ORIGINAL ARTICLE

Value of a skin island flap as a postoperative predictor of vascularized fibula graft viability in extensive diaphyseal bone defect reconstruction


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KEYWORDS
Free vascularized fibular graft;
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Summary
Purpose: To evaluate the feasibility and reliability of free vascularized fibular graft with skin island flap for reconstruction of large diaphyseal bone defect.
Method: The clinical results of vascularized fibular graft and experiences related to the importance and reliability of a monitoring island flap for the reconstruction of various long-bone defects were reviewed in 87 patients.
Results: Bony reconstruction was achieved in 82 of the 87 patients. Arterial thrombosis of anastomosed vessel in two patients and venous congestion of monitoring flap in nine patients occurred in the early postoperative periods. All of them were managed by immediate thrombectomy and reanastomosis, alternatively the thrombotic veins were replaced by new veins to anastomose with the superficial veins in five patients. Partial flap necrosis was noted in six patients, but additional surgical intervention was not required. The vascularized fibula survived and bony fusion was achieved in all patients. Postoperative stress fractures of the fibula graft occurred in 19 (21.8%) patients (once in seven patients, twice in five patients, three or more times in seven) as the mechanical stress to the graft increased. Included fracture on the tibia in 12 patients, humerus in one and femur in six. Treatments included casting in 11 patients, percutaneous pinning in one case, and adjustment of external fixator in seven patients. Bony union was finally achieved an average of 9.6 months after fracture.
Conclusions: Correct alignment between the recipient bone and the external fixator is a prerequisite to preventing graft fracture. Vascularized fibula transfer is a valuable procedure for long-bone defects, and a skin island-monitoring flap is a simple, extremely useful, and reliable method for assessing the vascular status of vascularized fibula.
Level of evidence: Level IV. Retrospective study.
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Vascularized bone transfer has been used in the treatment of skeletal defects that are more than six centimeters long, particularly those defects associated with inadequate vascularity of the surrounding soft-tissue [1–5]. Consequently, many more superior results than with conventional treatment have been reported [6–11]. However, there have been other reports on the disadvantages of this procedure, such as stress fracture of the grafted fibula, complete or partial necrosis of the skin flap, and morbidity at the donor site [12–14]. To improve the success rate of vascularized fibular transfers into a buried area, it is important to monitor the circulation of the island flap during the early stage. In our experience, a skin island based on perforators from the peroneal vessels serve as a continuously monitor for the flap vascularity, includes such advantages as simplicity, reliability, non-invasiveness, and the ability to fill associated soft-tissue defects. The purpose of the current study was to review the clinical results of 87 free vascularized osteocutaneous fibular grafts carried out for the reconstruction of long-bone defects and the experiences related to the importance and reliability of a monitoring island flap from March 1988 to February 2004.

Patients and methods

From March 1988 to February 2004, 87 patients with long-bone defects over 6 cm in length received vascularized fibular graft including a monitoring skin island flap in our department. There were 52 men and 35 women in the study, with an average age of 32.3 years (range, 4 to 52 years). The bone defects were caused by trauma in 53 patients, infection in 10 patients, tumor in 18 patients and malformation in six patients. The recipient sites were the femur in 14 patients, tibia in 37 patients, humerus in 15 patients, ulna in eight patients, and radius in 13 patients. The mean length of the bony defect was 11.5 cm (range: 6.5 to 20 cm) and the mean length of the fibular graft was 16.5 cm (range: 10.5 to 24 cm). The average length of time for surgical procedures was 255 minutes (range: 195 to 365 minutes), mean blood lost was 340 mL (range: 250 to 710 mL), and mean blood supply was 400 mL (range: 200 to 800 mL). All the 87 patients received operations at different time points. Among them, 17 patients received one operation, 31 patients received two operations, and 39 patients received more than two operations. All the 87 patients received vascularized fibular grafts including a small skin island flap (about 5 cm × 3 cm) to monitor the early vascular status or a cutaneous flap was designed about 20% larger than the skin defect, to prevent postoperative circulatory disturbance by contraction or swelling (Fig. 1).

Preoperatively, 53 patients were examined by Doppler spectrum analyzer to select proper vessels at the donor and recipient sites, and 14 patients were found to have only one main artery in the limbs. The artery on the external side of the donor’s fibula was monitored with a Doppler blood flow monitor in all patients to design the monitoring island flap of required size (Fig. 2).

