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Original Research

Versatility of Vascularized Fibular Graft in Forearm Bone Loss: From Initial Treatment to Secondary Nonunion Treatment

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A R T I C L E I N F O

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Purpose: Managing mangled forearms poses a considerable challenge for hand surgeons. The vascularized fibular graft (VFG) is a commonly used technique for addressing this complex issue. This retrospective study aims to assess the outcomes of advanced treatment for complex forearm bone loss necessitating microsurgical treatment with a vascularized fibula flap.
Methods: Patients treated with VFG between January 2010 and December 2022 were included in this analysis. Physical and radiographic evaluations were performed for all patients, and they completed patient-reported outcome measures such as the disability of the arm, shoulder, and hand scores, Mayo Wrist scores, and visual analog scale pain (VAS-Pain) scores for both the recipient and donor sites. Patients treated with one-bone forearm (OBF) reconstruction were also assessed using the outcome score of the OBF according to Peterson.
Results: A total of 26 cases were treated with VFG for forearm bone defect reconstruction (13 for primary treatment and 13 for secondary treatment of nonunion). Vascularized fibular graft was employed to create a OBF in four cases, a double barrel in three cases, and an osteocutaneous composite flap in nine cases. The average bone defect measured 81 ± 3.4 mm (range: 50–150 mm). Bone healing was achieved at an average of 8.3 ± 5.5 months (range: 4–15 months), with nonunion at one docking point observed in eight cases necessitating revision. At the follow-up end point, patients reported an average disability of the arm, shoulder, and hand score of 13.5%, a Mayo Wrist score of 80%, and a VAS-Pain score of 3/10. The VAS-Pain outcome at the donor site was rated at 4/10. One-bone forearm's mean score was 7/10.
Conclusions: Vascularized fibular graft stands as a viable option for mangled forearm reconstruction. Whether through the double barrel technique or as an osteocutaneous composite graft, VFG allows for the simultaneous reconstruction of both forearm bones and associated soft tissue injuries.
Type of study/level of evidence: Therapeutic IV.

The treatment of mangled forearms is a challenging task for hand surgeons. The management of these injuries involving bone can be demanding, not only in the acute stage but also in dealing with the associated complications and outcomes. Soft tissues can also show varying degrees of damage as a result of high-energy closed trauma, with the risk of secondary bone exposure.

Whether caused by trauma or as a direct consequence, these defects can seriously impact a patient's quality of life. Over the years, various surgical techniques have been developed aiming at restoring function and improving patients' lives. Bone grafts are an effective option for filling substance loss because of fractures, infections, and nonunion (NU).

Vascularized bone transfer represents a more complex and specialized approach to dealing with bone substance loss.

The main advantage of vascularized bone transfer is the high success rate in achieving bone union. Since the graft maintains its blood supply, it is more resistant, with fewer potential complications, and promotes faster healing by preventing resorption and soliciting bone callus apposition under functional stimulation.

The fibula is one of the most commonly used bone flaps for the management of extensive bone defects in long bones because of its wide size and remarkable mechanical strength.[1] Its pedicle[2] offers the ideal caliber and length to allow microsurgical anastomoses.

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It is possible to harvest up to 26 cm of fibula either as a single tissue flap or as a composite flap involving skin, fascia, and muscle to deal with large losses of substance and more than 5–6 cm of bone loss.[3–5] It finds applicability in a wide range of scenarios, including defects resulting from severe trauma, extensive resections because of osteomyelitis and tumor pathology,[6] congenital, infected NU, or posttraumatic atrophic bone loss, which is often resistant to alternative treatments.[7,8] The double barrel technique with a single pedicle and two bone splints can be performed in selected cases, such as in the case of radius and ulna losses, because the bone graft receives both endosteal and periosteal blood supply.[9] In cases of large bone defects in both radius and ulna, an alternative approach can be used to reconstruct a single forearm bone shaft maintaining distal radius and proximal ulna. This method can take advantage of the use of the interposed vascularized fibula flap, thus maintaining adequate forearm length, unlike the classic "one-bone forearm" (OBF) described by Hey-Groves.[10]

This retrospective study conducted at the Department of Orthopaedics and Traumatology II, Hand Surgery of the AOU Città della Salute e della Scienza CTO in Turin, Italy, aims to analyze, observe, and evaluate the outcome of advanced treatment of complex forearm bone loss in which microsurgical treatment with a vascularized fibula flap was required.

