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Flow-Through Free Anterolateral Thigh Flap in Reconstruction of Severe Limb Injury

Zhao Yang, MD,[a] Chao Xu, MD,[b] Yonggang Zhu, MM,[b] Jun Li, MM,[b] Jiwei Zou, MD,[b] Baobao Xue, MM,[b] Xiaojiang Yang, MD,[b] and Guangyue Zhao, MD[b]

Objective: This study aimed to present the use of flow-through free anterolateral thigh (ALT) flap for the reconstruction of severe limb injury.

Patients and Methods: Four patients (2 male and 2 female subjects), with an average age of 26 (9–39) years, were included. These injuries referred to upper and lower limbs, including bone, soft tissue, nerve, and arterial segments. Two patients experienced large soft tissue defects in the lower limb and were repaired by double flow-through ALT flaps. The sizes of damaged soft tissues in the remaining 2 patients were 14×10 cm^2 and 21×13 cm^2, respectively. Three patients had bone fractures, in which one of them experienced bone shortening during operation. The arterial injury was observed in 2 patients and the lengths of defects were 5 and 12 cm, respectively. Flow-through free ALT flap was applied for all 4 patients.

Results: Patients were followed up for 18 months. All the flaps have survived successfully without any vascular crisis or infection. All incision wounds were under primary healing stage, without any severe complications. The flaps showed better appearance, color, texture, and satisfactory sensation. All patients had satisfactory functional recovery of their injured limbs.

Conclusions: The flow-through free ALT flap assists in overcoming complex traumatic injuries with severe soft tissue and arterial defects in the limbs. This flow-through ALT flap can be an effective alternative for reconstruction of severe limb injury.

Key Words: flow-through free anterolateral thigh flap, severe limb injury, composite tissue defects

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Severe traumatic injuries that lead to large soft tissue defects and/or vascular impairment have become a challenging problem for reconstructive surgeons. Microsurgical techniques such as flap transfer causes tissue loss in extremities in patients but is a reliable option for assessing healthy free tissues and recipient vessels.[1,2] However, the major trauma of extremities, especially during severe injury, more often involves bones, vascular, and their soft tissue coverage defects. Traditional flap could not solve the problem in these cases, as the complex injuries not only involves closure of the defects but also requires restoration of complete hemoperfusion of the distal artery and functioning of the limb.

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From the [a]Department of Military Medical Psychology, Air Force Military Medical University; and [b]Department of Orthopeadic Surgery, Xijing Hospital, Air Force Military Medical University, Xi'an, Shaanxi Province, People's Republic of China.

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Z.Y. and C.X. contributed equally to this work.

Reprints: Guangyue Zhao, MD, Department of Orthopeadic Surgery, Xijing Hospital, Air Force Military Medical University, No. 127 Changle Xi Rd, Xi'an, Shaanxi Province, 710032, PR China. E-mail: zhaogyue@fmmu.edu.cn.

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Flow-through flaps have been widely used in reconstructive surgery since 1983.[3] It is advantageous because of sufficient perfusion of it into the distal tissue, as free flap with vascular pedicle is anastomosed to both proximal and distal ends.[4] The flap cover also plays an important role in reconstruction when deep structures (such as tendons, nerve, and/or bone) are exposed. Flaps from free anterolateral thigh (ALT) have been reported to successfully bridge the vascular gaps of up to 20 cm and provide soft tissue coverage of up to 30 cm in length and 15 cm in width.[5] We herein presented the use of flow-through free ALT flap for reconstruction of severe limb injuries, which include bone, vascular, and large soft tissue defects.

PATIENTS AND METHODS

Clinical Data

This retrospective observational study was approved by the ethics committee of the Air Force Military Medical University. Four patients (2 male and 2 female subjects), with an average age of 26 (9–39) years, were included. The characteristics of these patients were analyzed and presented in Table 1. All patients included have experienced high-energy trauma. These injuries referred to upper and lower limbs, including bone, soft tissue, nerves, and arterial segments. Two patients had large soft tissue defects in the lower limb and underwent repair by double flow-through ALT flaps. The sizes of damaged soft tissues of the remaining 2 patients were 14×10 cm^2 and 21×13 cm^2, respectively. Three patients had bone fractures, and one of them experienced bone shortening during operation. Arterial injury was observed in 2 patients and the lengths of defects were 5 and 12 cm, respectively.