Operations at the donor and the recipient sites were performed by two teams simultaneously on a supine position. In fibula donor-site team, an incision was made behind the required island flap to expose and confirm the peroneal artery. Then the incision was extended to form an island flap (about 5 cm × 3 cm) and the fibular vessels were exposed along this subcutaneous island flap to form a vascularized fibular graft. The donor fibula should be 4 to 5 cm longer than the recipient bone defect (Fig. 2). In this process, we should make sure that the blood supply of both the skin flap and the fibula was normal before cutting off the pedicles.
In recipient site team, the bone defect was exposed and the scar tissues caused by injury or inflammations were excised thoroughly. The bone marrow cavity was opened and enlarged for the fibular graft. A good recipient vessel should be selected. The deep brachial artery, radial artery, ulnar artery and its accompanying veins in the upper extremities, saphenous artery, anterior tibial artery and its accompanying veins in the lower extremities were often selected for anastomosis. In addition, one superficial vein, such as cephalic vein or great saphenous vein was often necessary. Arterial anastomoses were performed with the end-to-end method in 63 patients and end-to-side method in 24 patients. All the donor peroneal veins were anastomosed with the corresponding deep veins except nine donor veins with the superficial veins. The ratio of arteries to veins was 1:2. The monitoring island flap was sutured, floating like a kite, to the edge of the newly-created incisional wound along the cutaneous artery. A drainage tube was placed and the incision was closed (Fig. 3A) window was opened in the dressing to expose the monitoring island flap for postoperative observation (Fig. 4B).

Fixation of fibular grafts: at the early period, combined internal fixation with screws or pin and external fixation with plaster were used in 19 cases (include five paediatric patients) and mono-arm external frame fixators were used in 22 cases. Mono-arm external frame fixator and calcaneum bone traction were used in nine cases.

At the late period, arbeitsgemeinschaft osteosynthesefragen (AO) wave or bridge plates were used in the rest 46 cases.

Postoperative management: after surgery, the island skin should be checked periodically for color, capillary refill and even bleeding after needle prick.

Along with clinical assessment of the blood flow to the skin island, our vascularized fibular transplants were monitored continuously for 2 weeks postoperatively with a transcutaneous PCO$_2$ and PO$_2$ monitoring device MicroGas 7650-500 (Kontron Instruments Medical Sensors, Basel, Switzerland), with the MicroGas 7650-500 probe attached to the center of the skin paddle with use of double-sided adhesive rings (Fig. 4A).

When cyanosis of the skin island was being developed after operation, and temperature being decreased, elasticity being bad, capillary circulation being abnormal, combined evaluation with the value of transcutaneous oxygen (PtCO$_2$) falls below 10 mmHg and transcutaneous carbon dioxide (PtCO$_2$) increase exceeds 55 mmHg, surgical exploration is needed.

In the lower extremity, reconstructed limbs were casted for 3 months in patients with screws fixation alone, gradually increasing weight-bearing is permitted with the aid of a long brace and crutches. When sound clinical and radiographic union of the graft is evident, full weight-bearing is allowed.
Skin island flap as predictor of fibula graft post-operative viability

The average follow-up period was 4.3 years (range, 1.9 to 16 years). Among the total 87 grafts, 82 of the grafted fibulae united with the recipient bone at an average of 4.6 months (range: 3 to 8.1 months) after operation (Fig. 5); two patients failed to unite, and the other three showed delayed union. Hypertrophy was not calculated for the 21 patients involving the radius and ulnas. Hypertrophy could be seen in all grafted fibulae in lower extremity and humera reconstruction, hypertrophy was observed between 6 months and 12 months after the operation, more early in the adolescent patients, which was between 4 months and 10 months after the operation. Among the 51 patients with defects in the lower extremities, partial and full weight-bearing could be permitted at an average of 4.3 and 7.5 months after operation, respectively. The results of the functional assessments are listed in Table 1 according to Chen [2] and other functional evaluation programs of lower limb replantation.

The skin island flaps were normal in 78 patients and cyanosis of the skin island developed in 11 patients at 6 to 49 hours after operation. According to the color, temperature, elasticity, capillary circulation, the value of transcutaneous oxygen (PtcO₂) falls below 10 mmHg and transcutaneous carbon dioxide (PtcCO₂) increase exceeds 55 mmHg, surgical exploration in 11 patients found that circulatory problems included two arterial thrombosis and nine patients of venous congestion of the monitoring flap. All of them were managed by immediate thrombectomy and reanastomosis, or the thrombotic veins were replaced by new veins to anastomose with the superficial veins in five patients. Partial edge necrosis of the flap was noted in six patients on 7 to 14 days after operation, but additional surgical intervention was not required. All skin island flaps were survived without subside or necrotic.

Postoperative stress fractures of the fibula graft occurred in 19 (21.8%) patients (once in seven patients, twice in five patients, three or more times in seven), included the tibia in 12 patients, humerus in one, and femur in six. The average duration between fracture and reconstruction was 6.1 months (range, 1 to 8 months). In 15 patients, fracture occurred after bony fusion was achieved. Treatments included casting in 11 patients, percutaneous pinning in one case, and adjustment of external fixator in seven patients. Bony fusion was finally achieved at an average of 9.6 months after fracture.