Materials and Methods

Patients treated, with different modalities, with vascularized fibular graft (VFG) between January 2010 and December 2022 are analyzed in this study.

Inclusion criteria used were as follows: patients with forearm trauma with bone loss (with or without large bone exposure), patients with forearm open fractures treated with bone synthesis complicated by NU (whether infected) with substance loss (> 5 cm), and patients with considerable bone loss and soft tissue compromise even without trauma.

Patients were clinically and radiographically re-evaluated according to monthly follow-up until bone healing and according to the needs and possible complications of individual cases. They were recalled for evaluation between January and September 2023 for the final follow-up, prior to the structure's institutional approval. Each patient expressed an informed agreement to take part in the study.

All patients underwent physical and radiographic examinations and were asked to complete patient-reported outcome measures, including the disability of the arm, shoulder, and hand, Mayo Wrist score, and visual analog scale (VAS-Pain) for the recipient site and the VAS-Pain for the donor site.

Patients receiving a OBF were also evaluated with the outcome score of the OBF according to Peterson.[11]

Healing was radiographically determined and defined by the presence of bone callus at the fracture site of at least three of the four corticals of the bone.

Results

A total of 25 patients, four women and 21 men with a mean age at the time of injury of 43.4 ± 11.7 years (range: 13–64 years), underwent vascularized fibula flap surgery following forearm bone loss in the examined time range.

The mean follow-up was 5.4 ± 3.6 years (range: 1–13 years).

Thus, we examined a total of 26 cases (one patient underwent bilateral surgery). In 13 cases, vascularized fibular grafting was necessary as primary treatment, whereas in the remaining 12 cases, it was performed as secondary treatment of NU resulting from complex forearm trauma (including six septic NUs).

In the 13 cases of VFG as primary surgery, patients experienced a bony forearm fracture in six cases and a single bone forearm fracture in four cases (two cases of ulna fracture and two cases of radius fracture). In five cases, it was type 2 exposure according to Gustilo-Anderson classification,[12] whereas in one case, it was 3A exposure, and in four cases, 3B exposure. In all those 10 cases, patients underwent acute debridement and stabilization surgery with an external fixator and subsequently managed with definitive osteosynthesis with a VFG (at an average of 2.4 months after the initial injury ± 1.7; range: 1–6 months).

In the remaining three cases, there was no trauma, but the considerable bone and soft tissue damage was caused by toxic injection outcomes that, over time, led to a condition comparable with a type 3B according to Gustilo-Anderson,[12] and VFG was used as the first and only type of treatment.

Of the 13 NU cases, 10 cases were bony forearm fractures, and three cases were radius fractures. In five cases, the initial trauma caused a bone exposure (two cases of type 2 according to Gustilo-Anderson classification,[12] one cases of type 3A, and two cases of type 3C). In eight cases, no bone exposure occurred during the initial trauma.

In Table 1, preoperative assessment data are reported.

Patients had already carried out an average of 2.3 ± 1.3 surgeries on the same segment since the fracture before performing the definitive surgery (range: 1–5).

After adequate debridement, a mean bone defect of 81 ± 3.4 mm (range: 50–150 mm) was detected.

The vascular fibula graft was used to develop a OBF in four cases, a double barrel was performed in three cases, and an osteocutaneous composite flap was performed in nine cases because of concomitant soft tissue defects.

Bone healing was achieved on average at 13.6 ± 9.2 months (range: 4–36 months).

Except for the eight cases in which a NU occurred at one of the two docking points and whose healing times were thus prolonged, the average healing times were 8.3 ± 5.5 months (range: 4–15 months).

In the eight cases just mentioned, NUs occurred: seven at the proximal level and one at the distal level. These NUs were treated with a new stabilization because of the lack of stability in seven cases with achievement of complete bone healing within the next 6 months. In one case, since these NUs were asymptomatic, the patient preferred to avoid undergoing further surgery (Table 2).

The several tests that were administered to the patients all showed favorable results. Specifically, regarding the recipient site, the mean disability of the arm, shoulder, and hand score was 13.4%; the mean Mayo Wrist score was 80%, and the mean VAS-Pain scale was calculated to be 3/10.

Visual analog scale pain outcome at the donor site stood at 4/10.

The mean outcome score for the OBF of patients who received this procedure was 7/10.

