones, providing both mechanical strength and biological stimulus for healing. Furthermore, based upon the fasciocutaneous arterial branches of the peroneal artery, skin, fascia, and muscle may be harvested concomitantly with the fibula to allow for more complex soft tissue reconstruction. Finally, given the ability to transfer the proximal fibular epiphysis with the diaphysis during free vascularized fibular grafting, there is potential for preserving continued skeletal growth of the fibular graft.(10)

Despite its many theoretical advantages and applications, however, free vascularized fibula grafting is technically challenging and confers its own set of inherent risks and potential complications. Sound microsurgical technique is essential in performing the required arterial and venous anastamoses and ensuring long-term graft viability. Furthermore, donor site morbidity has been well documented, and up to 10% of patients may subsequently develop ankle pain, instability, and/or progressive valgus deformity if fibula harvest is not performed with proper technique.(7,8) Given these considerations, free vascularized fibula grafting should be employed in specific clinical situations.

Segmental bone defects Greater than 6 – 8 cm	Traumatic bone loss
	Tumor resection
	Osteomyelitis
	Infected nonunion
Biological failure of bony healing	Persistent nonunion
	Osteonecrosis
	Congenital pseudarthrosis

Table 2. Indications for free vascularized fibula grafting

Presently, the indications for free vascularized fibula grafting fall into two categories.(11) (Table 2) The first indication is for segmental bony defects of greater than 6 to 8 cm, such as seen in post-traumatic or post-infectious bone loss and tumor resection. The second indication is for smaller bony defects in which there has been a biological failure of bony healing, such as seen in recalcitrant fracture nonunions, congenital pseudarthroses, and osteonecrosis.

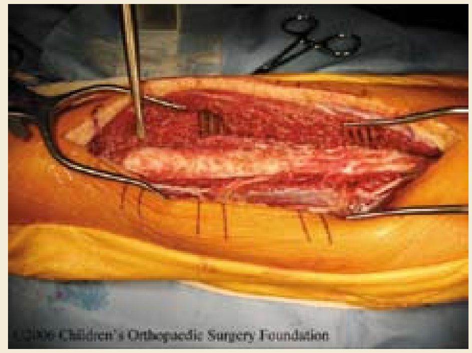

Figure 1a

Figure 1b

Figure 1. Free vascularized fibula harvest. (a) Extra-periosteal dissection is performed of the fibula in efforts to preserve its periosteal blood supply, giving the fibular diaphysis its typical "marbled" appearance. (b) The planned vascularized fibula graft is isolated on its peroneal arterial pedicle

SURGICAL TECHNIQUE

While a detailed explanation is beyond the scope of this review, a brief description of the technique of free vascularized fibula graft harvest is provided to give the reader some insight into the pertinent surgical considerations and applications.

When the fibula is to be harvested without accompanying skin or soft-tissue, a longitudinal incision is made over the lateral aspect of the fibula. Superficial dissection is performed in the interval between the peroneus longus muscle anteriorly and the soleus posteriorly. The diaphysis of the fibula is then circumferentially exposed with care being made to preserve the periosteum and periosteal blood supply; this results in the typical "marbled" appearance to the fibular graft. (Figure 1a) Circumferential dissection of the fibula is continued anteriorly and posteriorly, reflecting the peroneal and flexor hallucis longus muscles, respectively. The peroneal artery and vein are identified along the posterior aspect of the fibula and carefully protected as the intermuscular septum is divided along the length of the proposed graft. The fibula is osteotomized proximally and distally, with preservation of the peroneal vessels. (Figure 1b) Once the recipient site is prepared, the vascular pedicle may be divided and the fibula transferred to the desired location. Following stabilization of the fibula to the recipient site ---typically performed with rigid internal screw fixation—microvascular anastamoses are performed, reconstituting both arterial inflow and venous outflow to the fibular graft.

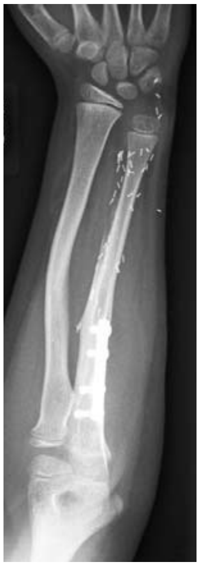

Figure 2. Free vascularized fibular graft for congenital ulnar pseudarthrosis. Anteroposterior radiograph of the forearm following free vascularized fibular grafting with concomitant proximal epiphyseal transfer for congenital ulnar pseudarthrosis. Note is made of bony healing at the osteosynthesis site and evidence of continued epiphyseal growth

APPLICATIONS IN PEDIATRIC ORTHOPAEDICS

Congenital Ulnar Pseudarthrosis

Congenital ulnar pseudarthrosis is a rare abnormality of skeletal growth characterized by the development of pathological fractures of the ulna and long-standing pseudarthroses. Often associated with neurofibromatosis or fibrous dysplasia, congenital ulnar pseudarthrosis may lead to pain, deformity, and growth disturbance. Traditional methods of fracture care, including open reduction and internal fixation with non-vascularized bone grafting, are often unsuccessful. For these reasons, free vascularized fibula grafting has been proposed as a potential treatment option.

