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Review Article

Bone Bridges: A Case Series of Vascularized Free Fibular Graft for the Reconstruction of Complex Defects

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Abstract

Introduction: Massive bone defects may be secondary, resulting from the excision of diseased tissue from atrophic non-union, chronic osteomyelitis, congenital pseudarthrosis, or resection of bone tumors, or they may be primary, owing to high-energy trauma with considerable bone loss. By virtue of its inherent vascularity, the free vascularized fibula graft (FVFG) avoids necrosis and promotes revascularization. This paper explores the versatile clinical applications of vascularized fibula grafts in orthopedic and trauma surgery.

Materials and Methods: Six patients were operated on, all of whom were of different ages and genders. The only commonality among this diverse group was the existence of sizable segmental bone defects in the bones of the face and extremities (humerus, radius, metacarpals, femur, tibia). The harvesting technique remained uniform (anterior approach) across patients, whereas fixation techniques were customized according to defect location.

Results: All the flaps healed well without complications except for one patient who developed distal extremity ischemia due to the steal phenomenon. There were no infections or long-term morbidities at the donor site in any of the patients. It has been demonstrated that using FVFG to reconstruct extensive bone defects in the extremities is related to satisfactory functional success assessed in terms of the Musculoskeletal Tumor Society score, with an average of 26.8 at the end of the follow-up period.

Discussion: Our experience emphasizes the importance of pre-planning when using FVFG for mandible reconstruction to ensure length preservation and for future dental rehabilitation. Accurate measurements are necessary for metacarpal and femoral neck reconstruction, considering spatial constraints and long-term outcomes. Our restrictions were a short follow-up period and the inability to record cases of FVFG for the maxilla.

Conclusion: This case series highlights the efficacy of FVFG as a reconstructive option for complex bone defects, showcasing its adaptability across various anatomical sites and etiologies.

Key words: Case series, Complex bone defects, Free vascularized fibula graft, Reconstructive surgery, Triple-barrel fibula

INTRODUCTION

Massive bone defects may be secondary, resulting from the excision of diseased tissue from atrophic non-union, chronic osteomyelitis, congenital pseudarthrosis, or resection of bone tumors, or they may be primary, owing to high-energy trauma with considerable bone loss.[1,2] Bone grafts, including allografts and autografts, have historically been used to treat bone loss. Vascularity is a critical factor influencing bone healing and, as a result, plays a crucial part in attaining successful graft repair. Since vascularized bone grafts have higher success rates and hasten the healing process in the rebuilding of skeletal deformities and necrotic lesions, they are a natural alternative in situations where there is a reduced blood supply.[3,4] The transfer of bony tissue with its nutritive vascular pedicle for complex defects

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has emerged as an efficient means of filling bone voids due to advancements in microsurgical techniques. By virtue of its inherent vascularity, the free vascularized fibula graft (FVFG) avoids necrosis and promotes revascularization. The added benefit of harvesting vascularized bone grafts in conjunction with skin and/or muscle gives solutions to challenging issues in the repair of skeletal/soft-tissue defects.[5,6] Vascularized, cancellous autografts integrate into the skeleton most effectively. Potential donors include the iliac crest, ribs, and fibula. By leveraging the fibula's dual vascularity, the biological conditions at the recipient site are optimized, enabling enhanced recovery and regeneration.[7] This paper explores the versatile clinical applications of vascularized fibula grafts in orthopedic and trauma surgery.

MATERIALS AND METHODS

Six patients were operated on, all of whom were of different ages and genders. The only commonality among this diverse group was the existence of sizable segmental bone defects in the bones of the face and extremities. The harvesting technique remained uniform (anterior approach) across patients, whereas fixation techniques were customized according to defect location.

