

Original Article

Comparison of venous drainage in flow-through and conventional dorsalis pedis flaps for repair of dorsal foot defects

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Abstract: Inadequate venous drainage can lead to congestion and necrosis of flaps used in the repair of defects, thereby elevating the risk of flap failure. In this study, we sought to test the hypothesis that the venous drainage was better in flow-through flaps than in conventional dorsalis pedis free flaps used in the repair of dorsal foot defects. In this retrospective study, we investigated the data of 14 patients who underwent repair with flow-through flaps ($n = 7$) or conventional flaps ($n = 7$) for dorsal foot defects, between January 2007 and December 2013. The defects ranged from 6.2×11 cm to 9.5×16 cm in size. The donor sites were resurfaced using full-thickness free-skin grafts, and after transfer, the flaps were evaluated for postoperative congestion, surviving area, and sensory function. The results showed that the operative time was significantly longer for flow-through flaps than for conventional flaps (6.4 ± 1.7 h vs. 4.3 ± 1.2 h, $P = 0.020$), mainly due to additional dissection of the first dorsal metatarsal artery required in the case of the former. Necrosis was observed in the case of 4 conventional flaps, but not in the case of flow-through flaps. The flow-through flaps showed significantly lower incidence of congestion and higher survival area proportion than the conventional flaps ($P < 0.05$). The flow-through dorsalis pedis flaps have the advantages of lower incidence of necrosis and congestion and better survival over the conventional flaps in the repair of dorsal foot defects, and absence of additional morbidities, but required a longer operative time than conventional flaps.

Keywords: Reconstruction, dorsalis pedis flap, foot, defect, necrosis, venous outflow

Introduction

Insufficient venous drainage, which frequently occurs after flap grafting, is an independent risk factor for further complications [1]. The lack of venous outflow can lead to flap congestion and necrosis, increase the risk of flap failure, and necessitate secondary surgery [2]. If insufficiency of venous drainage is detected, various methods are employed to limit congestion and necrosis and prevent possible flap failure; these methods include the local administration of heparin [3], venous catheterization [4], and application of medical leeches [4]. However, a more desirable approach would be to prevent the insufficiency of venous drainage, rather than correct its consequences.

Large tissue defects with associated vascular damage can occur as a result of severe trauma,

tumor resection, or infection. The repair of such defects is aimed at achieving two goals—the revascularization of the area via a vascular conduit and the coverage of the soft-tissue defect by using a flap. Both these goals can be met by using flow-through flaps; these flaps are therefore considered ideal solutions in such cases and are extensively used in clinical practice. Over the years, various types of flow-through flaps have been designed to fit various kinds of defects, including the following: radial forearm flow-through flap [5, 6], ulnar forearm flap [7, 8], lateral forearm flap [9], rectus abdominis flap [10], anterior thigh flap [11, 12], and dorsalis pedis flap [13].

In this study, we used flow-through flaps retrieved from the dorsalis pedis to repair extensive scars of the dorsum of the foot and thereby improve the distal circulation in the foot

Venous drainage in flow-through and conventional dorsalis pedis flaps

of patients who experienced a cold sensation in the toe region. In our experience, flow-through flaps showed good survival and were not associated with venous sufficiency. Therefore, we sought to confirm whether the venous outflow in flow-through dorsalis pedis flaps is better than that in conventional dorsalis pedis flaps used in the repair of complex dorsal foot skin defects.

Materials and methods

Study design and patients

This study was designed as a retrospective review of the clinical data of 14 patients treated for complex, unilateral defects of the dorsum of the foot between January 2007 and December 2013 at our hospital. The repair was performed using flow-through flaps and conventional free flaps in seven patients each. The study protocol was approved by the Institutional Review Board at Gansu Provincial Hospital of Traditional Chinese Medicine, and informed consent was obtained from all patients.

Surgical technique

The same surgical team lead by a board-certified plastic surgeon performed all the 14 flap transfer surgeries investigated in this study. The donor site was assessed for the patency of the dorsalis pedis artery and the first dorsal metatarsal artery by Doppler ultrasonography or contrast angiography. Then, the recipient site, including the involved tissues with scarring and/or infection, was thoroughly debrided under general anesthesia or continuous epidural block. The dorsalis pedis flap from the contralateral donor foot was then elevated. The flap was designed to cover the wound at the recipient site. The lateral margin of the flap was incised to expose the superficial fascia with the intact superficial veins and cutaneous nerves. The medial aspect of the deep fascia was then dissected until the medial margin of the second tendon of the extensor digitorum longus was reached. Subsequently, dissection of the dorsalis pedis artery and the venae comitantes was started and continued until the deep plantar branch and the point of origin of the first dorsal metatarsal artery were visualized. Then, the free flap was harvested by the transection of the deep plantar branch of the dorsalis pedis artery and dissection of the first dorsal meta-

tarsal artery towards the distal end. Vascular flow was then established by anastomosing the first dorsal metatarsal artery of the flow-through flap with the same artery at the recipient site as the outflow artery and by anastomosing the dorsalis pedis artery and its venae comitantes as the inflow artery. In the case of the conventional flaps, the anastomosis between the first dorsal metatarsal artery at the flap and recipient site was not established. Subsequently, the donor site was resurfaced with a full-thickness skin graft harvested from the groin area or the medial thigh.

