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Cross-Bridge Free Vascularized Fibular Graft for Reconstruction of Extensive Traumatic Tibial Defects

Tarek Abdalla El-Gammal, MD, PhD[1,2] Amr El-Sayed, MD[1] Mohamed Mostafa Kotb, MD[1]
Waleed Riad Saleh, MD[1] Yasser Farouk Ragheb, MD[1] Mohamed Mohamed Morsy, MD[1,3]
Yousif Tarek El-Gammal, MD[1,4] Mahmoud Mohammed Saad, MD[1] Omar Ahmed Refai, MD[1]

[1] Department of Orthopedics and Traumatology, Center for Hand and Reconstructive Microsurgery Unit, Assiut University Hospitals and School of Medicine, Assiut, Egypt
[2] Department of Orthopedics and Sports Medicine, Division of Hand and Upper Extremity, University of Florida, Gainesville, Florida, USA
[3] Departments of Orthopedic Surgery, University of Alabama at Birmingham, Alabama, USA
[4] Department of Orthopedic Surgery, University of Louisville, Louisville, Kentucky, USA

Address for correspondence Tarek Abdalla El-Gammal, MD, PhD, Department of Orthopedics and Traumatology. Reconstructive Microsurgery Unit. Assiut University Hospitals and School of Medicine, Assiut 71526, Egypt (e-mail: Tarek.elgammal@aun.edu.eg).

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Abstract

Background The cross-bridge free flap technique has been described for salvage of cases of traumatic lower limb defects when adequate recipient vessels in the same limb are lacking. While previous accounts mainly focused on utilizing muscle, myocutaneous, or perforator skin flaps, this study presents a series of cross-bridge free vascularized fibular transfer for reconstruction of traumatic tibial defects with extensive soft tissue loss.

Methods The study included 22 cases with an average age at surgery of 24 ± 8 years and an average tibial bone defect of 14.2 ± 3.3 cm. In this technique, the fibula was inset into the tibial defect and vascularization was performed using the posterior tibial artery of the contralateral leg through a radial forearm flap. The two legs were coimmobilized using Hoffmann external fixator and subsequently separated after 6 weeks.

Results All flaps survived. Follow-up averaged 44.4 months. Union occurred in all cases within an average of 4.5 ± 1.9 months and Full weight-bearing was achieved at an average of 9.0 ± 2 months. Stress fractures occurred in eight patients (36.3%) after an average of 12 months. Mean graft hypertrophy at the final follow-up was 67.6%. Six patients showed an average limb length discrepancy of 4.2 cm. Two patients required corrective osteotomy, one ankle fusion, and another Achilles tendon lengthening. Functionally, 20 patients were able to walk without crutches.

Conclusion The cross-bridge free vascularized fibular graft is a viable option for reconstruction of complex and extensive tibial defects when no other reconstructive options are available.

Keywords
- cross-bridge
- vascularized fibula
- tibial defects

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Introduction

Microsurgical reconstruction is commonly employed for addressing complex defects of the leg that encompass both bone and soft tissue loss. Nevertheless, the severity and complexity of limb injuries can lead to damage to recipient bed vessels, thereby rendering these vessels unusable. In such instances, alternative vessels from the contralateral limb can be used as a salvage strategy to temporarily supply blood to the transferred tissue, a method known as the cross-bridge free flap technique. The inception of this procedure traces back to Taylor et al in 1979, when they transplanted a free iliac osteocutaneous flap to the right leg. This involved anastomosing the deep circumflex iliac vessels of the flap with the posterior tibial vessels of the left leg.[1] Subsequently, Townsend reported 10 cases involving cross-leg free deep circumflex iliac artery (DCIA) flaps.[2] While numerous authors have documented successful instances of cross-leg vascular anastomosis for repairing extremity tissue defects, most accounts predominantly encompass muscle, myocutaneous, or perforator skin flaps.[3–11] Reports focusing on cross-bridge composite flaps, such as the fibula osteocutaneous flap, are scarce and typically lack comprehensive long-term functional and radiological outcomes.[12]

In this study, we present our experience with the utilization of the cross-bridge free vascularized fibular transfer for the reconstruction of traumatic tibial defects accompanied by extensive loss of soft tissue. Specifically, we examine outcomes related to the rate of union, time required for union, duration until unrestricted weight-bearing is achieved, occurrences of graft fractures, and graft hypertrophy.

