Vascularized Bone Autografts

Experience with 41 Cases

ANDREW J. WEILAND, M.D.,* J. RUSSELL MOORE, M.D.,*
AND ROLLIN K. DANIEL, M.D.**

Forty-one autogenous vascularized bone grafts have been performed by the authors since 1976. Twenty-two free vascularized fibular grafts were performed in a lower extremity and ten in an upper extremity. Ten of these patients were treated for locally aggressive, benign, or low-grade malignant bone tumors, while the remainder of the patients were treated for massive trauma-derived, segmental bone defects. The average length of the bone defect was 14.9 cm for tumor cases and 16.2 cm for trauma cases. In four patients (12.5%), the operation was unsuccessful, resulting in amputation. Nine patients were treated by osteocutaneous groin flaps, with one failure, resulting in amputation. Vascularized autogenous bone grafts transferred by microvascular anastomoses have been found an effective method of treatment for massive segmental bone defects.

Alexis Carrel's classic paper published in 1908, "Results of the Transplantation of Blood Vessels, Organs and Limbs," heralded the birth of vascular surgery. Following World War II, the first vascular stapling machine was developed by Androsov. Various mechanical devices were designed and tested during the next decade. Salmon and Assimocopoulos, Buncke et al. and Cobett were responsible for improvements in microsurgical instrumentation, including the operating microscope, and early investigations on free vascularized tissue transfer.

The clinical application of replantation surgery was initiated by Dr. Ronald Malt in 1962 with the replantation of the right upper extremity of a 12-year-old boy. Through a report of the American Replantation Mission to China in 1973, the western world learned of the first successes in digital replantation. O'Brien et al. reported on the clinical replantation of digits in 1973, and in 1977 Weiland et al. reported the first large series of replantation of hands and digits in the United States, emphasizing the functional evaluation of the successful replant. Improved techniques in microvascular anastomoses, aided by Acland's work on the prevention of thrombus formation in microvascular surgery, led to the free transfer of skin flaps by microvascular anastomoses experimentally. The first successful clinical free flap was achieved by Daniel and Taylor in 1973. In the last decade, the scope of free tissue transfer has expanded rapidly. The possible role of microvascular surgery in orthopedics and traumatology has been discussed by Tamai et al.

One of the most difficult problems confronting the orthopedic surgeon is the reconstruction of large bone defects resulting from congenital malformations or trauma, or following resection of large bone segments for eradication of locally aggressive or malignant bone tumors. Restoration of skeletal continuity has reached a plateau; staged opera-
tions and prolonged immobilization with loss of limb function are often required to fill the bone defect.

In most cases, the ideal bone graft is a viable piece of autogenous bone that reliably remains organized, defies resorption, and undergoes hypertrophy, thereby increasing in structural strength. Microvascular free living bone grafts satisfy these objectives.

The first clinically successful free bone graft with microvascular anastomoses was reported by Taylor et al. in 1975. A fibular segment was transferred from the contralateral leg and used to reconstruct a large tibial defect. Similarly, Serafin et al. used a rib graft to treat a nonunion of the mandible following radical resection of a tumor. Osteocutaneous flaps consisting of the rib and overlying thoracic skin have been transferred by microvascular anastomoses to the tibia and Taylor et al. have described a one-stage repair of a composite leg defect with free vascularized flaps of skin and iliac bone. Weiland et al. have described the application of free vascularized bone grafts in the treatment of malignant or locally aggressive bone tumors, large traumatic bone defects, and congenital pseudarthroses of the tibia, as well as the application of the free vascularized fibular graft in surgery of the upper extremity.

INDICATIONS

Free vascularized bone grafts offer significant advantages over conventional treatment methods in selected patients with segmental bone defects greater than 6 cm, secondary to trauma or following resection of locally aggressive or malignant bone tumors. A massive bone segment and accompanying vessels can be detached and transferred to a distant recipient site. Microvascular anastomoses to recipient vessels preserve nutrient blood supply; hence, osteocytes and osteoblasts in the graft can survive. Healing of the graft to the recipient bed, therefore, will be facilitated without creeping substitution.

Thus, bone fragments separated by a large defect can be stabilized more rapidly, without sacrificing viability. This is especially significant when the defect is in a highly traumatized or irradiated area; significant scarring and relative avascularity of the bed preclude the incorporation of conventional autogenous cancellous and corticocancellous bone grafts.

