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SPECIAL TOPIC
Reconstructive

A Comprehensive Approach to Lower Extremity Free-tissue Transfer

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Background: The purpose of this study was to introduce a comprehensive approach to lower extremity free-tissue transfer and report the clinical outcome that has been achieved with this approach.
Methods: The comprehensive approach developed by the author includes patient selection, flap selection, selection of the recipient vessels, flap dissection, flap preparation, microvascular anastomosis, flap inset, immediate postoperative care, intermediate postoperative care, and further follow-up care. Each part of this approach has its own special considerations. In an 8-year period, 28 consecutive lower extremity free-tissue transfers were performed in 28 patients by the author. The clinical outcomes were recorded based on the success of free-tissue transfer, any reoperations related to the revision of microvascular anastomosis, and any partial or total flap loss during an 8-year follow-up.
Results: All 28 lower extremity free-tissue transfers were performed successfully. All patients were discharged home once they tolerated dangling. No reoperations were needed for revision of microvascular anastomosis. No total or partial flap loss was encountered. Overall success of free-tissue transfer to the lower extremity in this series was 100%.
Conclusions: An ideal outcome of free-tissue transfer to the lower extremity can be accomplished with this comprehensive approach developed by the author. With good surgical judgment, adequate microsurgical skill, step-by-step intraoperative execution, and a protocol-driven clinical practice, the reconstructive surgeon should be able to improve his or her success for free-tissue transfer to the lower extremity. *(Plast Reconstr Surg Glob Open 2017;5:e1228; doi: 10.1097/GOX.0000000000001228; Published online 9 February 2017.)*

With many recent advances in reconstructive microsurgery, a successful free-tissue transfer can often be achieved for soft-tissue reconstruction of the lower extremity.[1,2] Frequently, free-tissue transfer to the lower extremity may be the only option for limb salvage in patients with a complex traumatic wound.[3]

The overall success rate of free-tissue transfer to the lower extremity is significantly lower than to the head and neck or breast even from some of the best microsurgery centers in the country.[4–6] This may be due to several important factors; for example, massive edema of the leg is frequently presented after trauma. Abnormal or thrombogenic recipient vessels are a common problem secondary to peripheral vascular disease or traumatic injury. The acceptable success rate of microsurgical free-tissue transfer to the lower extremity is less than 95% in contrast with up to 98% for microsurgical head and neck reconstruction and up to 99% for microsurgical breast reconstruction by some of high-volume centers. The failure of free-tissue transfer to the lower extremity remains relatively common compared with free-tissue transfer to the head and neck or breast.[4–6] Therefore, free-tissue transfer to the lower extremity for limb salvage is still challenging to many reconstructive surgeons.[7]

The purpose of this report was to introduce a comprehensive approach developed by the author for free-tissue transfer to the lower extremity. The clinical outcome with

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use of this comprehensive approach has also been reported. It becomes clear that the clinical outcome of free-tissue transfer to the lower extremity can be improved with this approach.

COMPREHENSIVE APPROACH

The comprehensive approach developed by the author includes patient selection, flap selection, selection of the recipient vessels, flap dissection, flap preparation, microvascular anastomosis, flap inset, immediate postoperative care, intermediate postoperative care, and further follow-up care (Table 1). Each part of this approach has its own special considerations with well-described procedures and standard protocols.

Patient Selection

When a patient is evaluated for free-tissue transfer to the lower extremity, his or her medical condition should be carefully evaluated, especially if the patient has an associated injury from trauma. Just like any other surgeries, major surgical risks such as previous heart attack, stroke, severe diabetes, uncontrolled hypertension, and significant hepatic or renal insufficiency. For many orthopedic trauma patients, it is common that they are placed on anticoagulation agents. Therefore, proper management of anticoagulation therapy for these patients perioperatively can be important to ensure a successful free-tissue transfer. It may also be critical to screen certain patients for hypercoagulable state if they have a history of recurrence vessel thrombosis or embolism because of the fact that patients with hypercoagulable state are very poor candidates for free-tissue transfer. Appropriate hematological consultation may be needed for those patients.