None of the patients had pain in the donor-site, but there were some soft-tissue donor-site complications as following. Mild clawing of the big toe due to tight sutures of the flexor hallucis longus muscle at its origin developed in two patients, but patients did not complain of walking disturbance. Mild weakness (grade 4/5) of the extensor hallucis longus was observed in eight patients, and there was no weakness involving the ankle. Paresthesia on the dorsum of the foot or calf area was noted in 11 patients during the first few postoperative months, but disappeared by follow-up in all patients.

**Discussion**

Large diaphyseal bone defect in the limb may be reconstructed using different surgical techniques. Conventional options include cancellous bone graft, autologous non-vascularised fibula graft, allograft, bone substitutes techniques. Non-vascularised autografts [16] is reserved to small bone defects but are not indicated in the case of long bony defects, especially in infected, scarred and poorly vascularised beds. Allograft reconstruction maintains a role in tumour cases [17] and a very stable osteosynthesis is mandatory and prolonged immobilization recommended because of healing by creeping substitution. However, when large diaphyseal bone defect exceeds 6 cm, the vascularized bone free transfer and distraction osteogenesis with the ilizarov bone transport method have been widely accepted and emerged as gold standards [18–21]. Vascularized fibular transfers are generally accepted as an established procedure for the reconstruction of composite segmental long-bone defects [18]. Otherwise, microsurgical technique demanding, time consuming, vessels being sacrificed are disadvantages of vascularized fibular grafting [19]. The ilizarov method is a very satisfactory technique for the reconstruction of long-bone defects accompanied with soft-tissue problem, however, successful result depend on surgical experience and patient’s collaboration [21]. Bioactive membranes, intramedullary lengthening devices, osteogenic proteins and tissue engineering are novel techniques for larger bone defects, which have arisen during the last 10 years. Bioactive membranes include two different techniques: Masquelet induced membrane technique and bioreabsorbable polylactide membranes technique, have been effectively used experimentally. Masquelet [22,23] described induced membrane combined with cancellous autografts to reconstruct long-bone defects, which opens new perspectives. However, bioreabsorbable polylactide membranes described by Cobos, Lindsey and Gugala may isolate bone graft from the soft-tissue, which leads to necrosis [23,24]. Intramedullary lengthening devices have been reported to overcome the long period of external fixation.
normally needed during lengthening, and will provide a one-stage alternative to external fixators for reliable distraction osteogenesis [25,26]. However, patient compliance and effective monitoring of the distraction are essential, because of the rate of distraction is determined by the patient’s activity level [27]. Osteogenic proteins and tissue engineering may overcome difficulties for reconstruction of large diaphyseal bone defect and create opportunities not previously imagined in the future [28,29].

Previous basic and clinical research demonstrated the inherent advantages of vascularized bone [1,3,7]. The vascularized fibula graft is considered the most suitable graft for reconstructing long bones because of its straight shape, sufficient length, mechanical strength, predictable vascular pedicle, and limited donor-site morbidity [16,18,19]. Yet the patency of microvascular anastomosis is difficult to monitor because the fibular graft deeply buried.

Selective angiography and technetium-99 m bone scanning, and digital subtraction angiogram have all been used to assess the viability of the transferred fibular graft. Angiography and bone scanning are difficult to use routinely because they are expensive and invasive procedures that require highly sophisticated equipment. Even if they are used, continuous monitoring is impossible. Therefore, ultrasound Doppler tracing has been used because it is simple and noninvasive. However, although Doppler ultrasound is an indirect method of surveillance, it is limited by the interference of other vessels in the extremities, it cannot be performed frequently enough to be useful, and it requires special skill and sophisticated equipment [30].

Accordingly, clinical assessment of the tissue color, turgor, capillary refill, and bleeding of skin island monitoring flap would seem to be the most effective method of assessing the viability of a vascularized fibular graft. However, the treatment of postoperative venous congestion of the monitoring flap is still controversial. Minami et al. [31] reported that they performed thrombectomy in all 14 patients of postoperative thrombosis. However, Han et al. [32] did not perform thrombectomy and managed such patients with a prolonged period of immobilization and a delay in weight-bearing. Lee and Park [8] also mentioned that a failed cutaneous flap does not always indicate a failed fibular graft. Postoperative circulation of the flap was greatly influenced by edema or the local tension of skin closure, especially in femur reconstruction [33] Although the skin paddle of the fibula osteocutaneous flap has been considered unreliable [34], Wei et al. reported no isolated skin flap loss in 80 extremity reconstructions and 27 composite mandibular reconstructions [35].

