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Interperforator Flow Pattern and Clinical Application of Distal Extended Peroneal Artery Perforator Flaps

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Introduction: Peroneal artery perforator flaps are the most widely used pedicled flaps for soft tissue defects of the distal lower extremity. Most research regarding peroneal artery flaps focuses on the location, diameter, and number of peroneal artery perforators. However, there is little literature regarding interperforator flow patterns within the peroneal artery perforator flaps. The aims of the present study were to describe interperforator flow patterns of the distally based extended peroneal artery perforator flaps through digital subtraction angiography and review their clinical application.

Methods: Twelve consecutive patients underwent digital subtraction angiography of the lower-limb arteries. The number and classification of peroneal artery perforators and the interperforator flow patterns were observed. Based on these observations, distally based extended peroneal artery perforator flaps were designed to repair nonhealing wounds located on the ankles and feet of 14 patients.

Results: The peroneal artery gives out grades I to IV perforators in the lateral leg. There were 2 to 7 grade I perforators and true anastomoses between adjacent grade II perforators, which generate directly linked vessels in the middle leg. The grade III or IV perforators form a reticular vascular network through a large number of chock and potential anastomoses. All flaps survived and had excellent appearance and texture.

Conclusions: Distally based extended peroneal artery perforator flaps appear reliable for repairing wounds located on or around the ankle and front foot. However, whether the middle perforator or peroneal artery should be used depends on the condition of the anastomosis between direct linking vessels and the distal perforator.

Key Words: angiography, interperforator flow pattern, perforator flap, peroneal artery

(*Ann Plast Surg* 2018;80: 546–552)

The peroneal artery flap is a free-osseous flap that was originally described by Taylor et al[1] in 1975 and is based on the concept of vascularized bone grafting for treatment of a large bone defect. The peroneal artery flap was previously thought to lack reliable blood supply, largely due to the complex nature of the blood supply to the lateral leg, which is supplied by perforating branches of the peroneal artery, anterior tibial artery, and posterior tibial artery.[2–4] With advances in understanding the anatomy of the peroneal artery and its donor site, including detailed descriptions of the diameter, number of perforating branches, and route of the peroneal artery through autopsies, the clinical applications of peroneal artery flaps and peroneal artery perforator flaps are becoming more widely recognized in reconstructive surgery.[5–8] However, despite our ability to locate a perforator, it remains difficult to make a precise estimate of the maximum area and length-to-width ratio of a peroneal artery perforator flap. Necrosis of postoperative skin flaps remains a common occurrence due to lack of evidence regarding interperforator flow patterns and survival within peroneal artery perforator flaps.

Recently, various imaging and ultrasound technologies, such as color Doppler ultrasonography,[9,10] digital subtraction angiography (DSA),[11] magnetic resonance angiography,[11] and computed tomography angiography,[12] have been used for preoperative surgical planning in candidates for free fibular flaps. However, most studies investigating the use of these imaging techniques for flap evaluation excluded anatomical variants and pathological vessel stenoses of the lower leg and therefore did not describe interperforator flow patterns of peroneal artery perforators. Sur et al[13] illustrated the interperforator flow patterns of peroneal artery perforators using 3-dimensional computed tomography angiography on fresh cadavers. However, this study has never been replicated in living human subjects. A solid understanding of interperforator flow patterns and physiology in living humans is essential to ensure flap survival in peroneal artery perforators flaps.

Digital subtraction angiography is still the clinical standard for evaluation of vascular injuries in the lower extremity. In this study, we used DSA to identify and describe the number and classification of peroneal artery perforators and interperforator flow patterns between perforator vessels in 12 consecutive patients without peroneal artery injuries. Based on these observations, peroneal artery perforator flaps were designed to restore soft tissue coverage to defects around the ankle and forefoot of 14 patients. To our knowledge, this is the first article that systematically describes interperforator flow patterns, survival theory, and the clinical applications of extended peroneal artery perforator flaps.

MATERIALS AND METHODS

Digital Subtraction Angiography

Between September 2010 and September 2012, data of 12 patients (8 male and 4 female patients) who underwent DSA at the Affiliated Hospital of Zunyi Medical College for evaluation of potential vascular injuries located in the lower extremities were analyzed. The average age of the patients was 46.8 years, ranging from 22 to 61 years. The lower-extremity injuries resulted from a traffic accident in 4 patients, a fall in 3 patients, a machinery injury in 3 patients, and a crash injury in 2 patients. The patients had no obvious underlying vascular disease, hypertension, or diabetes and had no obvious injury to the peroneal artery (Table 1).