Treatments

The patient was placed in supine position after undergoing general anesthesia. All devitalized tissues have been removed thoroughly after aggressive debridement. K-wires were used for fixing phalanges and small joints in the left hand of a patient. External fixator along with lag screw was used for fixing tibial fractures in the other 2 cases. Emergency "orthoplastic" surgery (do bone, soft tissue, and other vessel/nerve defects reconstruction in the same stage) was performed in 2 cases and in the remaining 2 patients traditional orthopedic treatment (reconstruction completed by more than one stage) was performed. The defect associated with ulnar artery and median nerve in one case was repaired by small saphenous vein and sural nerve transplantation. The soft tissue defects in all cases were reconstructed by flow-through ALT flaps. Anterolateral thigh flaps with vessel were harvested from contralateral thigh in 2 patients with upper limb and hand injuries. The lower limb in the other 2 patients was repaired by double flow-through ALT flaps and skin grafting. Microsurgical end-to-end anastomosis was performed between the proximal/distal peroneal arteries of the flap and the proximal/distal arteries of the recipient site, respectively, and similarly was done for anastomosis of the veins. The flaps were sutured loosely in situ and then carefully manage the blood supply, anti-infection, anticoagulant, and antispasmodic methods. Radiography

TABLE 1. Demographic and Clinical Characteristics of Included Patients Case

Case	Age, y	Sex	Cause of Injury	Location	Flap Type	Timing of Flap Coverage	Anastomotic A	Area of Soft Tissue Defects	Vessel Injuries of the Limb	Follow-up Period, mo
1	19	M	High-energy trauma	Left forearm and hand	Right ALT	Primary operation (<1 d)	Radial A	14×10 cm^2	Radial A and V, ulnar A and V, cephalic V, basilic V, median V	18
2	39	F	High-energy trauma	Right leg	Bilateral ALT	Primary operation (1 d < T < 4 d)	Anterior tibial A	The entire right leg (approximate 6.5% of body surface area)	Great and small saphenous V, peroneal A and V	36
3	37	F	High-energy trauma	Left hand	Right ALT	Second operation (<2 d)	Radial A	21×13 cm^2	Cephalic V	18
4	9	M	High-energy trauma	Left lower limb	Bilateral ALT + foster plantar skin	Second operation (1 wk < T < 4 wk)	Posterior tibial A	The entire left leg, ankle, and foot (approximate 10% of body surface area)	Great saphenous V	24

No complications were found in any patients.

A, artery; F, female; M, male; V, vein.

was performed after 1 week of surgery. The duration of follow-up period was more than 18 months.

RESULTS

The flow-through ALT flaps have survived in all patients uneventfully. The blood supply and the arterial pulse of distal limbs in these cases appeared normal after operation. After removing the stitches at 2 weeks, patients were followed up every 6 weeks. K-wires and external fixation were removed after 6 months of operation. At week 12 after operation, the patient was permitted for partial weight bearing. Functional recovery and movements were achieved after 9 to 10 months. All the flaps have survived successfully without vascular crisis or infection. All incision wounds were in primary healing stage and showed no severe complications. The flaps showed better appearance, color, texture, and satisfactory sensation. All patients were satisfied with the functional recovery of their injured limbs.