The vascularized fibular graft and composite osteocutaneous groin flap have been employed most often in the treatment of patients with segmental bone defects. In patients with massive diaphyseal bone loss secondary to trauma or following tumor resection with intact overlying skin, the free vascularized fibular graft proves ideal; it is a straight, cortical bone and will restore long bone defects. When both skin and bone defects exist, the free osteocutaneous groin flap may be used. However, the curvature of the iliac crest limits its applicability to defects of 10 cm or less.

ANATOMY AND SURGICAL TECHNIQUE

The anatomy and surgical technique of the composite osteocutaneous groin flap having been described in meticulous detail by Taylor et al., the following section will concentrate on the vascular anatomy and surgical technique as applied to the free vascularized fibular graft.

The artery of the fibula arises as a branch of the peroneal artery, which originates from the posterior tibial-peroneal trunk. The peroneal artery gives rise to several periosteal branches before the artery that supplies the medullary flow to the fibula. Penetration through the fibular cortex usually occurs at the mid-diaphysis level, with a variation of 2.5 cm proximally or distally. The artery external to the fibula ranges from 5 to 15 mm in length and from 0.25 to 1.00 mm in diameter. The peroneal artery continues distally along the medial and posterior aspects of the fibular diaphysis and provides
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fore, preservation of the medullary and peri-
osteal blood supply to the fibula is possible
by isolating the peroneal artery at its origin,
the posterior tibial-peroneal arterial trunk (Fig. 1).

To facilitate a description of the dissection
 technique, fibula harvesting has been divided
into eight steps. The procedure is performed
with the patient supine and the donor knee
flexed approximately 135°. The surgeon and
first assistant stand lateral to the leg, with the
second assistant medial, supporting the flexed
extremity. A tourniquet is used during the
dissection.

Step 1. A straight lateral skin incision is
made along the line of the fibula, extending
from the neck as far distally as needed. The
incision is carried through the skin and sub-
cutaneous tissue to the fascia overlying the
peroneus longus muscle.

Step 2. The anterior and posterior flaps are
raised as needed, to identify the interval
between the peroneus longus and soleus mus-
cles. The deep fascia is then incised along this
interval, the entire length of the wound. The
fibula is palpated periodically during the dis-
section. Using a blunt elevator, the interval
between the peroneus longus and soleus muscles
is developed. Using an extraperiosteal dissec-
tion technique, the peroneus longus and soleus muscles are reflected from the fibu-
lar diaphysis anteriorly and posteriorly, re-
spectively.

Step 3. The lateral border of the fibula is
exposed. If skin is to be harvested with the
fibula, the three perforating vessels to the skin
lying immediately posterior to the fascia and
overlying the soleus muscle must be pre-
served. When the bone alone is to be trans-
ferred, these vessels should be ligated.

Step 4. Beginning proximally and using a
blunt elevator, the peroneus longus and
brevis muscles should be elevated from the
lateral border of the fibula until the anterior
crural septum is reached, staying close to
bone. A 1-cm muscle cuff is not left sur-
rounding the fibula, as previously de-
scribed. If the vascularized graft fails, the
muscle cuff will become necrotic and serve
as a nidus for infection. In addition, it will
delay graft replacement by creeping substi-
tution. The anterior crural septum is then
divided, and the extensor muscles (extensor
digitorum longus, peroneus tertius, and ex-
tensor hallucis longus) are dissected from the
interosseous membrane. The dissection con-
tinues until the anterior tibial artery and
nerve have been identified and protected.

Step 5. The posterior crural membrane is
divided along the entire length of the graft.
Using careful extraperiosteal dissection tech-
niques, the soleus and flexor hallucis muscles
are reflected off the posterior border of the
fibula. The dissection continues until the pe-
roneal vessels are encountered; they must be left attached to the posterior surface of the intermuscular septum, and any branches arising that will not be grafted must be coagulated. Dissection is continued anteriorly and posteriorly for the length of the graft required. Special care is needed not to damage the peroneal artery, which, in the distal one-third of the fibula, lies directly on the posterior surface of the bone.

Step 6. The length of graft needed is measured and marked with methylene blue. All attempts should be made to preserve the distal 6 cm of the fibula, to maintain the integrity of the lateral aspect of the ankle joint. If distal dissection is required in a child, a transfixion screw will preserve the integrity of the ankle mortise and prevent possible proximal migration of the distal fibula. At the site of the distal osteotomy, the peroneal vessels must be pushed medially from the intermuscular septum.

A hole is made in the septum sufficient to allow a 2.5-cm malleable retractor to be placed around the bone, protecting the vessels that lie posterior to the retractor. A Gigli saw may be used to cut the bone and the distal osteotomy performed. A similar procedure is carried out at the proximal end of the graft. The distal limb of the peroneal artery and veins are then ligated at the site of the distal fibular osteotomy.