Harvest technique:

1. Patient Positioning and Preparation: The patient was positioned supine on the operating table, with the knee flexed to 90° and the pelvic girdle internally rotated. A supportive roll was placed under the ipsilateral hip to maintain optimal positioning. A tourniquet was applied around the thigh, without exsanguination.
2. Flap Design and Marking: Pre-operative markings were made to outline the fibula flap, including the head of the fibula, lateral malleolus, anterior and posterior borders of the fibula, and the planned skin paddle centered over Doppler-perforators. A 6-cm segment of fibula was preserved both proximally and distally to ensure ankle stability and preservation of the common fibular nerve and the fibular collateral ligament. The skin island design was carefully planned to incorporate Doppler-perforators located over the middle/distal third of the fibula.
3. Surgical Dissection: Anterior Incision and Dissection → An anterior incision was made, taking care to avoid injury to the superficial peroneal nerve. The peroneal muscles were dissected off the anterior surface of the fibula, and the anterior intermuscular septum was incised to gain access to the anterior compartment. Posterior dissection → Posteriorly, incision was made, skin paddle raised, and a 3-mm cuff of muscles was preserved adjoining the bone to maintain vascularity. Vascular pedicle dissection → The peroneal vessels were identified between the tibialis posterior and flexor hallucis longus muscles. The vascular pedicle was carefully dissected up to its origin at the level of the bifurcation from the posterior tibial artery. Osteotomy → The fibula was osteotomized (single or double) using an electric saw or Gigli saw, harvesting 10–12 cm of bone in all cases, preserving a strip of periosteum overlying the proximal and distal osteotomy sites. The fixation techniques are detailed within the respective case description.
4. Anastomosis: Using a microscope or surgical loupe, microvascular anastomosis was carried out, starting with the vein and then proceeding to the artery. The peroneal and the corresponding venae commitates were sutured in the end-to-end/end-to-side manner. Between the peroneal and the corresponding arteries (facial artery, lateral circumflex femoral artery, radial collateral branch of the profunda brachii artery, radial artery) were similarly anastomosed, and the flap inset followed.
5. Donor site: Managed with either primary closure or split-thickness skin graft. For the initial 3 weeks, the donor leg was immobilized in below-knee posterior plaster of Paris (POP) slab with the ankle in neutral position. Graded weight bearing (up to 5 weeks with walker) and full weight bearing were permitted in all the patients.
6. Post-operative follow-up appointments were scheduled at weekly intervals for the 1st month, monthly for the next 3 months, and at 6 and 12 months.

CASE REPORTS

Case 1: Fibula for mandible

A 22-year-old female patient presented with adamantinoma of the right mandibular body, requiring segmental mandibular resection and wide local excision [Figure 1]. Reconstruction involved a free vascularized fibular graft anastomosed to the facial artery and venae commitantes; two closed wedge osteotomies were performed, and the bone was secured with titanium plates and screws, with an additional intermaxillary fixation. Postoperatively, the patient was kept nil by mouth for the initial 3–4 days, followed by liquids for 1 week and soft solid diet from the 2nd week onward. The patient was given intravenous antibiotics for a week and did not encounter any implant infection or extrusion. Follow-up at 3 months revealed successful graft integration as revealed by Orthopantomogram (OPG), and at 6 months, the patient had achieved a satisfactory cosmetic outcome.

Case 2: Fibula for humerus

An 11-year-old female patient was diagnosed with an aneurysmal bone cyst of the right humerus shaft [Figure 2].

Figure 1: (a and b) Pre-operative picture - frontal and lateral views. (c) Intra-operative picture showing the body of mandible with tumour *in situ*. (d) Wide local excision specimen. (e) Free fibula harvested. (f) Harvested free fibula flap is fixed with recon titanium plate. (g) Intra-operative photograph of the graft showing osteosynthesis with titanium plates and screws. (h) Post-operative OPG showing revascularization of graft. (i and j) Post-operative images after 1 month. (k) Post-operative intra-oral picture