Patients and Methods

Between February 2010 and July 2021, a cohort of 22 cases with traumatic tibial defects underwent reconstruction using the cross-bridge free vascularized fibula osteoseptocutaneous flap technique. This technique was selected for young patients exhibiting traumatic tibial defects exceeding 6 cm in length and involving soft tissue loss (skin and/or muscles). It was also employed for cases with an extended injury zone lacking suitable recipient vessels, and when the utilization of ipsilateral vein grafts was unsuitable. All patients, except for one, were males and the fractures were the result of road traffic or train accidents. The mean age at the time of the primary procedure was 24 ± 8 years (range: 4–35). The average length of the bone defect measured 14.2 ± 3.3 cm (range: 6–22), and the mean size of the skin defect was 8×15 cm (range: 3×8–20×15). The surgery was performed approximately 4.8 ± 3.5 months after the initial injury (range: 1.5–14 months). Five cases presented with accompanying ipsilateral femoral shaft fractures. On average, 3.4 debridement procedures were conducted prior to the primary operation.

Surgical Technique

The recipient site was prepared under tourniquet control, commencing with comprehensive debridement and exposure of the bone ends. On the contralateral side, the posterior tibial vessels were exposed via a distally based U-shaped incision situated above and behind the medial malleolus. The fibula was harvested as an osteoseptocutaneous flap, including a skin paddle based on septocutaneous perforators along the posterior crural septum, following the technique outlined by Wei et al.[13] The fibular graft was then inset into the tibial defect, either by doweling into the tibial medullary cavity or by positioning it within a created gutter at the adjacent tibial ends. Proximal and distal fixation were achieved using screws. Both legs were securely immobilized with a Hoffmann external fixator featuring quadrilateral support for the pins. The pin positions were adjusted to facilitate unimpeded access to the anastomosis. The external fixation was performed prior to the anastomosis to ensure optimal leg positioning without jeopardizing the anastomosis integrity. To prevent a notable pressure gradient that could lead to arterial insufficiency or venous congestion of the flap, the legs were maintained at the same horizontal level. A free radial forearm flap was elevated and configured into a tube to cover the radial vessels, serving as a bridge or flow-through flap between both legs. The flap's length should be sufficient to allow comfortable leg fixation. The distal ends of the radial vessels were initially anastomosed to the peroneal vessels followed by anastomosis of the proximal ends to the posterior tibial vessels in an end-to-end fashion, to ensure perfusion and prevent blood stasis upon vascular clamp release. The mean duration of the operation was 12.4 hours (range: 8.4–14), and the average ischemia time was 4.3 hours (range: 3–5).

Postoperative Management

After 6 weeks, the legs were separated. The radial forearm flap was divided near the unaffected limb, and its skin was employed for additional coverage at the recipient site. The external fixator was adjusted across the original bone defect to safeguard the transplanted fibula and retained until radiological evidence of union was observed. Subsequently, it was replaced with a splint to facilitate gradual weight-bearing. Clinical and radiological assessments were conducted monthly for the initial 6 months, followed by evaluations every 3 months. Partial weight-bearing was authorized upon radiological union, progressing to full weight-bearing (FWB) when graft hypertrophy reached 30% of the original bone diameter.

Results

All flaps survived transplantation. Follow-up averaged 44.4 months (range: 18–97). All flaps eventually united within an average period of 4.5 ± 1.9 months from the index operation (range: 3–9). Stress fractures occurred in eight patients (36.3%) after an average of 12 months from the index operation; four were managed by casting, and the rest required plating to achieve union. Eventually, all fractures united within an average of 2.8 months. The mean graft hypertrophy at the final follow-up was 67.6% (range: 40–120). The progress of graft hypertrophy over time is presented in ►**Table 1**. Full