Discussion

Forearm bone reconstruction in cases of bone loss in the radius and/or ulna is a complex challenge. Over the years, several treatment options have been proposed. In cases of small bone deficits or in cases in which the bone loss is not because of blood perfusion problems, a nonvascularized bone graft may occasionally be sufficient.[12,13] However, the cases considered in this analysis had large bone losses requiring considerable biomechanical structural support or smaller bone defects but with limited vascular supply or local soft tissue compromise.

It should be noted that in cases of substantial bone deficit, forearm bone loss reconstruction using external fixators

Table 1
Preoperative Assessment

Case	Age (y)	sex	Bone Lesion	Gustilo-Anderson Grade	Initial Treatment	No. of Previous Operation	Nonunion
1	46	M	Open fracture, radius	3C	ORIF (plate)	4	Yes
2	55	M	Open fracture, radius and ulna	3A	ExFix/ORIF (plate)	4	Yes
3	42	M	Open fracture, radius and ulna	3C	ExFix/ORIF (plate)	3	Infected nonunion
4	50	F	Radius fracture	/	ORIF (plate)	2	Yes
5	41	M	Open fracture, radius and ulna	2	ExFix	1	
6	26	M	Radius and ulna fracture	/	ExFix/ORIF (plate)/ExFix	4	Infected nonunion
7	32	M	Radius fracture	/	ORIF (plate)	2	Infected nonunion
8	44	M	Open fracture, ulna	3B	ExFix	2	
9	64	F	Open fracture, radius and ulna	2	ExFix/ORIF (plate)	2	Yes
10	50	M	Loss of bone radius and ulna and soft tissue (toxic injection)	3B	/	/	
11	50	M	Loss of bone radius and ulna and soft tissue (toxic injection)	3B	/	/	
12	52	M	Open fracture, radius and ulna	2	ExFix	1	
13	45	M	Radius and ulna fracture	/	ORIF (plate)	2	Yes
14	36	F	Open fracture, radius and ulna (burn)	3B	/	1	
15	44	M	Loss of bone radius and ulna and soft tissue (toxic injection)	3B	/	/	
16	19	M	Radius and ulna fracture	/	ORIF (plate) / ExFix	5	Infected nonunion
17	45	M	Open fracture, radius and ulna	3B	ExFix	2	
18	44	F	Open fracture, radius and ulna	3A	ExFix	1	
19	44	M	Open fracture, radius	2	ExFix	1	
20	52	M	Open fracture, ulna	2	ExFix	1	
21	50	M	Open fracture, radius	2	ExFix	1	
22	54	M	Radius and ulna fracture	/	ORIF (plate)/ExFix	2	Infected nonunion
23	42	M	Open fracture, radius and ulna	2	ExFix/ORIF (plate)/ExFix	4	Infected nonunion
24	32	M	Radius and ulna fracture	/	ORIF (plate)/ExFix	2	Yes
25	13	M	Radius and ulna fracture	/	ORIF (plate)/ExFix	1	Yes
26	55	M	Radius and ulna fracture	/	ExFix	1	

ORIF, open reduction internal fixation; ExFix, external fixation.

Table 2
Type of Surgery and Bone Healing

Case	Site of Defect	Graft Length (cm)	Osteocutaneous	Use	Graft Fixation	Additional Procedures	Bone Healing (mo)
1	Radius	6			Single plate		5
2	Ulna	8			Single plate	(Refused synthesis revision)	Prox nonunion
3	Radius	8	Yes		Single plate		13
4	Radius	6			Single plate		8
5	Radius	7			Single plate + ExFix		6
6	Radius and ulna	5	Yes	Double barrel	Single plate radius and ulna		13
7	Radius	5			Double plate		6
8	Ulna	12	Yes		Single plate		3
9	Radius and ulna	5		Double barrel	Single plate radius and ulna		15
10	Radius and ulna	15	Yes	One-bone forearm	Double Plate	Prox synthesis revision	36
11	Radius and ulna	15	Yes	One-bone forearm	Single plate	Prox synthesis revision	31
12	Radius	10			Double plate		12
13	Radius	6			Single plate		4
14	Radius and ulna	6	Yes	Double barrel	Single plate radius and ulna		13
15	Ulna	9	Yes		Single plate	Prox synthesis revision	27
16	Ulna	15	Yes		Single plate		7
17	Ulna	5			Single plate		10
18	Ulna	5,5			Single plate	Prox synthesis revision	24
19	Radius	6			Single plate		10
20	Ulna	10			Single plate	Prox synthesis revision	15
21	Radius	8			Single plate	Prox synthesis revision	16
22	Radius	7			Single plate		5
23	Radius	7	yes		Single plate		7
24	Radius	5			Single plate		6
25	Radius and ulna	7		One-bone forearm	Double plate	Distal synthesis revision	26
26	Radius and ulna	10		One-bone forearm	Single plate		4

according to the Ilizarov technique[14,15] or Masquelet's technique,[16–18] although effective, may require prolonged healing time for patients, resulting in long immobilization and prolonged abstention from activity. In some cases, there has also been enough loss of structural bone substance that temporary stable biomechanical stabilization with an external fixator would not be possible.