Case 1

A 19-year-old man was referred to our hospital with severe trauma in the left forearm because of a rolling injury after 6 hours of the initial accident. The volar defect area in the left forearm of this patient was 1014 cm^2. The muscles and tendons (including brachioradialis, flexor carpi radialis, flexor carpi ulnaris, palmaris longus, superficial flexor of the index finger, middle finger, ring finger, and little finger), ulnar nerve, radial nerve and median nerve, radial artery and vein, as well as ulnar artery and vein were severely damaged (including defects and contamination; Fig. 1A). Radiographic examination showed no fracture of the left forearm and hand (Figs. 1B, C). After aggressive debridement of the contaminated tissue, the left ALT flap (10 × 14 cm) used for covering was measured (Fig. 1D). However, because of vascular variation of the left ALT flap, the right ALT flap was chosen (Figs. 1E, F). The rupture of tendons was reconstructed by anastomosis and weaving. The defect of ulnar artery and median nerve was repaired by left small saphenous vein and left sural nerve transplantation, respectively. External fixator was used for wrist stabilization. The pedicled ALT flap was end-to-end anastomosed onto the proximal radial artery in the proximal pedicle and anastomosed onto the distal radial artery in distal pedicle. The vein of ALT flap was end-to-end anastomosed onto the radial vein in the same manner by using a 10-0 nylon suture (Fig. 1G). Angiography showed complete patency of the radial artery and ulnar artery (Fig. 1H). The patient was requested to undergo functional training after surgery (showed in supplementary data, http://links.lww.com/SAP/A484, http://links.lww.com/SAP/A485, http://links.lww.com/SAP/A486, http://links.lww.com/SAP/A487, http://links.lww.com/SAP/A488, http://links.lww.com/SAP/A489, http://links.lww.com/SAP/A490, http://links.lww.com/SAP/A491). However, as the muscles and tendons were severely damaged in this patient, the strength of the muscles and tendons showed slow improvement and the patient was permitted to undergo partial weight bearing (such as carrying heavy things) until 12 weeks postoperatively. External fixation was removed at 6 months postoperation. Satisfactory functional recovery was achieved at 9 months postoperation (Figs. 1I, J).

Case 2

A 39-year-old woman was transferred to our department with severe trauma of right leg because of a bruise injury after 39 hours of initial accident. Large defects of soft tissues and serious contusion were observed in her right leg (Fig. 2A). All the devitalized tissue was removed by thorough debridement (Fig. 2B). Composite defects were observed and the reserved tissues included the right anterior tibial artery and vein, posterior tibial artery and vein, tibial nerve, superficial peroneal nerve, extensor digitorum longus, peroneus, tibialis posterior, Achilles tendon, partial gastrocnemius, and flexor digitorum longus. Other tissues of right leg were all removed (Fig. 2C). Radiographic examination showed fractures of right tibial and fibular bones (Fig. 2D). Bone shortening was done for restoring the length of the tibia. External fixator along with lag screw was used for fixing the tibial fracture (Figs. 2E–G). The design of double flow-through ALT flaps for repairing the right leg was shown in Figure 3. Both sides of the ALT flaps were harvested. A microsurgical end-to-end anastomosis was performed between proximal artery of the pedicled ALT flap and proximal anterior tibial artery by using a 10-0 nylon suture. Another pedicled ALT flap was end-to-end anastomosed onto the distal artery and anastomosed onto the distal anterior tibial artery in the distal pedicle as illustrated in Figure 3. The vein of ALT flap was anastomosed in the similar manner. These 2 flaps covered the tibia, fibular, and deep tissues in a satisfactory manner (Figs. 3A–F). Skin grafting was used to cover the exposed muscles in the right leg after 2 weeks. Tibial osteotomy lengthening operation was conducted at 8 months of postoperation, and the fixation was replaced by unilateral external fixation (Figs. 3G–J). The flaps and the grafted skin survived uneventfully with no perioperative