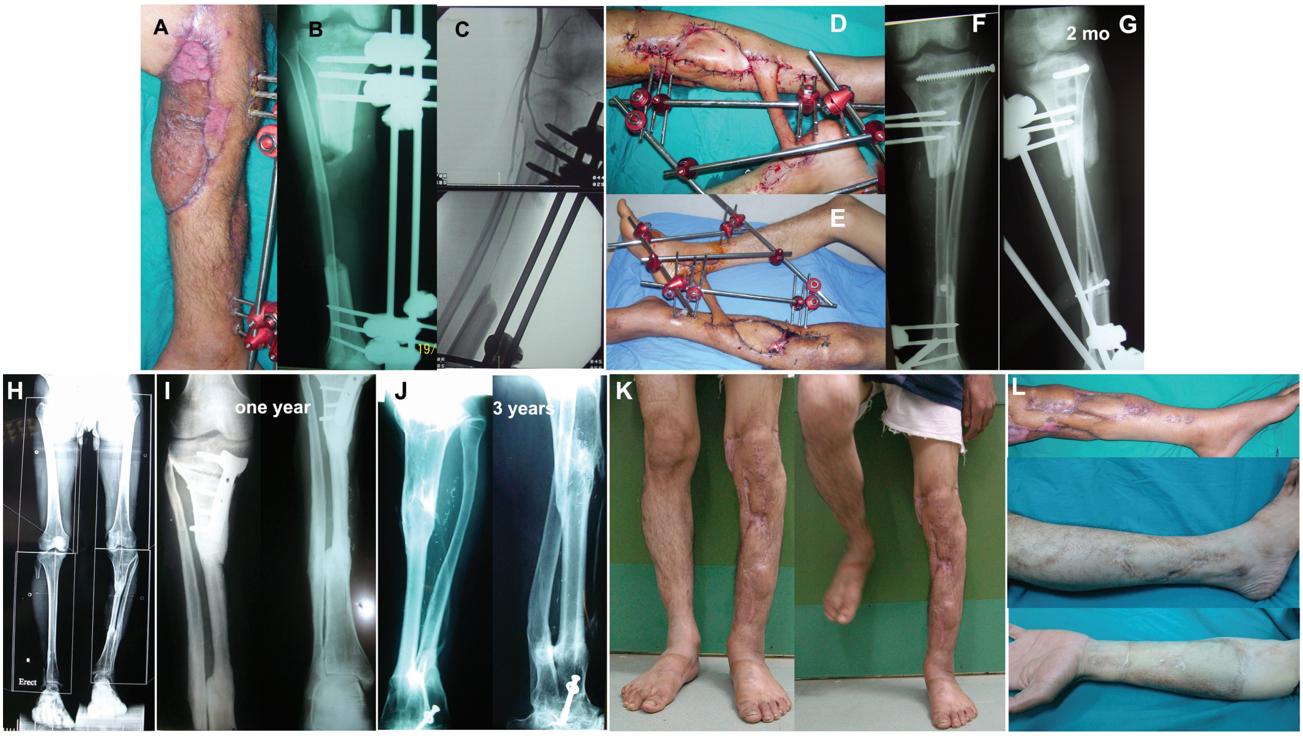

Fig. 1 (A) Traumatic left tibial defect with soft tissue loss covered with split-thickness skin graft. (B) Radiographs demonstrating 10-cm midshaft tibial defect. (C) Angiography demonstrating poor distal circulation. (D) A cross-leg vascularized fibular graft was performed. The fibula was inset into the left leg. Vascularization was performed using the posterior tibial artery of the contralateral leg through a radial forearm flap. (E) Two weeks postoperative. (F, G) Immediate postoperative anteroposterior and lateral radiographs. (H) Nine-month postoperative radiographs showing sound healing and varus deformity of the left knee. (I) Lateral wedge closing osteotomy performed at 1 year. (J) Three-year postoperative radiographs demonstrating 90% hypertrophy of the vascularized fibular graft. (K) Clinical standing radiographs. (L) Photographs of the recipient and donor sites.

unprotected weight-bearing was achieved at an average of 9.0 ± 2 months (range: 5–12). Six patients had limb length discrepancy that averaged 4.2 cm (range: 1.5–6), of them, two patients required Ilizarov bone distraction for lengthening. Two patients had corrective osteotomy and fixation for tibial deformity, one had ankle fusion, and another had Achilles tendon lengthening for equinus deformity. Functionally, 20 patients were able to walk without crutches. Ankle motion was limited in 11 patients and knee motion was limited in 3 patients. Two case examples are shown in ►**Figs. 1** and **2**.