An alternative option to VFG is the corticoperiosteal flap from medial femoral condyle. However, in the literature, it is generally indicated for coverage of bone deficits up to a length of approximately 5–6 cm, although indications for the use of this flap are gradually growing.[19,20]

In contrast, the use of the vascularized fibula flap has been shown to be extremely beneficial in these situations. Main

Figure 1. Man, 55-year-old. Left forearm crushing trauma in industrial carding machine.

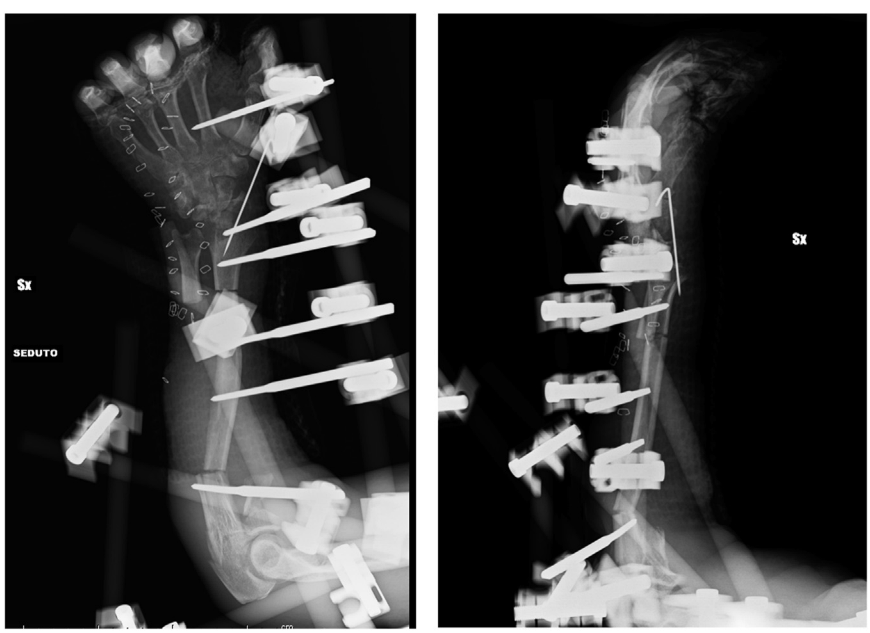

Figure 2. Debridement and emergency stabilization with ExFix.

indications for vascularized fibula transplantation on long bones involve NU and bone loss caused by both trauma and tumor and osteomyelitis.[6]

The fibula flap can be harvested as a composite osteocutaneous flap, allowing direct all-in-one soft tissue reconstruction. This option becomes very important when musculocutaneous defects occur together with bone loss, making the clinical condition even more complex to manage. In our experience, this one-stage surgical treatment, even in cases of infection, seems to be the most advantageous approach if meticulously planned and performed on suitable patients.[21–23]

Once harvested, the fibula flap, whether with or without skin paddle, can be used for immediate reconstruction with a diameter that corresponds to that of the forearm bones, thus

Figure 3. Day 30: One-bone forearm with vascularized fibular graft.