Step 7. A small bone hook in the medullary canal of the distal portion of the fibular graft is used to stabilize the fibula during the remaining dissection. The graft is retracted posteriorly, and the interosseous membrane is divided along the entire length of the graft.

The graft is then carefully retracted anteriorly, and the tibialis posterior is dissected distal-to-proximal from the posterior middle one-third of the graft, where it has remained attached to the fibula.

The fibula is retracted anteriorly or posteriorly, as needed, to leave the fibular graft isolated on its vascular pedicle proximally.

Step 8. The surgeon traces the peroneal artery proximally to its junction with the posterior tibial artery. A vessel loop is placed around the peroneal artery and vein. The fibula is then placed back into its bed, where it remains until the recipient site is prepared. The tourniquet is deflated. When the dissection in the recipient bed is completed, the fibula is harvested and placed into the defect. After stable fixation is achieved, microvascular anastomoses of the peroneal artery and vein to recipient vessels are performed.

MATERIALS

The authors have performed 41 vascularized autogenous bone grafts since 1976. In 32 of these procedures, free vascularized fibular grafts were employed to reconstruct massive segmental bone defects where good soft tissue coverage was present, while nine osteocutaneous groin flaps, consisting of iliac crest and overlying skin, were carried out for combined soft tissue and bone defects. All osteocutaneous groin flaps were grafted for tibial defects secondary to trauma.

The use of free vascularized fibular grafts (32 cases) can be divided into two main categories. In ten patients, vascularized fibular grafts were employed for reconstructing large segmental diaphyseal defects following resection of locally aggressive or low-grade malignant bone tumors. Two of these cases involved an upper extremity and the remaining eight, a lower extremity. The upper extremity cases consisted of a recurrent unicameral bone cyst of the proximal humerus, which had recurred four times and been treated by cortical steroid injections, and a giant cell tumor of the distal radius. The lower extremity tumors consisted of three congenital pseudarthroses, one adamantinoma, one fibrosarcoma, and three chondrosarcomas.

The vast majority (22) of free vascularized fibular grafts were carried out for massive segmental bone defects following trauma. Eight cases involved an upper extremity and 14, a lower extremity. All of these patients had previous unsuccessful surgical procedures, resulting in severely scarred and traumatized soft tissue beds. Hence, the incorporation of conventional autografts, would be unlikely, due to lack of local vascularity. In many cases, amputation would have been the only alternative.

The average length of the fibular graft perfused for tumor reconstruction was 14.9 cm, while grafts perfused in trauma cases averaged 16.2 cm.
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Figs. 2A and 2B. (A) Clinical appearance of the left leg prior to surgery illustrating the 9-cm tibial defect. (B) Anteroposterior (left) and lateral (right) roentgenograms of the left leg demonstrating bony defect.

CASE REPORTS

Case 1. A 22-year-old man was involved in a motorcycle accident, sustaining a fracture-dislocation of the left hip, an intra-articular fracture of the left knee, and an open fracture of the left mid-tibia, with a 9-cm segmental bone loss. Six months after injury he presented with a healed wound over the left leg (Figs. 2A and 2B). A free vascularized fibular graft was used, with micro-
vascular anastomoses of the peroneal artery and vein of the graft to the anterior tibial artery and its venae comitantes (Fig. 3). The leg was im-
mobilized in a Hoffman device for three months (Fig. 4), followed with a patelletendon-bearing brace for an additional three months. Six months after operation, complete healing and hypertrophy of the vascularized fibular graft were noted (Fig. 5).

Case 2. A 29-year-old man sustained an open comminuted fracture of the right tibia and fibula, with loss of skin and muscle posteriorly and laceration of the posterior tibial artery. Eight months after injury, and after multiple procedures consisting of irrigation and debridement, he presented with an 8-cm tibial bone defect and tenuous split-thickness skin graft coverage over the leg (Figs. 6A and 6B). Preoperative arteriograms revealed only the anterior tibial artery to be intact, with retrograde filling of the posterior tibial artery at the level of the medial malleolus. An osteocutaneous groin flap was elevated, based on the superficial circumflex iliac vessels. (The authors now base this on the deep circumflex system.) The cutaneous 

Fig. 3. Intraoperative photograph demonstrating bleeding from the distal end of the fibular graft prior to section of the vascular pedicle.