Evaluation of complications

After the surgery, the operated limb was placed in an elevated position and the blood flow within the flap was closely monitored. The degree of flap congestion was assessed and graded into the following four levels on postoperative days 1, 3, 7, 10, and 14: grade I, which was defined by mild swelling; grade II, which was defined by moderate swelling with visible skin creases; grade III, which was defined by large swelling and non-visibility of skin creases; and grade IV, extremely large swelling with blister formation.

The proportion of the surviving flap area was determined using the following formula: survival area/total flap area \times 100%. All patients attended regular follow up at the outpatient clinic and underwent evaluation of sensory function over the flap area and foot mobility.

The sensory function of the flap area was classified into the following grades on postoperative months 1, 3, 6, and 12, as per the following criteria, which have been detailed earlier [14]: S0, complete absence of all sensation; S1, deep pain sensation; S2, partial recovery of pain and touch sensations; S3, complete recovery of shallow pain and touch, without any hyperalgesia; S3+, criteria for S3 in addition to ability for partial two-point discrimination; S4, complete recovery of all sensory function, but two-point discrimination remains at > 6 mm.

Statistical analysis

Continuous data were expressed as mean \pm standard deviation, and categorical data were expressed as n (%). Student's *t*-test was used to compare the continuous data, and Fisher's exact test or Wilcoxon rank-sum test, for cate-

Venous drainage in flow-through and conventional dorsalis pedis flaps

Table 1. Patient characteristics

	Flow-through flaps (n = 7)	Conventional flaps (n = 7)	P-value
Age, year, mean \pm SD	31.3 \pm 13.3	32.6 \pm 12.2	> 0.05
Sex, male/female	4/3	5/2	
Body mass index, kg/m ² , mean \pm SD	23.04 \pm 2.94	22.98 \pm 3.01	> 0.05
Defect size, cm ² , mean \pm SD	110.3 \pm 63.2	117.8 \pm 54.7	> 0.05