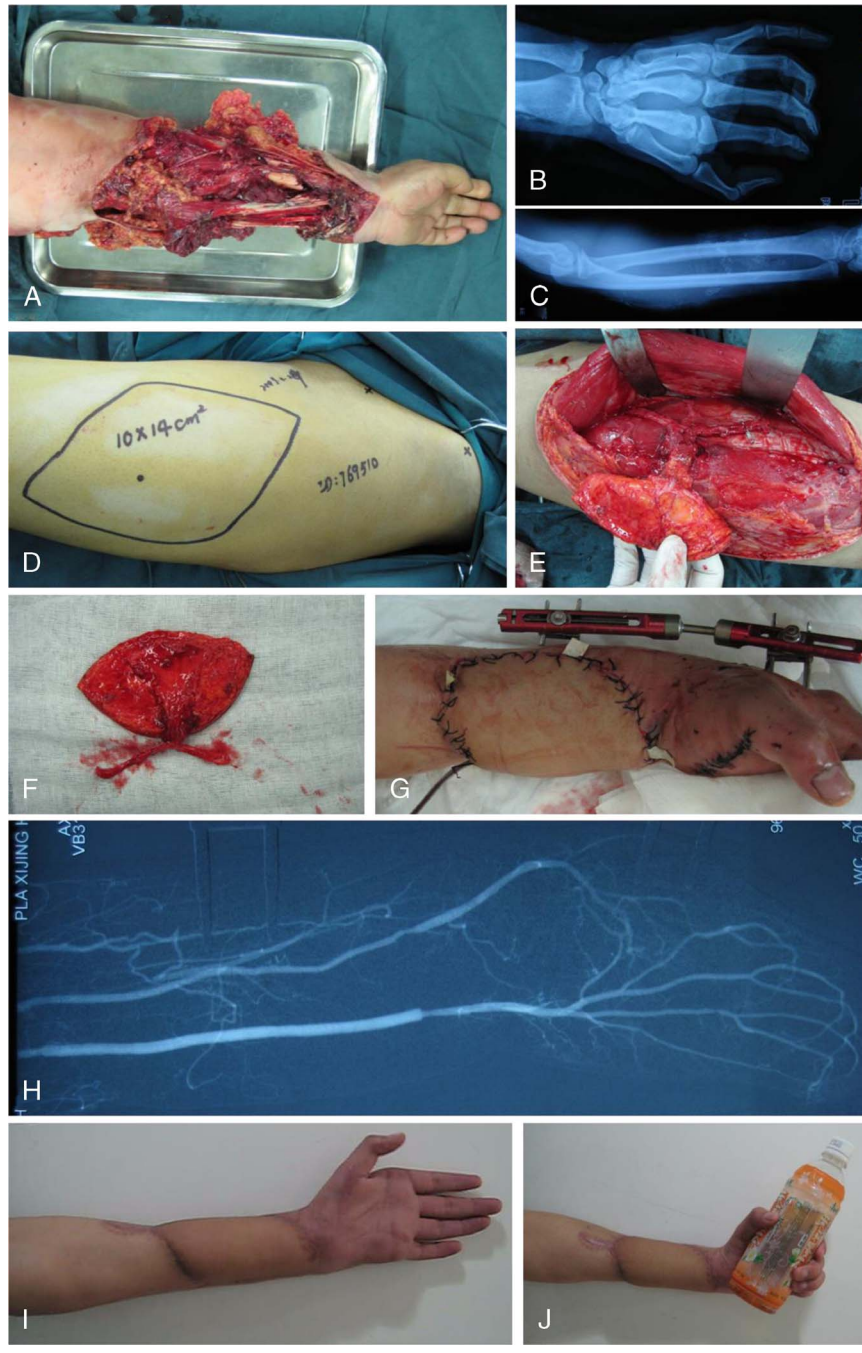

FIGURE 1. Appearance of left forearm due to a ground injury after 6 hours of initial accident (A–C). Appearance of left ALT flap (D) and right ALT flap (E and F). Defects were covered by ALT flap (G) and angiography evaluation of left radial and ulnar arteries (H). The patient's conditions and functional recovery at 9 months of postoperation (I and J). full color online

complications and achieved satisfactory functional recovery and ambulation at 9 months of postoperation (Figs. 3K–N).