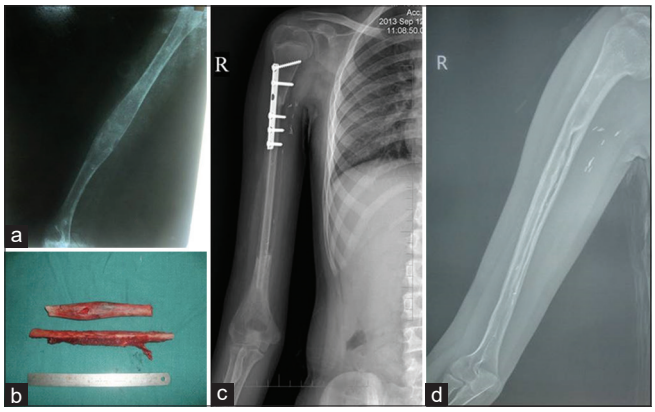

Figure 2: (a) X-ray showing right arm - fusiform dilation and ballooning with a radiolucent area of the humeral diaphysis. (b) Segmental excision of humerus and Free fibula harvested. (c) Early post-operative X-ray. (d) Late post-operative X-ray

Treatment involved segmental humeral excision resulting in a bony defect of size 14 cm, followed by reconstruction with a free fibula flap. The recipient site was immobilized in above-elbow POP for 6 weeks, followed by active mobilization of the elbow and the hand. Gradual weight-bearing as tolerated by the patient was permitted after ensuring callus formation on imaging studies at 3 months. By 6 months, the fibula had entirely replaced the humeral shaft in terms of length and circumference, with preservation of limb length, mobility, and a satisfactory cosmetic outcome.

Case 3: Fibula for the lower end of the radius

A 14-year-old male sustained a high-voltage electrical burn to his left hand, resulting in gangrene of the fingers [Figure 3]. Following serial debridement, a bilobed abdominal flap was used to cover the soft-tissue defect over the hand and wrist at 1 month. However, the patient developed a pathological fracture and osteomyelitis of the lower end of the radius at 2 months post-surgery, requiring sequestrectomy, segmental excision, and application of a distractor to maintain limb length. The patient was administered IV antibiotics based on culture and sensitivity reports. As the patient insisted on retaining the limb length and did not consent to amputation, at 5 months, the segmental bony defect was reconstructed with a free fibular graft after explaining the risks. The anastomosis was carried out to the radial artery and venae commitantes and stabilized with a 2 mm K-wire. Although the fibular flap survived, the extremity suffered progressive ischemia due to the steal phenomenon, confirmed by arterial

Doppler. Despite attempted medical revascularization, serial debridement of necrotic tissue was necessary, and the defect was eventually covered with a split skin graft, which healed adequately. Survival of the graft was confirmed by X-ray at 1 month post-FVFG. This case underscores the importance of preoperative computed tomography angiography in cases of electrical burns or limbs relying on a single vessel.

Case 4: Fibula for metacarpal bone

A 14-year-old girl suffered a complex crush injury to her right hand in a road traffic accident, resulting in the loss of three metacarpal bones, extensor tendons, and skin, creating a large three-dimensional defect [Figure 4]. A FVFG was harvested and osteotomized to replace the three metacarpals as three barrels. The original plan involved a triple-barrel fibula design to restore the three missing metacarpal segments, employing two strategic osteotomies [Figure 5]. The folding technique aimed to place the pedicle close to the recipient vessel, ensuring a comfortable vascular anastomosis. Due to spatial constraints, a two-barrel design was used instead of three. Post-operative X-rays showed sound healing of the graft at 1 month, and by 3 months, the flap had completely healed.

Figure 3: (a) Pre-operative picture before debridement. (b and c) Post-wound debridement pictures. (d and e) Well-healed post-abdominal flap cover. (f) X-ray showing distal end of radius with features of osteomyelitis. (g) X-ray image after sequestrectomy. (h) Distractor application. (i) Free fibula graft transfer and stabilization with K-wire. (j) Post-operative X-ray after 2 weeks. (k) Flap necrosis due to steal phenomenon

Figure 4: (a) Pre-operative picture of right hand. (b) Pre-operative X-ray. (c) Post-debridement picture. (d) Free fibula graft harvested along with skin paddle. (e) Osteotomy done. (f) Post-operative X-ray. (g) Post-operative picture