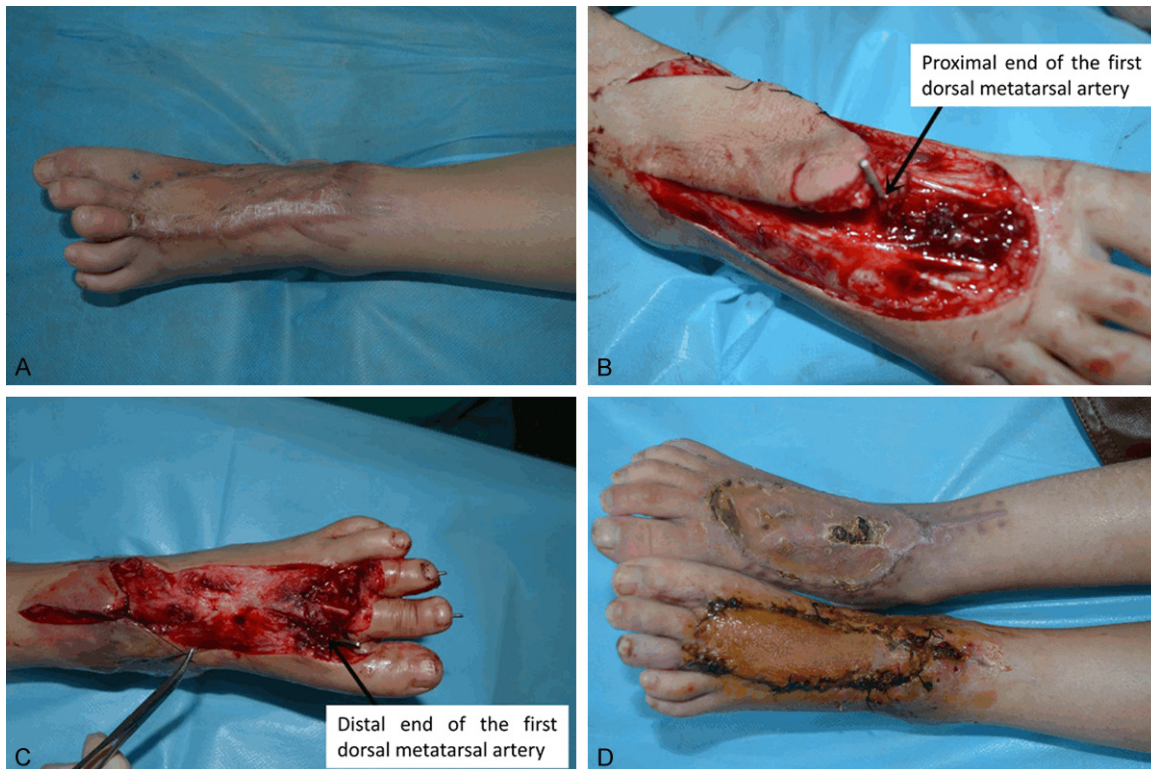


Figure 1. A case of flow-through dorsalis pedis flap.

gorical data. The statistical analyses were performed using the IBM Corp Released 2010. IBM SPSS Statistics for Windows, Version 19.0 (Armonk, NY: IBM Corp). Statistical significance was set at $P < 0.05$.

Results

Patient information

Of the patients included in the study, 8 were male and 6 were female, and the mean age of the patients was 31.9 years (range, 6-49 years). The foot injury was caused by a motor vehicle accident in the case of 10 patients and crush injury in the case of 4 patients. The size of the skin defects ranged from 6.2 cm \times 11 cm to 9.5 cm \times 16 cm. No significant difference was noted between the two groups with respect to

age, sex, body mass index, and defect size (**Table 1**; all $P > 0.05$).

Operative data

None of the patients developed any intraoperative complications. The mean flap size, as recorded for the seven cases of flow-through flaps, was 110.3 \pm 63.2 cm², while that in the case of the conventional flaps was 117.8 \pm 54.7 cm². The operative time for the placement of the flow-through flaps (6.4 \pm 1.7 h) was significantly greater than that required for the placement of the conventional flaps (4.3 \pm 1.2 h) ($P = 0.020$); this increase in duration can be attributed to the additional time required to complete the dissection of the first dorsal metatarsal artery in the case of the flow-through flaps. No significant difference was



Figure 2. A case of conventional dorsalis pedis flap.

noted between the two types of flaps with respect to intraoperative blood loss (180 ± 30 mL vs. 200 ± 50 mL for conventional flaps vs. flow-through flaps; $P > 0.05$).

Case reports

Case 1: A 6-year-old girl sustained injuries in a car accident that occurred 5 months before presentation. After the initial coverage of the wounds, the left foot developed a scar contracture (**Figure 1A**). A flow-through dorsalis pedis flap was harvested from the right foot (**Figure 1B**). The scar on the left foot scar was resected and covered with the harvested flap (**Figure 1C**). Postoperative survival of the flap was good and the flap showed no signs of congestion or necrosis (**Figure 1D**).

Case 2: A 41-year-old man sustained a crushing injury to his right foot, which resulted in a large soft-tissue defect (**Figure 2A**). A conventional dorsalis pedis flap was harvested from the left foot (**Figure 2B**). The right foot defect was covered using the harvested flap (**Figure 2C**). The flap survived although the rim showed necrosis (**Figure 2D**).

Complications

The flow-through flaps showed significantly lower incidence of congestion and higher survival area proportion than the conventional flaps ($P < 0.05$; **Table 2**). No significant difference was noted in the grades of sensory function, as assessed at the end of postoperative months 1, 3, 6, and 12 ($P = 0.312, 0.280, 0.834, \text{ and } 0.476$, respectively **Table 3**). All the patients were followed up for a mean period of 15 months (range, 6-20 months). At the end of postoperative month 6, patients in both groups had regained sufficient ability for standing and walking, without any impairment. However, partial necrosis was observed in the case of 4 patients who underwent placement of conventional flaps; two of these patients recovered after appropriate dressing care, whereas the remaining two required secondary skin grafting. None of the patients who underwent placement of the flow-through flaps developed necrosis.