We have recently reviewed our institution's experience in treating congenital ulnar pseudarthrosis with free vascularized fibula grafting.(12) In a retrospective analysis of 4 patients (average age 10 years), free vascularized fibula grafting resulted in successful bony healing in all cases. In addition to achieving bony healing across the site of the previous pseudarthrosis, careful restoration of ulnar length and alignment resulted in preserved elbow and wrist motion and distal radioulnar joint stability in all cases. Furthermore, when used in an intercalary fashion, vascularized fibula graft allowed for the revascularization of the dystrophic, hypoplastic distal ulnar segment.

In addition, two of the patients in this series underwent concomitant proximal fibular epiphyseal transfer in efforts to preserve skeletal growth potential.(10,12) (Figure 2) At most recent follow-up, there was clinical and radiographic evidence of continued skeletal growth of the "distal ulna" in both instances.

Based upon this report as well as others, we conclude that free vascularized fibula grafting is an attractive treatment option for congenital ulnar pseudarthrosis. Concomitant proximal fibular epiphyseal transfer should be considered in young patients with considerable skeletal growth remaining.

Allograft Nonunion

Limb salvage surgery is an appealing option in skeletally immature patients with malignant bone tumors. In these situations, intercalary or osteoarticular allograft is often utilized during bony reconstruction. Unfortunately, allograft fracture occurs in up to 20% of cases, and traditional methods of fracture care are often unsuccessful in these cases due to the high mechanical stresses and altered biological milieu.(13) Free vascularlized fibular grafting has been proposed in these situations to promote fracture healing while preserving allograft structural integrity.

Figure 3. Free vascularized fibular graft for allograft fracture nonunion following limb salvage surgery for malignant bone tumors. Anteroposterior radiograph following free vascularized fibular grafting of an allograft fracture nonunion of the humerus. This patient had undergone prior osteoarticular allograft reconstruction after resection of a humeral osteosarcoma.

We recently completed a retrospective study of patients who underwent free vascularized fibular grafting for established allograft fracture nonunions following limb salvage surgery for malignant bone tumors.(14) All patients had established allograft fracture nonunions following the use of allograft reconstruction for either osteosarcoma or Ewing's sarcoma of the extremities. Average age at the time of surgery was 13 years, and average clinical and radiographic follow-up was almost 4 years.

Almost 90% of patients achieved successful bony healing following free fibular grafting, resulting in limb preservation, pain relief, extremity stability, and satisfactory functional outcomes. (Figure 3) Despite the relatively high complication rate, these results support the use of free vascularized fibular grafting in these complex clinical situations. Careful attention to rigid internal fixation, meticulous microvascular surgical technique, and anatomic limb alignment is essential to optimize clinical outcomes.

Figure 4. Free vascularized fibular graft for osteonecrosis of the femoral head. Anteroposterior radiograph of the pelvis following free fibular grafting of the left femoral head. The fibular graft can be seen traversing the femoral neck and ending in the region of segmental osteonecrosis; fixation is achieved with the use of a single Kirschner-wire.

Osteonecrosis of the Femoral Head

Osteonecrosis of the femoral head continues to be a cause of pain and disability to thousands of adolescents and young adults each year.(15) This is particularly true in the pediatric patient population, where osteonecrosis of the femoral head may be a result of hip trauma, septic arthritis of the hip, slipped capital femoral epiphysis, Legg-Calve-Perthes disease, or chronic steroid use (such as seen following solid organ transplantation). While many treatments have been proposed, no universal solution has been found.

Free vascularized fibular grafting has been proposed to provide mechanical support to and revascularization of the femoral head.(15,16,17) (Figure 4) Dean *et al.*, in one of the largest published series in pediatric patients, reported the early results of free fibular grafting in 50 patients, average age 14.8 years. The majority of patients developed osteonecrosis as a result of prior hip trauma, slipped femoral epiphysis, or steroid use. Average Harris Hip Scores improved from 55 pre-operatively to 90 post-operatively, and at most recent follow-up, only 16% of patients had clinical symptoms or radiographic progression severe enough to warrant conversion to hip arthrodesis or arthroplasty. Based upon these results, the authors conclude that free fibular grafting in pediatric patients with femoral head osteonecrosis may relieve pain, improve function, and delay the need for future hip arthroplasty.

CONCLUSIONS

Free vascularized fibula grafting provides an attractive reconstructive option for the orthopaedic surgeon. Given its ability to provide immediate structural support and vascularity – as well as its inherent osteoconductive, osteoinductive, and osteogenic properties—free fibular grafting should be considered in the management of large segmental bony defects as well as situations in which there has been a biological failure of bony healing. The use of rigid internal fixation, careful soft-tissue and bony reconstruction, and meticulous microvascular surgical technique are essential in achieving the best possible outcomes.

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