Discussion

The survival of a cross-leg free flap subsequent to its pedicle division depends on neovascularization originating from the recipient bed. Berggren et al established that a bone graft solely vascularized by periosteal vessels can achieve complete survival.[14] Verification of composite tissue graft viability is indicated by the survival of the skin monitor, followed by bone union and hypertrophy. The establishment of adequate neovascularization for a pedicled random flap typically necessitates around 3 weeks. This timeframe was corroborated by Yu et al, who demonstrated in a canine experiment that division of the pedicle for a lower abdominal flap raised on the superficial epigastric anterior vessels 2 and 3 weeks postoperatively led to survival rates of 94 and 100%, respectively.[15] Chen et al recommended pedicle division after 3 weeks for skin flaps and 4 weeks for muscle flaps due to the more rapid neovascularization facilitated by the rich dermal plexus network.[12] In the case of cross-leg composite bone flaps, we advise waiting for 6 weeks to ensure sufficient periosteal neovascularization before pedicle division.

Directly comparing outcomes between cross-leg and conventional vascularized bone transplantation techniques is challenging due to variations in patient age, defect length, and fixation methods. Nonetheless, it appears that the biological behavior of transplanted bone, particularly in terms of healing potential and hypertrophy, relies more on periosteal vascularity than the vascular pedicle itself. Shi et al demonstrated that the periosteum contributes more significantly to early postoperative hypertrophy, whereas endosteal hypertrophy and intramedullary canal growth occur

Table 1 Progress of graft hypertrophy

Hypertrophy (%)	Variable	Time (mo)			
		6	12	18	24
	Mean	14.8	32.4	48.4	66.8
	SD	12.4	17.1	19.3	23.1
	Min	0	14	16	40
	Max	62	76	127	120

Abbreviations: Max, maximum; min, minimum; SD, standard deviation.