Fig. 4. Anteroposterior roentgenogram obtained 3 months after operation showing healing of the graft proximally and distally. The patient is still in the Hoffman apparatus.
RESULTS

Of the 32 free vascularized fibular grafts, 28 were successful (87.5%), and four were failures (12.5%). The four failures resulted in two above-knee amputations and two below-knee amputations. The average operating time for these procedures was 7.5 hours. Bony union occurred at the proximal and distal juncture sites in three to five months, after which partial weight-bearing was allowed in the lower extremity cases, using patellotendon-bearing or ischial weight-bearing orthoses as indicated. Full weight-bearing was started when the graft showed signs of hypertrophy (average, 15 months). No fatigue fractures of the free vascularized fibular grafts were noted. Three patients required supplemental bone grafting procedures (9.4%), and in two of these the viability of the graft was questionable. The third, a pa-
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Figs. 7A and 7B. (A) The osteocutaneous groin flap is being elevated from the left groin based on the superficial circumflex system. (B) Appearance of the osteocutaneous flap prior to transfer to the leg. The surgical clamp is on the iliac crest portion (9 × 2 cm).

(A) Lateral roentgenogram one defect. (Reprinted with siland, A. J., and Daniel, anastomoses for bone grafts assive bone defects. J. Bone 79.) (B) Clinical appearance illustrates that only the an- as patent. (Reprinted with siland, A. J., and Daniel, anastomoses for bone grafts assive bone defects. J. Bone 79.)

patient with congenital pseudarthrosis of the tibia, incurred a fracture approximately 2 cm above the ankle distal to the free vascularized fibular graft. The fracture was secondary to neurofibromatous involvement of the bone and necessitated a second procedure.

The osteocutaneous groin flap was used in nine patients, with eight successful results and one failure. The failure resulted in a below-knee amputation. The average length of the iliac crest component was 9.8 cm, and average operating time was seven hours. Bony union occurred in six months, longer than the time required for the fibular grafts. No fatigue fractures were noted. Average time to partial weight-bearing was four months, and time to full weight-bearing was 18 months. A greater incidence of complications was experienced with these cases: two patients required revision of anastomoses due to venous thrombosis, and three patients required supplemental cancellous bone grafts to increase the volume of the graft.

DISCUSSION

The authors' preliminary experience with microvascular transfer of autogenous fibular grafts and osteocutaneous groin flaps has been favorable. These procedures have been employed in patients with severely traumatized extremities as well as those with locally aggressive or low-grade malignant tumors who were not considered candidates for traditional bone grafting methods. In many patients, amputation would have been the only alternative.

As evident from this series, trauma is the most common cause of segmental bone loss in the upper and lower extremities (31 of 41 cases); however, selected patients with locally aggressive or low-grade malignant bone tumors are treated by en bloc resection that

Figs. 8A and 8B. (A) Anteroposterior and (B) lateral appearance of the right leg 3 months after surgery. (Reprinted with permission from Weiland, A. J., and Daniel, R. K.: Microvascular anas-

Figures for bone grafts in the treatment of mass-
resulting from bone loss. The potential use of vascularized epiphyseal transfers to correct deformity associated with radial club hand and in children with epiphyseal arrest secondary to trauma or infection, awaits experimental validation of the growth potential of these transfers.

A significant problem associated with free vascularized fibular grafts concerns the immediate postoperative monitoring of circulation to the graft. Unlike osteocutaneous groin flaps, in which the skin serves to monitor arterial inflow and venous outflow, the fibular graft is subcutaneous and not visible for direct monitoring. Bone scans using technetium, employed in the immediate postoperative period (24–72 hours), afford the surgeon reasonable assurance that circulation to the graft is intact. In addition, encouraging preliminary work is being performed in several centers using a thermocouple to monitor the temperature differential proximal and distal to the site of the arterial anastomosis. However, if circulation is defective, a revision of anastomoses at this stage is not feasible.

Microsurgery is not a discipline, but rather a technique that can be used by any well trained orthopedic surgeon. With more clinical and laboratory experience, the applicability of free tissue transfer and, particularly, vascularized autogenous bone grafts in the treatment of musculoskeletal defects will become more clearly defined.

REFERENCES

includes an adequate margin of normal bone and soft tissue. Free vascularized bone grafting appears to be an excellent technique for the reconstruction of these massive bone defects.

Treatment of congenital pseudarthrosis of the tibia remains one of the most challenging problems of orthopedic surgery. Although various bone grafting techniques, as well as pulsating electromagnetic coils, have been advocated, a significant number of failures have occurred. The early experience with free vascularized fibular transfers, however, has been encouraging.10,15,32

In an upper extremity, vascularized fibular grafts permit correction of nonunions re-