Flap Selection

There are several issues that need to be considered for a free flap selection. In general, soft-tissue requirement, availability of the flap tissue, and adequate length and size of the flap pedicle are the first 3 important considerations. It has been the author's philosophy that a vein graft should be avoided if possible for free-tissue transfer to the lower extremity because of added complexities and risks of venous anastomotic thrombosis. It is also important to select a flap that has minimal donor-site morbidities. Sometimes, surgeon's familiarity with the flap may also be an important factor in flap selection. The commonly used flaps for lower extremity reconstructions in the author's practice are the anterolateral thigh (ALT) perforator flap, or latissimus dorsi, rectus abdominus, and gracilis muscle flaps. However, an ALT flap has recently been used more frequently in soft-tissue reconstruction of the lower extremity, representing a paradigm shift in the flap selection because most microsurgeons including the author are now familiar with the ALT flap, and the flap dissection becomes more manageable even it is still technically challenging.[8] Other perforator flaps can also be selected based on the surgeon's preference and familiarly with the flap.

Table 1. A Comprehensive Approach to Lower Extremity Free-tissue Transfer

1. Patient selection
2. Flap selection
3. Selection of recipient vessels
4. Flap dissection
5. Flap preparation
6. Microvascular anastomosis
7. Flap inset
8. Immediate postoperative care
9. Intermediate postoperative care
10. Further follow-up care

Selection of Recipient Vessels

When one considers the selection of recipient vessels, the surgeon should pay attention to both the artery and the vein because it is common that the flap loss is due to venous thrombosis. Therefore, the adequate size and quality of a vein without proximal obstruction is equally important as the artery to serve as a recipient vessel. To avoid the "zone of the injury" would also be an important consideration for selection of recipient vessels in lower extremity free-tissue transfer. Lower extremity angiography or computed tomography angiography has been routinely used in the author's practice as a baseline test to evaluate recipient vessels especially for orthopedic trauma patients. If the surgeon has any suspicion about potential trauma to recipient vessels or deep venous thrombosis, the accompanied vein should also be evaluated separately by duplex scan or venography.

For lower extremity free-tissue transfer, it has been the author's preference that one should try to perform end-to-end anastomosis even for the artery. This can be possible if the anterior tibial artery or dorsalis pedis artery is chosen as a recipient vessel because end-to-end arterial microanastomosis is considered technically easier by most surgeons, although there are no clear data to show that end-to-end anastomosis would have better outcomes than end-to-side one. Although the author prefers to perform end-to-end arterial anastomosis for his patients, end-to-side anastomosis should be done if the patient has only 1 or 2 patent vessels of the leg. The recipient vessel selection for soft-tissue reconstruction of a knee or thigh defect can be challenging; the descending branch of the lateral circumflex femoral vessel or the anterior tibial vessel can be dissected off to serve as the recipient vessels for end-to-end anastomosis.

Flap Dissection

To ensure a relatively quick and easy flap dissection, the surgeon should know as much as possible about the detailed vascular anatomy of the flap before its dissection. This is particularly true for most perforator flaps. In the author's practice, a duplex scan is routinely used for preoperative mapping of the perforators and the pedicle of the perforator flap before the flap dissection. In this way, the size and the number of the perforators that can be selected for the flap, the course of potential intramuscular dissection, and even the depth of the flap's pedicle are evaluated.[9] With the above critical information, a perforator flap, such as an ALT flap, can be elevated smoothly and safely. For an ALT flap dissection, the combination of retrograde and antegrade dissections of the pedicle can be performed for an easy flap dissection once the skin paddle of the flap is elevated. However, some surgeons do not find preoperative imaging studies that worthwhile and prefer not having them for their free perforator flap procedures.[10]

Flap Preparation

The pedicle preparation of the flap can also be an important step in free-tissue transfer. Once the pedicle of the flap is divided, it is the author's preference that the artery of the pedicle is flushed with a higher concentration of heparinized saline (100 units/ml). In this way, the microvascular system of the flap may be loaded with heparin so that future thrombosis within the flap may be prevented without systemic administration of heparin.[11] The pedicle vessels of the flap are prepared under loop magnification. It is the author's preference that the surgical preparation of the pedicle vessels can be done mostly with surgical loops so that a lengthy preparation of the pedicle vessels under an operating microscope can be avoided.

In general, no systemic heparinization is needed for a routine free-tissue transfer to the lower extremity in the author's practice although systemic heparin is still used by some surgeons before clamping vessels in trauma patients. Occasionally for the patient with severe peripheral vascular disease, heparinized saline may be perfused distally before the clamp of the recipient artery.