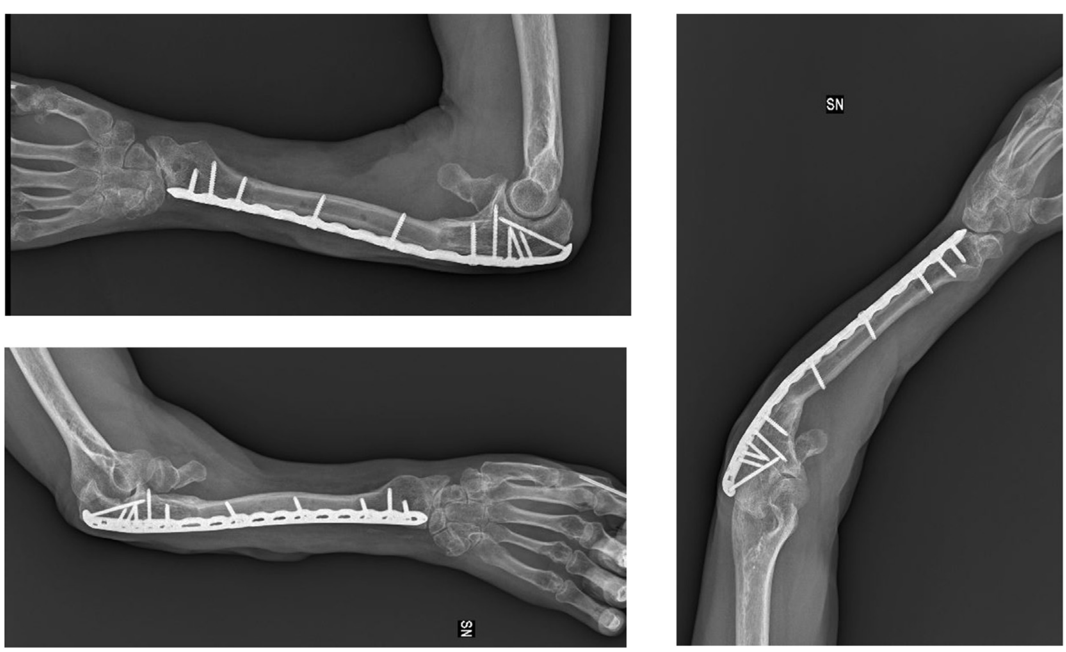

Figure 4. 36-month follow-up.

ensuring correct anatomical congruence.[24] To maximize the contact area between the fibula flap and the recipient bone and thus improve stability and the healing process, it is advisable to perform a chairside or step-cut osteotomy on both the fibula ends and the receiving forearm bone.[4] It is important to proceed with caution when adding spongy bone at the interface between the graft and the recipient's bone to avoid the risk of radioulnar synostosis.

In patients with moderate defects in both forearm bones, the fibula flap can be used as a "double barrel" flap to reconstruct both the radius and ulna.[4] In the literature by Fray et al,[25] average healing times of 6 months for the humerus and 4.8 months for the radius or ulna with a vascularized fibula flap have been reported. In our case series, patients who underwent this procedure presented an average healing time of 8.3 months.

Moreover, compared with the use of nonvascularized bone grafts, the vascularized fibula flap has been shown to achieve superior results in terms of healing, especially when the bone defect is associated with an infection.[26] Indeed, using a bone graft that by definition lacks its vascularization, and the formation of bone callus is conditioned by the well-vascularized recipient area, is not the best treatment, especially in cases where vascularization is compromised because of insults of various kinds.

The vascularized fibula flap also has an extreme indication for salvage of the creation of OBFs.[27] Historically, the indications for this procedure have been forearm instability and severe radius and ulna bone loss because of trauma, infection, tumor resection, or congenital deformities.[28–31] In the last two decades, more studies have been published in the literature, and it has been seen that massive post-traumatic bone defects are currently the most common indication[32] (Figs. 1–4). Although this involves the loss of prone-supination movement of the forearm, this technique can bring considerable benefits, including pain reduction, maintenance of elbow and wrist flexion and extension, and preservation of hand motion. The patients we treated also reported a resolution of their pathological condition and were able to return to daily activities, although with some inevitable adjustments and limitations. The use of free fibula graft improves the possibility of reconstruction in OBF technique allowing length restoration and superior healing: all patients receiving a free VFG in such cases healed uneventfully compared with the published series of nonvascularized OBF, which showed a percentage of NU.[26]

Special attention must be paid to the bone synthesis that is used, as it must have good stability and compression to facilitate healing.[27] Delayed healing at the proximal site has occurred in some of our cases because of the lack of stability. Revision of the synthesis with increased stability allowed all patients undergoing revision to achieve bone healing. Synthesis with good internal stability also allows faster and more complete healing.

Although it is a complex surgical procedure, requiring meticulous preoperative planning, accurate study of the fibula vascularization, and some morbidity at the donor site, this flap offers considerable advantages (such as biological and mechanical support, flexibility, bone strength, and rapid rate of consolidation) at the recipient site and today represents in our experience the gold standard for the treatment of large bone loss especially in poor vascularized or infected sites.[33–38]

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

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