Case 5: Fibula for neck of femur

A 19-year-old male patient had a nonunion of the left femoral neck fracture after 6 months [Figure 6]. The lower half of the fibula was harvested and used to bridge the femoral neck defect, secured by two cancellous screws between the greater trochanter and femoral head. Spatial limitations allowed for only half the fibular graft's circumference (vascular margin) to be accommodated. Successful anastomosis of the peroneal vessels to the descending branch of the lateral circumflex femoral artery was achieved. The patient was ambulated using a walker with global off-loading in the initial period. Isometric exercises for the quadriceps were carried out by the physiotherapist under supervision. With encouraging callus formation - re-establishment of trabecular formation and signs of bone union on imaging study (X-rays; Bone scan was not done as the patient had good clinical recovery assessed periodically), partial weight-bearing was started from 3 months onward as facilitated by the supporting construct.

Case 6: Fibula for tibia

A 24-year-old man sustained a Grade-3 Gustilo distal leg bone fracture [Figure 7]. After confirming negative culture results, serial debridement of the local wound was performed, followed by coverage with a local perforator propeller flap. Once the flap had stabilized after 4 weeks, the lower end of the tibia was replaced with a fibular graft from the opposite limb, secured with plating and screws. As the patient was not willing to undergo external fixator application and extended healing time due to distraction, the patient opted for a free flap over the ilizarov technique. Unfortunately, the patient was unable to be located for follow-up after 3 months.

RESULTS

The age range of the cases in this series was 11–24 years, with an average of 17.33 years. All the flaps healed well without complications except for one patient who developed distal extremity ischemia due to the steal phenomenon. There were no infections or long-term morbidities at the donor site in any of the patients. The average duration of hospital stay was 12 days with an average follow-up of 12 months. Our case reports were distinctive in terms of the pathology of bone loss as well

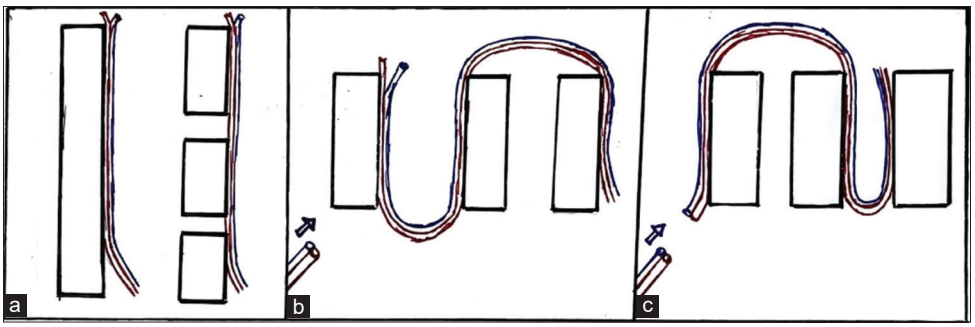

Figure 5: Shows the planning of triple-barrel fibula with osteotomy for the reconstruction of metacarpals in the free fibular graft in order to prevent the kinking of vessels