DISCUSSION

Free-flap techniques have been widely used for complex traumatic injuries to overcome recipient composite defects. However, patients with severe soft tissue and vessel defects in the distal limb are still facing challenges for reconstruction by traditional flap methods. This retrospective study demonstrated that flow-through free ALT flap was a reliable way for reconstruction of large soft tissues and main arterial segmental defects. All the flaps survived successfully without vascular crisis or infection. Satisfactory functional recovery and movements were achieved.

The failure rate of free tissue transfer in the lower extremity in some cases is more than 10%.[6–8] Besides, there are some other complications associated with lower extremity free flaps, such as the risks of venous and arterial thrombosis, venous congestion, and tissue edema because of limited venous outflow, which increase the risk of flap failure.[9,10]

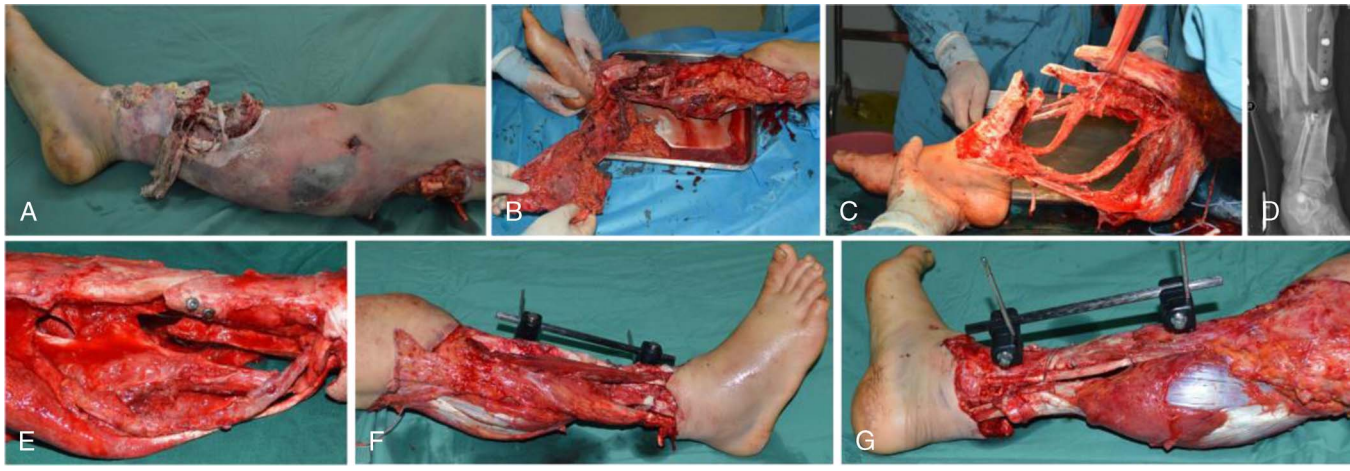

FIGURE 2. Appearance of right leg due to a bruise injury 39 hours after the initial accident (A and B). Appearance of right leg after debridement (C). Radiographic examination of right tibial and fibular fractures (D). Appearance of right leg after shortening and external fixation (E–G). full color online

On the other side, arterial vascular grafts have the advantages in the reconstruction of arterial defects based on high long-term patency rates.[11–15] Since 1983, numerous flow-through flaps have been reported.[3,16–19] Severe limb injury might lead to fractures, large area of soft tissue losses, and segmental defects on both sides of the arteries, and it not only requires wound covering but also requires blood supply to the distal limb. Effective approaches usually included a flap combined with a vein graft[20] or a flow-through flap.[21,22] The former method requires additional vein graft operation, thus increasing the risk of infection and influencing the blood circulation from the donor end. Moreover, this method might be impossible if the donor vein is injured. Flow-through flap provides opportunity to revascularize the recipient ischemic site rather than just covering the soft tissue defect. A flow-through flap, which requires more microvascular anastomoses, seems to be more complex than simple free flaps.[18] The traditional reconstruction by simple free flaps involves 2 stages: revascularization by vascular graft and flap coverage of the defect. This faces a second surgery, prolonging the operation time, increasing the complications, etc. These deficiencies are exactly avoided by flow-through flap. Besides, researches have shown that usage of long vein grafts might reverse the flow within the vein grafts and arteries, causing turbulent flow, stasis, and thrombosis.[23] Artificial blood vessel has some advantages but has significantly lower patency rate, high limb salvage rate, and risk of infectious complications, limiting its application.[24,25] Therefore, in complex extremity injuries, flow-through flap is regarded as an efficient alternative for revascularization and coverage.