Microvascular Anastomosis

Microvascular anastomosis is a critical step for the success of free-tissue transfer. After intense flap dissection and preparation of the recipient vessels, the surgeon should consider taking a break before the next intense part of the procedure (microvascular anastomosis). It is the author's belief that taking a short break (about 10–15 min) would greatly enhance the microsurgeon's performance for microvascular anastomosis under a microscope. There are also additional advantages for the patient while the surgeon takes a break. For example, the flap is allowed to rest and perfuse normally after flap dissection to restore normal perfusion, whereas the recipient vessels can be rested and recovered from vasospasm. In addition, hypothermia or hypovolemia, a common condition when a patient has been under general anesthesia for longer period of time, can also be corrected by the anesthesiologist while the surgeon is taking a break. Because of this break, the surgeon, the patient, the flap, and the recipient vessels are all in optimal conditions, and thus, the success of microvascular anastomosis can almost be guaranteed.

Before microvascular anastomosis, the surgeon should take time to set up the vessels. It is the author's preference that a double-armed microvascular clamp is used to aid an end-to-end arterial microanastomosis (Fig. 1). For an end-to-side arterial microanastomosis, the adequate size and shape of an arteriotomy over the recipient artery should be performed to ensure a successful end-to-side arterial microanastomosis (Fig. 2). The author prefers to use an 8-0 nylon suture for routine arterial microanastomosis when the size of the pedicle artery is greater than 1.5 mm, resulting in less number of sutures to be placed to the anastomosis.

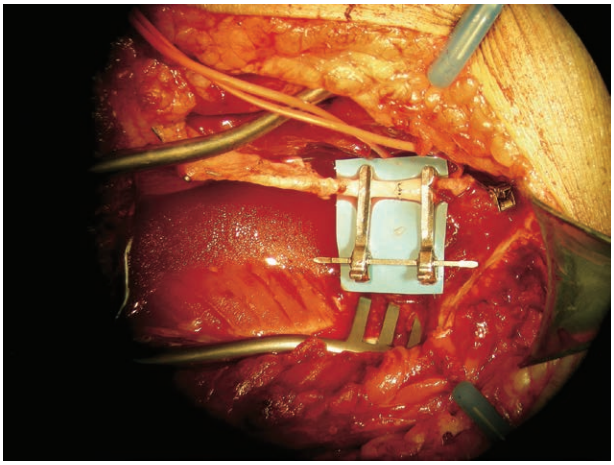

Fig. 1. An intraoperative view shows an end-to-end arterial microanastomosis under an operating microscope. The anastomosis is precisely performed with 8-0 nylon in an interrupted fashion after a proper preparation of both pedicle and recipient arteries.

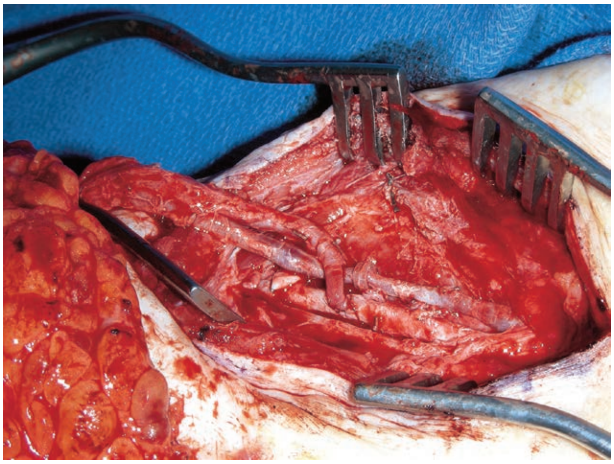

Fig. 2. An intraoperative view shows an end-to-side arterial microanastomosis. The anastomosis is precisely performed with 8-0 nylon in an interrupted fashion after the adequate size and shape of an arteriotomy over the recipient artery is made.

For venous microanastomosis, it is the author's preference that a coupler device is routinely used for an end-to-end venous anastomosis (Fig. 3). The author has always been able to find proper size of both pedicle and recipient veins for venous microanastomosis with the device. The coupler device has an excellent patency rate from the study of large clinical series even for the lower extremity free-tissue transfer.[12] It is fast and easy to learn and is shown not to leak once the anastomosis has been completed. It makes venous microanastomosis much more enjoyable without struggling. It also has an additional advantage because the ring of the device may be able to prevent external compression to the anastomotic site.