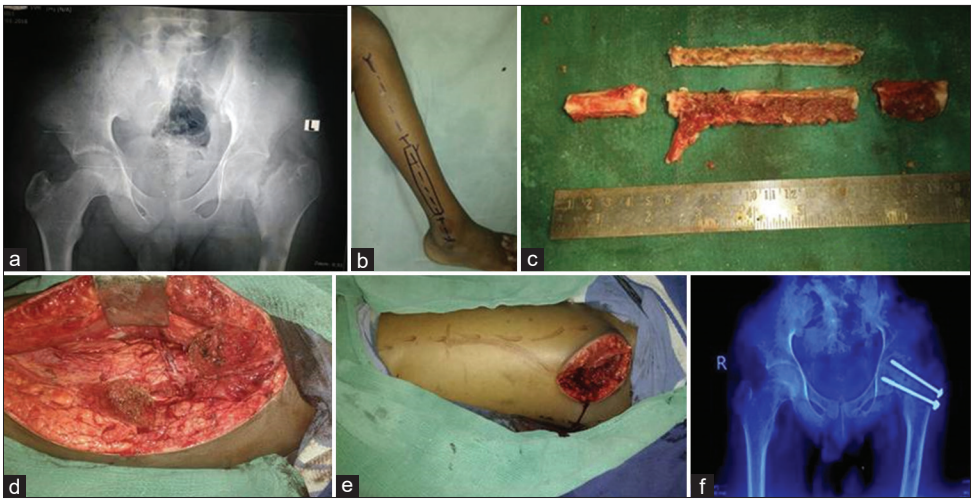

Figure 6: (a) Pre-operative X-ray showing fracture neck of left femur. (b) Pre-operative marking of the Right leg. (c) Free fibula graft harvested. (d) Intra-operative picture showing lateral approach and anastomosis to the descending branch of the lateral circumflex femoral artery. (e) Post-operative X-ray showing the free fibula fixed to acetabulum

as the location of bone loss. It has been demonstrated that using FVFG to reconstruct extensive bone defects in the extremities is related to satisfactory functional success assessed in terms of the Musculoskeletal Tumor Society score, with an average of 26.8 at the end of the follow-up period [Table 1]. Overall, it was showed that FVFG were able to efficiently rebuild major skeletal defects in the extremities, even when there was inadequate vascularity in the soft-tissue envelope around them or infection, which would hamper alternative techniques.

DISCUSSION

In order for bone grafting to be successful, the host bed must have sufficient vascularization. A bone graft's capacity to serve as a scaffold and host osteoblasts' capacity to synthesize bone through the process of "creeping substitution" are recent advancements in its application that reflect current understanding of osteoconduction.[8,9] Osteogenic qualities are provided by osteoinductive growth factors, osteogenic cells, and a structural framework in fresh autologous bone transplants, particularly cancellous bone. Autologous grafts are thought to be superior for encouraging bony healing because they support all facets of bone regeneration (osteoinduction, osteoconduction, and osteogenesis) at the recipient site. By "creeping substitution," cells migrate from the well-perfused resection and connection area into an almost acellular matrix when massive bone lesions are bridged with avascular grafts.[10] Because osteoblasts cannot thrive in biological environments with low oxygen tension, this is connected. Hence, using avascular grafts comes with a high risk of problems, such as bone atrophy, transplant fracture, and non-union, in addition to the time commitment.[11,12]

Figure 7: (a) Pre-operative clinical picture with external fixator. (b) Perforator propeller flap marked. (c) Post-operative clinical picture. (d) Pre-operative X-ray. (e) Post-operative X-ray after free fibular graft and stablization with titanium plating

Autografts with vascularization are preferred to those without. One of these is free fibular grafting, which is a common salvage technique and a perfect solution for regrowing a segmental bone defect.[13] Dual vascularity exists in the fibular graft. The biology at the recipient site is improved, and recovery is greatly aided by the fibula's two-fold vascularity, which includes periosteal and endosteal veins.[14] The nutritional artery, which normally reaches the posterior fibular cortex at the intersection of the proximal one-third and distal two-thirds, provides the endosteal blood supply. A branch of the peroneal artery called the nutritional artery runs down the back of the fibular diaphysis. Several musculo-periosteal vessels, which also branch off from the peroneal artery, feed the periosteal supply.[15,16] The stronger mechanical qualities enable quicker assimilation and graft hypertrophy while avoiding creeping substitution. When used for neoplasms, it permits the radical removal of the abnormal tissue, preventing recurrence and enhancing prognosis.[17] In comparison to