Discussion

Flow-through flaps are used to simultaneously achieve the revascularization and coverage of

Venous drainage in flow-through and conventional dorsalis pedis flaps

Table 2. Comparison of postoperative flap congestion and survival area proportion between the flow-through and conventional flaps

	Flow-through flaps (n = 7)	Conventional flaps (n = 7)	P-value
Flap congestion, I/II/III/IV			< 0.05
Day 1	7/0/0/0	5/2/0/0	
Day 3	4/2/1/0	0/2/2/3	
Day 7	6/1/0/0	1/3/2/1	
Day 10	7/0/0/0	1/3/2/1	
Day 14	7/0/0/0	5/2/0/0	
Flap survival area, cm ² , mean ± SD	110.3 ± 63.2	87.9 ± 41.6	< 0.05
Survival area proportion, %, mean ± SD	100.0	71.9 ± 8.1	< 0.05

The flow-through flaps showed significantly lower incidence of congestion than the conventional flaps at the end of postoperative days 1,3,7,10 and 14 (P < 0.05).

Table 3. Comparison of flap sensation between the flow-through and conventional flaps

	Sensation grades					
	S0	S1	S2	S3	S3+	S4
Flow-through flaps (n = 7)						
1 month	0	3	2	2	0	0
3 months	0	1	3	2	1	
6 months	0	0	3	3	1	
12 months	0	0	1	4	1	1
Conventional flaps (n = 7)						
1 month	0	2	4	1	0	0
3 months	0	1	4	2	0	0
6 months	0	0	4	2	1	0
12 months	0	0	2	4	1	0

No significant difference was noticed in sensation grades of the two groups at postoperative 1, 3, 6, and 12 months (P = 0.312, 0.280, 0.834, 0.476). Chi-square test.

soft-tissue defects. This comparative study in patients with defects of the dorsum of the foot showed that compared to the conventional flaps, flow-through dorsalis pedis flaps had a lower incidence of necrosis and congestion and better survival, which may be attributed to the better venous drainage in the latter.

In 1983, Soutar et al. [15] reported the successful establishment of uninterrupted vascular flow between the external carotid artery and distal facial artery by using a radial forearm flap for the repair of a head and neck defect caused by ablation for cancer. Later, Foucher et al. [16] modified the technique of using a flow-through flap for the reconstruction of vascular defects of the extremities. Subsequently, the flow-through flap was then further extended to include repair of defects of the hand and foot, limbs, sacrococcygeal region, and scalp.

Venous outflow impairment can be caused by several factors, including poor vascular anastomosis, increased flap tension, and presence of pedicle torsion, thereby increasing the intravenous hydrostatic pressure; this can lead to venous microthrombosis and, eventually, result in the disruption of the arterial inflow and ischemic necrosis. Disruption of the venous flow within the flap can generally be reversed within 6 hours of

venous microthrombosis, but it is rendered irreversible and causes flap necrosis at 8 hours. Impairment of the venous outflow in the flap is conventionally managed by flat decompression with suture removal, needle phlebotomy, and application of topical heparin. However, the therapeutic efficacy of these methods is not entirely conclusive, and these methods cannot be used to prevent the impairment of the flap venous outflow. On the other hand, the establishment of the anastomosis of the distal artery in the case of the flow-through flap allows for a balance to be maintained between the inflow to and outflow from the flap.

The comparison of the two types of flaps in this study showed that the venous drainage and flap survival was better in the case of the flow-through flap than the conventional flaps. Consequently, the use of the flow-through flap minimized the risk of postoperative flap morbidities and need for medical or surgical intervention. These benefits together contributed to better aesthetic appearance and better recovery of the motor and sensory functions at the recipient site in patients undergoing the flow-through flap transfer. We speculate that the provision for the arterial outflow at the distal end of the flap reduces the drainage pressure on the flap, thereby reducing the risk of impaired venous drainage and the consequent flap necrosis and increasing the possibility of flap survival.

The use of the flow-through flap also has some disadvantages. A longer operative time is required in the case of flow-through dorsalis pedis flaps because of the time required for the establishment of the anastomosis of an additional artery. Further, in the presence of ana-

Venous drainage in flow-through and conventional dorsalis pedis flaps

tomical variations of the artery, the flap may require conversion into the conventional fashion. Further, surgeons require specialized training to acquire adequate technical expertise in the reconstruction of defects using the flow-through dorsalis pedis flap.

This study has some limitations; these include the small sample size, the retrospective nature, and the lack of long-term follow ups. However, the findings do provide sufficient evidence to justify further large-scale studies on the use of flow-through flaps.

In conclusion, our study on cases of repair of the dorsum of the foot showed that compared to the conventional flow-end flap, the flow-through flap was associated with a significantly lower risk of venous backflow insufficiency and the resultant complications, better aesthetic outcome, and quicker recovery of motor-sensory function. However, a major limitation of using the flow-through flap is the relatively long operative time, which is due to the need for the intraoperative identification of the variant of the first dorsal metatarsal artery. Further large-scale, randomized, controlled studies are warranted to validate the effectiveness and safety of the flow-through flap.

Disclosure of conflict of interest

None.

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