Once microclamps are released, it is the author's preference that the arterial anastomosis is wrapped with gauze because most of the bleeding can be stopped with this ma-

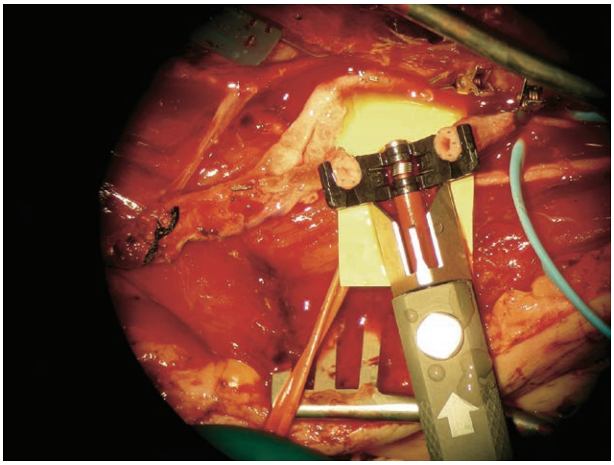

Fig. 3. An intraoperative view shows an end-to-end venous microanastomosis with a coupler device before its completion under an operating microscopy. The coupler device is precisely placed to each end of pedicle and recipient veins after a proper preparation.

Fig. 5. An intraoperative view shows the completion of a free ALT flap inset to a left distal leg wound. An acceptable contour of the flap is achieved in the operating room.

neuver. It is seldom necessary to place additional sutures unless there is a high flow of bleeding from the arterial anastomotic site. In that case, a 9-0 nylon suture is used to repair the leak site.

Flap Inset

For flap inset, it is important to avoid any tension or compression to both arterial and venous microanastomoses. The author prefers to place horizontal mattress sutures for flap inset so that a more cosmetic pleasing result can be achieved.[13] This can be done for either muscle flap or fasciocutaneous flap. A closed suction drain should be placed away from both microvascular anastomoses (Figs. 4, 5).

Immediate Postoperative Care

A standard postoperative care protocol for free-tissue transfer to the lower extremity is important and practical. This would ensure that everyone in the microsurgical team would be on the same page for patient care. It is the author's opinion that a protocol-driven postoperative care will be able to provide a better outcome of free-tissue transfer to the lower extremity especially in a teaching program. This can be true when even a small volume of free-tissue reconstructions is performed in a hospital. Table 2 summarizes the author's standard protocol for immediate postoperative care for free-tissue transfer to the lower extremity.[11,14]

Fig. 4. An intraoperative view shows the completion of a free rectus abdominis muscle flap inset to a large right knee wound before the placement of a skin graft. An acceptable contour of the flap is achieved in the operating room.

Intermediate Postoperative Care

Because the flap is always in a dependent position, intermediate postoperative care for free-tissue transfer to the lower extremity can be unique but also critical. It is agreeable that dangling should be done for each patient so that the flap can tolerate venous congestion because it is placed in a dependent position. Unfortunately, there is no unified dangling protocol that can be used during intermediate postoperative period.[15] Table 3 summarizes a standard dangling protocol used by the author. The protocol itself has been used widely by the author and his trainees with good success. It is up to the discretion of the surgeon to tailor the protocol so that it can be integrated into his or her practice. Recently, wrapping in combina-

Table 2. A Standard Protocol for Immediate Postoperative Care after Free-tissue Transfer to the Lower Extremity

Aspirin 325 mg suppository per rectum in recovery room, then 81 mg orally every day for 3 months.
Lactated Ringer's solution intravenously at ±125 ml/h for 3 days and keep urine output >50 ml/h.
Dextran-40 intravenously at 25 ml/h for the first 3 days, half at day 4 and off at day 5 (for difficult and complicated free-tissue transfer only).
Warm unit to flap site.
Flap check with Doppler/clinical examination every hour for first 24 hours, then every 4 hours for 4 days (alternative Cook implantable Doppler monitoring for first 5 days).
Bed rest for first 3 days and may get out-of-bed at day 4.
Physical therapy as per operating surgeon.