In this study, the monitoring island flap presented circulatory problems within 49 hours after operation in 11 patients, surgical exploration was performed timely and the blood supply was recovered instantaneously. To our experience, the skin island provides a non-doubtful indicator of fibula graft viability, and we also agree with that perhaps most critical factor that may result in failure of union and/or hypertrophy is questionable viability of the fibula graft [4,36].

Along with clinical assessment, supplemental monitoring device MicroGas 7650-500 was used to be monitoring the transcutaneous PCO₂ and PO₂ of the vascularized fibula graft continuously for two weeks postoperatively. In a recent study of 30 free flaps, we found that the monitoring device identified developing complications before clear clinical indices appeared [37]. The observed trend of the monitoring device measurements was more important than the absolute values were. The results of that study indicated that if the relative value of transcutaneous oxygen (PtcO₂) falls below 10~15 mmHg and transcutaneous carbon dioxide (PtcCO₂) increase exceeds 43~55 mmHg, the flap is at risk and surgical exploration should be strongly considered.

The most common complication is fracture of the grafted fibula. De Boer and Wood [3] reported an average 25% rate of fracture of the grafted fibula within a year after operation,
and up to a possible 40%, especially in the lower extremity. Doi et al. [12] reported a 15.4% of fibular fracture rate. When a free fibula was used as the sole bony replacement in lower extremity reconstruction, stress fractures were common, ranging from 9% to 22% [38,39]. The fibula is still a narrow and weaker bone than the original long-bone defects in low extremity, especially the femur. In a cadaver study, the cortical cross-sectional area of the mid femur was 384 mm², whereas that of the fibula was 102 mm² [40]. Even when its diameter has increased after union, a single-strut fibular graft is unlikely to withstand full loading. But it is sufficient in many patients of the humerus, radius.

In our study, fractures of the grafted fibula were noted in 19 patients (21.8%), which were consistent with the results aforementioned in the literature, but were inconsistent with the expected results in favour of the postoperative monitoring with monitoring flap. So there may be still some problem in the validity of the skin island to assess the vascularization of the fibula transfer. In case of a stretch on the skin pedicle, especially when the bone transfer is deeply buried as in femur reconstruction, may lead to a skin necrosis while the bone remains well vascularized. On the other hand, late thrombosis of the bone transfer may be underestimated because skin paddle has been revascularized by surrounding tissues, which may result in stress fractures and lack of hypertrophy. It is essential to improve the reliability of a monitoring flap, and is recommended that:

- the skin island must contain one or more skin branches of peroneal artery and vein;
- it is also important to avoid any torsion or tension of the perforator;
- a monitoring flap be larger than 1 × 2 cm to because early detection of an arterial occlusion is difficult when the monitoring flap is too small, because the pale color is obscured by the surrounding normal skin [30];
- the island flap and the fibular graft have normal blood supply before cutting off the pedicles and after revascularization.

The graft fractures in our series occurred when the mechanical stress to the graft increased by initiating partial weight-bearing or removing the external fixator. Han et al. [32] reported that the initiation of weight-bearing or increased use of the extremity before adequate hypertrophy of the bone would cause a stress fracture. Arai et al. [41] reported that correct alignment between the recipient bone and the external fixator is a prerequisite to preventing graft fracture.

To avoid fracture of fibular grafts, we think any malalignment between the recipient bone and external fixator should be corrected before weight-bearing. And the lower extremities should not bear weight within 6 months, and should increase weight-bearing only gradually over a few months postoperatively. In patients of upper extremities, the forearms need hanging for 3 months. If fracture occurs, plastic holder or external fixation should be used and the fracture is usually healed in 4 to 6 weeks. The healing and molding potentials of the fibular grafts are so great because of sufficient and specific blood supply together with stable and reliable internal fixation.

Concerning fixation of fibular grafts, to our experience, the principles of fibular graft fixation are simplicity, reliability, and early activity without pain. Classically, external fixation using a monolateral frame or cast was the preferred method of fixation to maximize graft hypertrophy [3,32,42]. However, it had been associated with many problems such as instability, and pin track infection with consequent frame loosening which eventually led to high incidence of delayed and non-union in the Mayo Clinic series of 160 vascularized bone grafts [15], the most favorable rate of union following the primary procedure was in patients who had internal fixation, and the least favorable rate was in those who had external fixation (71% vs. 47%). On the other hand, rigid internal fixation was usually blamed for its stress-shielding effect, which may prevent significant graft hypertrophy [43]. In this study, to our experience, we think bridge plates fixation may be a preferred choice for low extremity in adult, which allows early axial loading of the graft, and will stimulate graft hypertrophy in theory.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