Flow-through flap plays a role of "vessel bridge" by providing vascular pedicle for reconstruction of the main artery. The cutaneous branch or muscular branch of the flap pedicle can repair the wound by its affiliated fascia and muscle. Therefore, it is considered to be an ideal method for restoring arterial and soft tissue defects, thus achieving the goal of rebuilding the circulation and coverage simultaneous. This raises the question that the flow-through flap pedicle is long, wide in diameter, and with hypervascularity of cutaneous branch.

The significant advantage of this flow-through flap is that it provides blood supply without sacrificing the main vessels. Thus, the primary indication of flow-through flap is that the injured limb exists only by one main blood vessel. Flow-through flap can also be used for repairing an artery in which both the main blood vessels were injured. This method also eliminates complication such as autonomical disturbances.

As for these advantages, flow-through flaps can be used for numerous purposes of limb reconstruction. More specifically, the flow-through flap had been successfully chosen for reconstruction in electrical burns of the severely damaged upper extremity,[26] ischemic extremities,[27] posttraumatic defects of the foot,[28] and extremity injuries with soft tissue and long vascular gap[29] because of its capacity of providing soft tissue coverage and arterial repairing simultaneously. Other reports[30–35] showed that flow-through flaps supplied from multiple sources can satisfy varied requirements of complex soft tissue defects and major arterial damage.

Longer vascular pedicle, which does not need sacrifice the main artery and can be harvest through the supine position, made ALT flap superior to other types of flow-through flaps.[36] Tang et al[37] showed their application of flow-through chimeric ALT perforator flap for complex defects of the extremities. The results indicated that this kind of chimeric ALT flow-through flap is an effective method for complex injuries in the limbs with dead space.

Chen et al[38] have described their uses with regard to flow-through flap, pointing out that there is no vessel crisis occurred in their cases. However, a slight postoperative edema in flow-through flaps was observed. In our cases, functional recovery and movements were achieved without any severe complications, and also no postoperative edema was observed. All patients were satisfied with good functional recovery of their injured limbs.

The highlight of our study is that one of these cases (case 2) presents a typical concept of "orthoplastic," which refers to a well-combined approach to open fractures. The combined "orthoplastic" treatment aims to repair fractures and soft tissue in one stage and has been recommended by the publication of standards of care (British Orthopedic Association, British Association of Plastic Reconstructive and Aesthetic Surgery).[39] More than that, the debridement, fix, flap, and vascular anastomosis were accomplished in one stage in case 2. Based on thorough and satisfactory debridement, the timing of flap coverage in case 1 and case 2 was in primary operation. This operation made 2 patients achieved very satisfying limb functional recovery without any complication.

CONCLUSIONS

Our study indicated the flow-through free ALT flap was an effective and reliable option for the reconstruction of large soft tissue and main artery segmental defects. It provides a well-vascularized viable