Table 3. A Dangling Protocol for Intermediate Postoperative Care after Free-tissue Transfer to the Lower Extremity

At 1 week post operation—start dangling if flap has no complications:
- 5 min every hour for first and second days
- 10 min every hour for third and fourth days
- 15 min every hour for fifth and sixth days

At 2 weeks post operation:
- If patient tolerates dangling for 15 min, discharge home with ace wrap but maintain leg elevation as much as possible and no weight bearing

At 3 weeks postoperation:
- Start progressive weight bearing with ace wrap protection for up to 3 months

tion with dangling has been proposed by other surgeons to speed up the process of the flap maturity.[16]

Further Follow-up Care

Besides ensuring adequate healing of the flap, the contour of the flap in the lower extremity can become an issue during further follow-up. It has been common that the bulkiness of the flap needs to be revised so that a better contour of the lower extremity can be achieved. It is the author's preference that a minimum of 6 months' waiting period should be expected before a debulking procedure can be considered especially for a skin-grafted muscle flap. Within the 6 months postoperatively, an ace wrapping to the flap site can be placed to improve swelling of the flap. However, some surgeons may perform the flap debulking procedure earlier as long as they believe it would be safe to do so.

After 6 months, the revision surgery can be performed to improve the contour of the flap.[12] For a muscle flap, it has been the author's preference that a tangential incision of excess flap tissue can be performed to achieve a better contour. Once adequate excision of excess flap tissue is done, additional skin grafts are placed to the rest of the flap. In this way, a better contour of the leg or foot can be achieved (Fig. 6). For a fasciocutaneous flap, suction-assisted lipectomy should be performed first to remove excess adipose tissue of the flap. Additional skin resection is often necessary to achieve better contour of the flap (Fig. 7).

PATIENTS AND METHODS

Between 2007 and 2015, 28 consecutive lower extremity free-tissue transfers were performed by the author in 28 patients for soft-tissue reconstruction of a leg, ankle, or foot wound primarily after orthopedic trauma (Table 4). The comprehensive approach developed by the author was applied for all patients. There were 20 fasciocutaneous flaps (18 anterolateral thigh and 2 free-style thigh) and 8 muscle flaps (3 rectus abdominis, 3 gracilis, and 2 latissimus dorsi). The clinical outcome was recorded based on the success of free-tissue transfer in the perioperative period, any reoperations related or unrelated to the revision of microvascular anastomosis, and any partial or total flap loss during up to 8-year follow-up. The study was approved by our institutional review board.

RESULTS

All 28 lower extremity free-tissue transfers were performed successfully in the operating room. All patients were discharged home once they tolerated dangling according to the protocol. One patient had evacuation of hematoma under the flap, 1 patient had flap readvancement for closure of the dehisced skin incision, 3 patients had flap elevation for subsequent orthopedic procedures, 2 patients had additional skin grafting procedures, and 2 patients had flap debulking for contour improvement. There were no reoperations related to the revision of microvascular anastomosis. No partial or total flap loss was encountered in this series. The overall success rate of free-tissue transfer to the lower extremity was 100%. All patients in this series had a healed flap reconstruction site with a reliable soft-tissue coverage during follow-up (Table 4) (Fig. 9).

DISCUSSION

To ensure success for every free-tissue transfer to the lower extremity, the author has developed this comprehensive approach that includes patient selection, flap selection, selection of recipient vessels, flap dissection, flap preparation, microvascular anastomosis, flap inset, immediate postoperative care, intermediate postoperative care, and further follow-up care (Table 1). Every single step in this comprehensive approach is critical to the success for

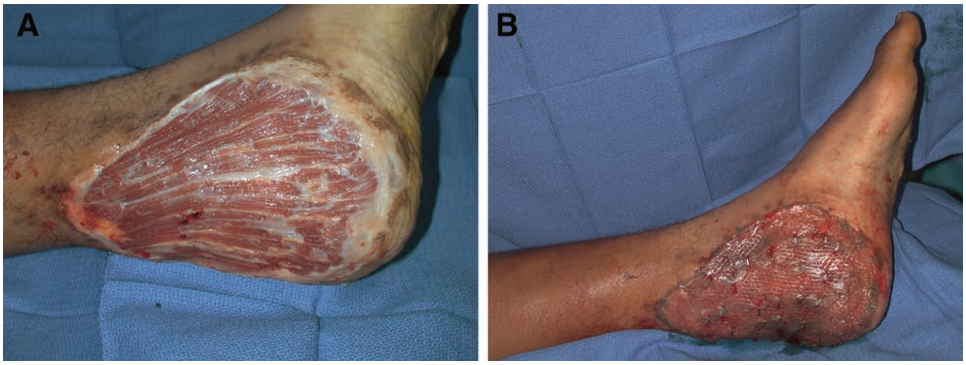

Fig. 6. A, An intraoperative view shows the completion of a skin-grafted free latissimus dorsi muscle flap debulking in the left foot and ankle. The excess flap tissue is tangentially excised under tourniquet control. B, The raw surface of the flap is then placed with new split-thickness skin grafts.