Table 1: Tabulated data from the cases

Case	Age/sex	Defect site	Hospital stay (days)	Follow-up time (months)	Time to full weight-bearing/healing (months)	Musculoskeletal tumor society score (assessed at the end of follow-up period)	Complications
1.	22/ Female	Mandible	9	12	3 (For chewing solid food)	-	-
2.	11/Female	Humerus	11	12	6	28	-
3.	14/Male	Radius	18	18	8	22	Distal extremity ischemia due to steal phenomenon
4.	14/ Female	Metacarpals	8	9	6	28	-
5.	19/Male	Femur neck	12	18	12 (For bipedal walking)	30	-
6.	24/Male	Tibia	14	Lost to follow-up at 3 months	Lost to follow-up	26	-

avascular autografts, vascularized autografts have higher rates of union, lower rates of cortical bone resorption, and lower rates of stress fractures. When bridging a gap larger than 6 cm, these characteristics are extremely crucial.[18,19]

The fibula works effectively for the repair of long bones with significant deficiencies because of its size (up to 26 cm), configuration, and capacity to encourage early remodeling and hypertrophy. The vascular fibular graft has been used to treat osteomyelitis, bone loss following tumor removal, kyphosis, and congenital pseudarthrosis of the tibia, in addition to segmental bony abnormalities.[20] The peroneal artery and veins serve as a sufficient vascular pedicle for either a free or pedicle graft.[21] It almost closely matches those of the radius and ulna, and it fits into the humerus' medullary canal. Given that the arm is immediately functional after both junction sites have healed, there is less need for hypertrophy as a result of the anatomical match. The so-called "double barrel" free vascularized fibular graft can be used for big bones like the femur or tibia, as well as patients with segmental bone defects with adjacent radius and ulna bony abnormalities.[22] The fibula's distance from the head and neck also makes it possible to use a simultaneous two-team approach, which reduces the duration of the operation. However, the drawbacks of microsurgical reconstructive techniques include the need for specialized training and equipment, the possibility of donor site morbidity, and the length of time required for these procedures and the completion of the treatment. Patients who have peroneal artery-dominant legs are not candidates for use of the fibula.[23,24]

Our experience has highlighted the importance of pre-planning when using FVFG for mandible reconstruction to ensure length preservation. A comprehensive approach to care, including functional rehabilitation with osseointegrated dental implants, is crucial. When employing FVFG for metacarpals as a double-barrel graft, careful planning and execution of osteotomy are necessary to prevent vessel kinking due to spatial constraints. The largest size of skin paddle that can be safely harvested on a single perforator still remains debatable. The correlation between the size of the perforator, the blood flowing through it, and the volume of tissues it can safely sustain plays a role. Perforating vessels from the peroneal artery can support a skin paddle with a surface area of up to 10 × 20 cm, which is particularly beneficial for head-and-neck reconstruction.[25] In this case, the donor site was grafted and healed well. For humerus reconstruction, consideration must be given to the long-term determination of humerus size by the length of the pedicle and fibula circumference. In cases of ischemic limb extremities, such as post-AV fistula and atherosclerosis, the steal phenomenon must be taken into account when performing free flaps. Accurate measurement of the femoral neck length is essential to ensure sufficient space for the vascularized bone graft and cancellous screws. Since the patient had non-union of femoral neck fracture, avascular bone grafting was not preferred due to a higher risk of bone resorption and mechanical failure from poor integration with the recipient bone. For lower tibial defects, FVFG is preferred, while pedicled fibula grafts are preferred for upper tibial defects, with plating to avoid damaging nearby neurovascular structures. The load-bearing capacity of FVFF and ilizarov bone lengthening was comparable.[26] The Ilizarov bone lengthening procedure was associated with a longer time to achieve bone union, prolonged external fixator application, resulting in a higher incidence of complications. As the patient was not willing to undergo external fixator application and extended healing time due to distraction, the patient opted for a free flap over the Ilizarov technique. Our restrictions were a short follow-up period and the inability to record cases of FVFG for the maxilla.

CONCLUSION

FVFG is a dependable choice for reconstructing complex bone defects at various topographic areas across the body with various etiologies. Like with any graft reconstruction, FVFG requires precise pre-operative planning and preparation, careful intraoperative management, as well as watchful post-operative care. The surgeon's judgment will choose when and where to utilize the FVFG, taking into account the procedure's numerous advantages and disadvantages.

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