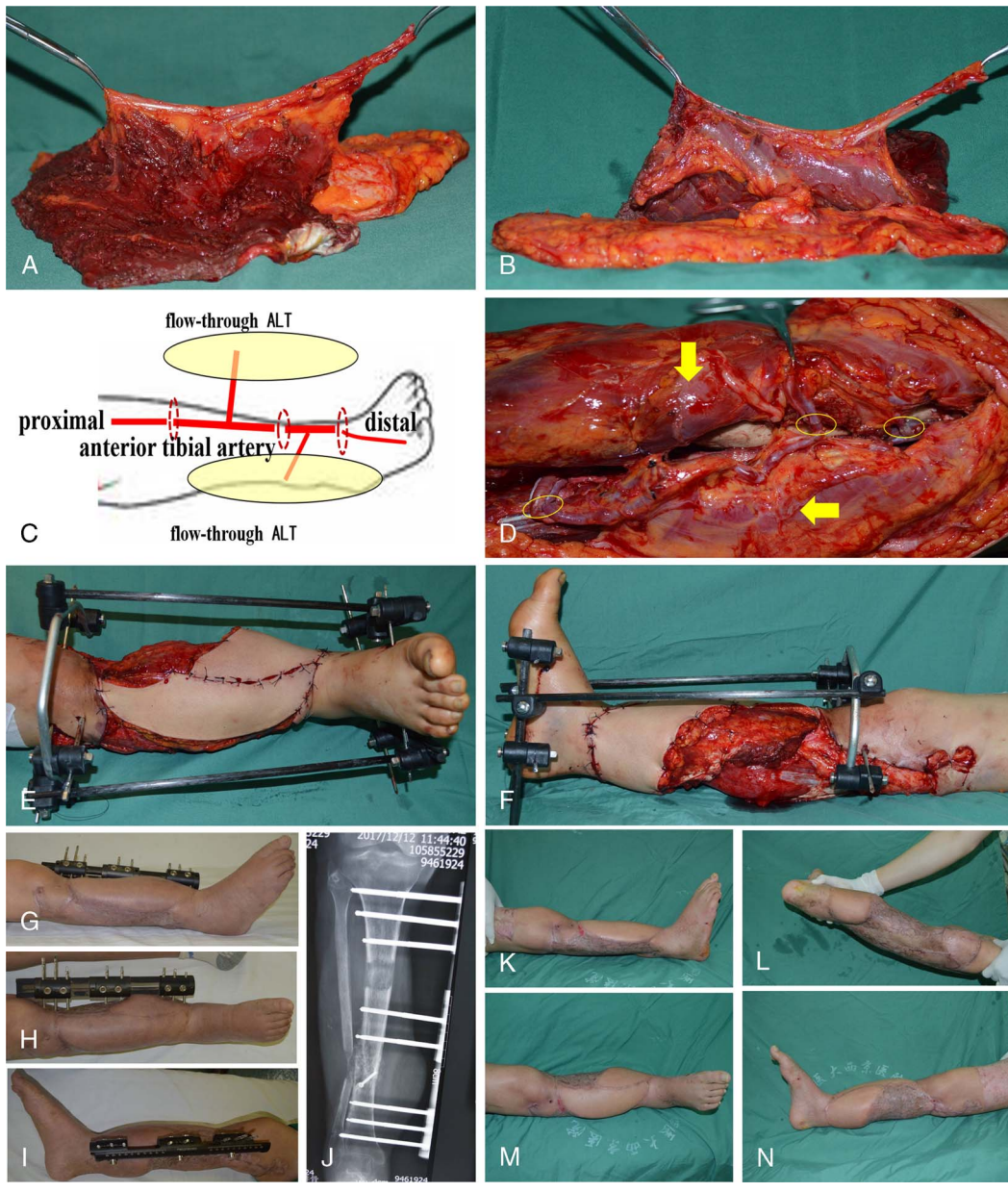

FIGURE 3. The design of double flow-through ALT flaps for right leg reconstruction. Appearance of left ALT flap (A) and right ALT flap (B). Diagram of double flow-through ALT flap (C). Intraoperative appearance after flap transfer (D) (yellow arrows: ALT flap; yellow circle: vascular anastomoses). Defects covered by double ALT flaps (E and F). The appearance of survived composite flap in the right leg at 8 months of postoperation (G–I). X-ray examinations of tibial osteotomy lengthening (J). Appearance of the survived composite flap at 9 months of follow-up (K–N). full color online

tissue cover for exposed deep structures (tendons, nerve, and/or bone). It avoids further infection after first debridement. This one-stage management has been proved more effectively and safely in severe open fracture managements.

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