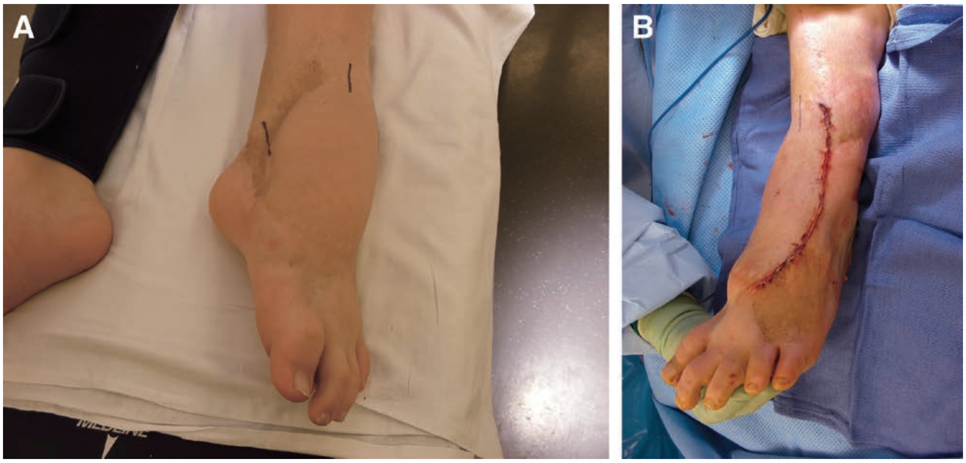

Fig. 7. A, An intraoperative view shows a well-healed free ALT flap in the left foot and ankle. B, The completion of the flap debulking procedure. The excess subcutaneous flap tissue is removed via liposuction, and the subsequent excess skin is excised directly.

Table 4. Clinical Data for 28 Consecutive Free-tissue Transfers to the Lower Extremity

	Age	Sex	Location of Defect	Flap Selected	Anastomosis	Reoperation	Outcome
1	39	M	R leg	Rectus abdominis	AT, end-to-end	No	Good
2	51	M	R foot	Anterolateral thigh	DP, end-to-end	Flap debulking	Good
3	70	M	L leg	Rectus abdominis	PT, end-to-side	No	Good
4	63	M	R leg	Gracilis	PT, end-to-side	No	Good
5	34	F	R leg	Gracilis	PT, end-to-side	No	Good
6	31	F	R leg	Latissimus dorsi	AT, end-to-end	Skin grafting	Good
7	28	M	L foot/ankle	Anterolateral thigh	PT, end-to-side	No	Good
8	40	M	L leg	Anterolateral thigh	AT, end-to-end	Skin grafting	Good
9	31	M	L leg	Anterolateral thigh	AT, end-to-end	No	Good
10	19	F	L thigh AKA stump	Anterolateral thigh	SFA, end-to-side	No	Good
11	36	M	L knee	Free-style thigh	AT, end-to-side	Flap elevation	Good
12	41	M	L hip	Latissimus dorsi	DBLCFA, end-to-end	Flap elevation	Good
13	62	F	R knee	Rectus abdominis	AT, end-to-end	Removal hematoma	Good
14	33	F	R leg	Anterolateral thigh	AT, end-to-end	Flap readvancement	Good
15	64	M	L leg	Anterolateral thigh	PT, end-to-side	No	Good
16	19	M	L knee	Anterolateral thigh	DBLCFA, end-to-end	No	Good
17	27	M	L knee	Anterolateral thigh	AT, end-to-end	No	Good
18	54	M	L leg	Anterolateral thigh	AT, end-to-end	No	Good
19	24	M	R BKA stump	Anterolateral thigh	SFA, end-to-end	No	Good
20	61	M	R leg	Anterolateral thigh	PT, end-to-side	No	Good
21	53	M	R leg	Anterolateral thigh	AT, end-to-end	Flap debulking	Good
22	55	M	R leg	Anterolateral thigh	AT, end-to-end	No	Good
23	52	M	R ankle	Anterolateral thigh	AT, end-to-end	No	Good
24	49	M	L leg	Anterolateral thigh	AT, end-to-end	No	Good
25	55	M	R leg	Gracilis	PT, end-to-side	Flap elevation	Good
26	30	M	L foot	Free-style thigh	AT, end-to-end	No	Good
27	62	M	R foot	Anterolateral thigh	AT, end-to-end	No	Good
28	47	M	L leg	Anterolateral thigh	PT, end-to-side	No	Good