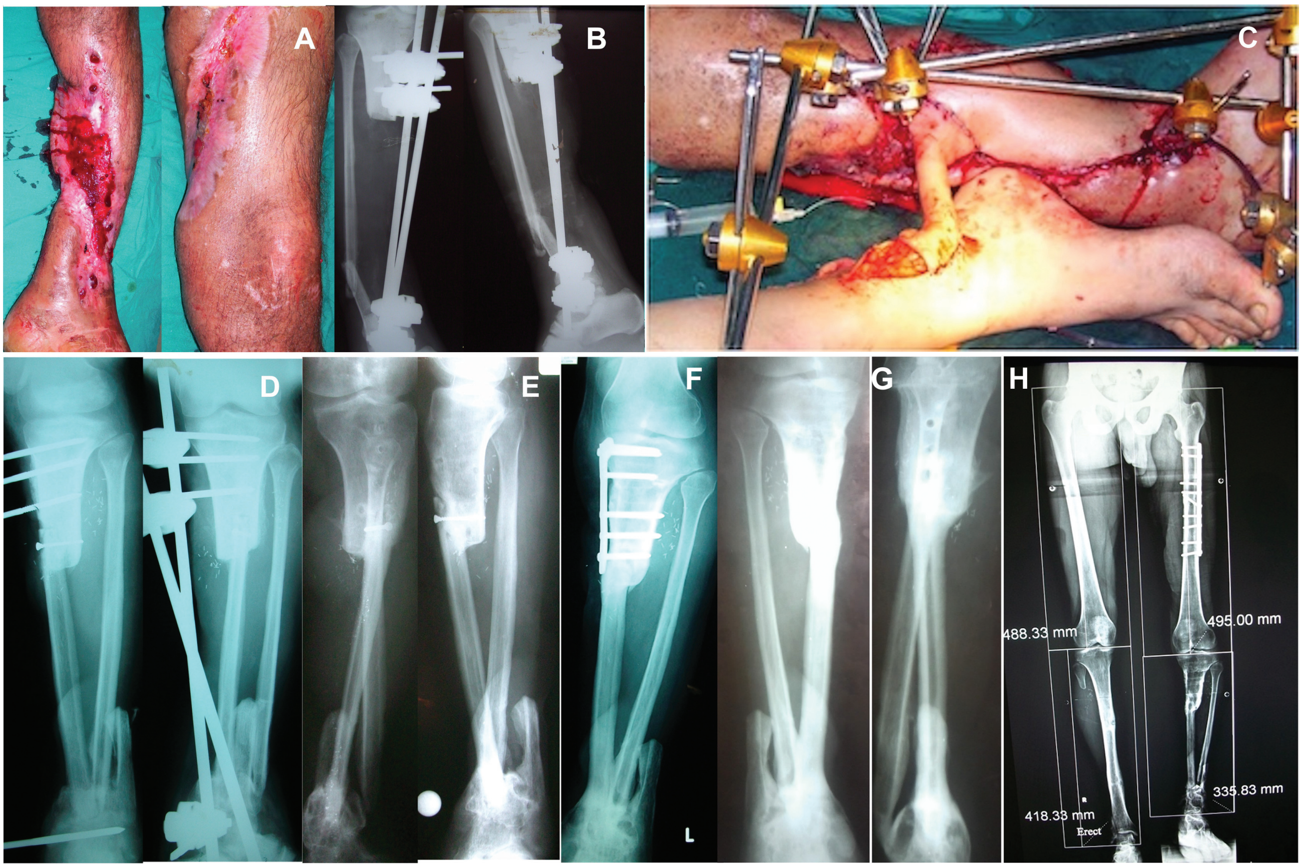

Fig. 2 (**A**) Left tibial defect after ipsilateral femoral plating and reconstruction of the popliteal artery using vein graft. (**B**) Radiographs demonstrating 20-cm tibial bone defect. (**C**) Immediate postoperative photograph. (**D**) Immediate postoperative radiographs. (**E**) Three-month postoperative radiographs showing proximal and distal union of the fibular graft. (**F**) One-year postoperative radiograph demonstrating healed derotation osteotomy of the proximal tibia. (**G**) Anteroposterior and lateral radiographs following plate removal. (**H**) Standing radiographs of both limbs showing 7.5-cm shortening.

later.[16] This might explain the similarities observed in times to union, FWB, and the rate of hypertrophy between the two transplantation techniques. In our study, the average times to radiological union and FWB were 4.7 and 8.6 months, respectively. Comparatively, a prior series of 13 traumatic tibial defects treated with conventional vascularized fibular transfer exhibited a 9-month time to FWB.[17] Townsend reported an average time to union of 6.5 months (range: 4–11.5) in a series of 10 cross-leg DCIA composite flaps[2]. He found no significant difference in time to union compared with a series of 13 similar flaps with anastomosis to vessels within the same leg.[2]

Vascularized fibular graft hypertrophy is a phenomenon influenced by time and mechanical loading.[17] Authors have documented that graft hypertrophy notably advances at a rate of 3.3% per month up to 24 months, with minimal to no further increase afterward.[17] In the present series, all cases experienced significant (>30%) hypertrophy, with approximately 3% increase per month, close to the rate already reported.

We regard cross-bridge free vascularized fibular grafting as a final recourse for limb salvage when suitable recipient vessels are lacking, and amputation risk is evident. Performing a free flap transfer in a patient with a single vessel poses considerable challenges primarily due to possible thrombosis and extended limb ischemia time and the potential for blood flow diminution, resulting in irreversible ischemic injury. The utilization of long vein grafts has shown a significant increase in thrombotic occurrences.[18] Although the arteriovenous loop (AVL) technique has emerged as a potentially effective alternative approach that enables anastomoses outside the injury area, the AVL is not applicable when the skin condition is not adequate for the proximal loop coverage and when the femoral artery itself has been reconstructed using a graft. The cross-bridge free vascularized fibular grafting, however, necessitates a skilled microsurgeon and involves several intricate steps with multiple anastomoses. Patient age plays a crucial role, with only motivated young patients being ideal candidates. Elderly patients who cannot tolerate the immobilization of both legs might not be suitable candidates. On the other hand, enhanced bone healing is anticipated in children due to active periosteal engagement in circumferential bone growth and a higher proportion of cortex supplied by periosteal vessels.

Conclusion

In conclusion, the cross-bridge free vascularized fibular graft is a viable option for reconstruction of complex and extensive tibial defects when no other reconstructive options are available.

Conflict of Interest
None declared.

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