AKA, above knee amputation; AT, anterior tibial artery; BKA, below knee amputation; DBLCFA, descending branch of lateral circumflex femoral artery; DP, dorsalis pedis; F, female; L, left; M, male; PT, posterior tibial artery; R, right; SFA, superficial femoral artery.

free-tissue transfer to the lower extremity in contrast to some beliefs that only microvascular anastomosis is important. If each step in this comprehensive approach is not properly conducted, failure of free-tissue transfer to the lower extremity is likely to happen.[17]

There are many justifications or reasoning behind each different step in the protocol. Some justifications are based on the best available knowledge in each specific topic the author has learned from his clinical experience. For example, the justification to use dextran after free perforator flap reconstruction is based on the beneficial effects dextran may have and the nature of free perforator flap surgery. In addition, the author has not encountered any complications related to the use of dextran in his patients. However, dextran-related complications in head and neck microsurgery have been reported in the literature so the routine use of the agent after a less complicated free flap surgery should be discouraged.[14]

There is a learning curve for a young surgeon to master his or her technique for free-tissue transfer to the lower extremity. Other issues such as avoiding the zone of injury where microvascular anastomosis is performed and the timing of the free flap surgery are also critical to

Fig. 8. A, A 30-year-old African American man (case 26) had a large (15 × 9 cm) left dorsal foot wound with exposed extensor tendons and reconstruction plate after motor vehicle accident. B, A perforator within the skin paddle was identified by intraoperative duplex scan, and a 15 × 8 cm ALT flap was designed. C, During the flap elevation, the perforator, however, was found to be small and less reliable, but a larger and reliable perforator was found more proximally in an unusual location. After a tedious intramuscular dissection, an adequate length and diameter of the flap pedicle was determined, and the flap was elevated as a free-style free thigh flap. D, Intraoperative view showing completion of the flap inset and placement of a split-thickness skin graft. The flap donor site was closed primarily.

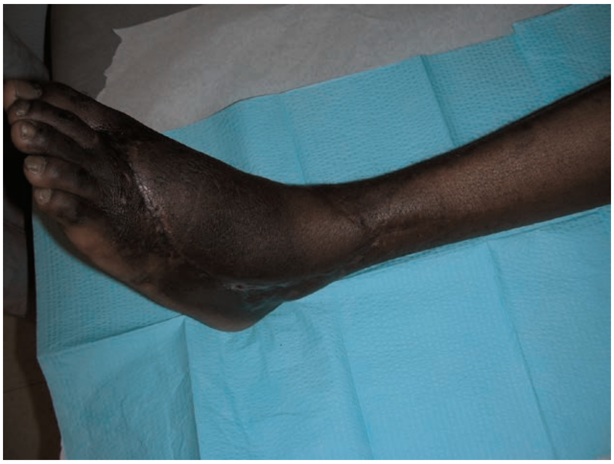

Fig. 9. Results at 3-month follow-up.

the success. In the author's practice, the zone of injury is determined based on the mechanism of injury and the findings during surgical exploration, and a definitive reconstruction with free-tissue transfer is usually performed within 3 weeks after initial injury or surgical resection.

The successful clinical outcome of free-tissue transfer to the lower extremity has been achieved by the author with this approach. Such an approach provides the first detailed strategy and effective perioperative management that can optimize the outcome of free-tissue transfer to the lower extremity. It may help less-experienced surgeons to master their skills in lower extremity free-tissue transfer if these 10 important steps are properly evaluated, conducted, and managed. This comprehensive approach may only represent a single surgeon's preference and management protocol. However, it can be integrated and adapted by others to maximize their success and avoid the failure of free-tissue transfer to the lower extremity.

CONCLUSIONS

An ideal clinical outcome of free-tissue transfer to the lower extremity can be accomplished with this comprehensive approach developed by the author. With adequate microsurgical skill, good surgical judgment, well-instructed and step-by-step intraoperative execution, and a protocol-driven practice, one can certainly be able to improve his or her success for free-tissue transfer to the lower extremity with minimal complications.

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