Intra-arterial DSA was performed through retrograde contralateral femoral access using crossover technique in accordance with standard clinical protocol in a digital angiography unit (Multistar; Siemens, Erlangen, Germany). Briefly, the common femoral artery

Received March 8, 2017, and accepted for publication, after revision October 16, 2017.
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Z.W. designed and guided this study.
Conflicts of interest and sources of funding: This work was supported by the National Nature Science Foundation of China (81560315, 81360295, 81660323) and Clinical Medical (Wound Healing) Center of Guizhou Province (20162910).
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ISSN: 0148-7043/18/8005–0546
DOI: 10.1097/SAP.0000000000001290

TABLE 1. Characteristics of 12 Patients Who Underwent Lower-Extremity Peroneal Artery Angiography

				No. Perforators			
Patients	Age, y/Sex	Side	Cause of Injury	Proximal	Middle	Distal	Total
1	57/M	L	Traffic accident	1	1	1	3
2	56/M	R	Tumble	2	3	2	7
3	55/M	L	Traffic accident	0	2	1	3
4	33/F	L	Crash injury	0	2	2	4
5	42/F	R	Tumble	1	3	1	5
6	38/M	L	Tumble	1	2	1	4
7	56/M	R	Crash injury	0	2	2	4
8	52/M	L	Machinery injury	0	2	1	3
9	44/F	L	Traffic accident	1	2	2	5
10	61/F	R	Machinery injury	0	1	1	2
11	45/M	R	Machinery injury	1	3	2	6
12	22/M	L	Traffic accident	1	2	1	4

F indicates female; L, left lower extremity; M, male; R, right lower extremity.

or superficial femoral artery was punctured, and a sheath was introduced. Contrast medium was injected intra-arterially over the sheath using an infusion pump with a flow rate of 4 to 5 mL/s and a mean injection volume of 25 mL per patient. The DSA images were evaluated in a separate reading session based on consensus by 1 radiologist and 1 plastic surgeon. Then, 3 zones (proximal, middle, and distal) were defined based on the fibular length, measuring from the lateral malleolus to the fibula head. The number and classification of peroneal artery perforators and the interperforator flow patterns between peroneal artery perforators were analyzed.

Clinical Application

This was a retrospective study consisting of 14 patients treated between October 2012 and October 2015 at the Affiliated Hospital of Zunyi Medical College. Patients with soft tissue defects of the lower extremity underwent reconstruction with a distally based extended peroneal artery perforator flap transfer. Of the 14 patients, 10 were males and 4 were females, with a median age of 43 years (range, 21–66 years). The etiologies of the soft tissue defects with bone and/or tendon exposure included traffic injuries, machinery injuries, and high-fall injuries. The wound area ranged from 11 × 3.5 to 14 × 12 cm, and the flap areas ranged from 22 × 4 to 26 × 12 cm. The donor sites were directly sutured in 4 patients and were covered with skin grafts in the other 10 patients. Details of all 14 patients are shown in Table 2.

After surgery, patients were treated with antibiotics, antivasospasm medications, and anticoagulants. Capillary filling time, color, and temperature of the skin flap were recorded. Arterial infusion and venous drainage in the skin flap were evaluated, and rosy and elastic flaps suggest that arterial infusion and venous drainage were no problem. If the skin flap was pale, hypothermic, and inelastic, then the arterial infusion was insufficiency, and if the flap was cyanotic with high tension and blisters, then the venous drainage was disorder.

Surgical Technique

The surgical procedures were performed with patients under spinal or continuous epidural anesthesia. The patients were positioned in a lateral decubitus position or supine position, with the knee joint bent to get optimal access to the lateral aspect of the calf. Then, the peroneal perforators were identified using handheld Doppler ultrasonography. According to the size and site of the wound, the flap was designed on

TABLE 2. Summary of Patients Who Underwent Flap Surgery

Patient	Sex	Age, y	Cause of Injury	Defect Site	Defect Size, cm	Flap Size, cm	Donor Site Closure	Complications	Follow-up, mo
1	M	40	Traffic accident	Left ankle	8 × 5/4 × 4	28 × 5	Primary suture	No	22
2	F	32	Machinery injuries	Right foot	13 × 5	22 × 5.5	Skin graft	No	6
3	M	48	High-fall injuries	Left foot	11 × 3.5	22 × 4	Primary suture	No	12
4	M	51	Traffic accident	Left foot	12 × 11	26 × 12	Skin graft	No	9
5	M	66	Machinery injuries	Right ankle	9 × 6	20 × 7	Skin graft	No	14
6	M	55	Traffic accident	Left foot	15 × 7	25 × 8	Skin graft	No	12
7	M	38	Traffic accident	Left foot	14 × 12	19 × 14	Skin graft	No	6
8	F	43	Traffic accident	Left foot	13 × 5	25 × 6	Skin graft	No	36
9	M	43	Traffic accident	Left ankle	15 × 8	20 × 9	Skin graft	No	8
10	M	40	Machinery injuries	Left ankle	16 × 6	18 × 7	Skin graft	No	15
11	M	49	Machinery injuries	Right leg	11 × 4	24 × 4.5	Primary suture	No	16
12	M	21	High-fall injuries	Left foot	25 × 3.5	30 × 4	Primary suture	No	12
13	F	24	Traffic accident	Right foot	9 × 6	20 × 7	Skin graft	No	14
14	F	43	Machinery injuries	Right foot	9 × 9	20 × 10	Skin graft	No	9

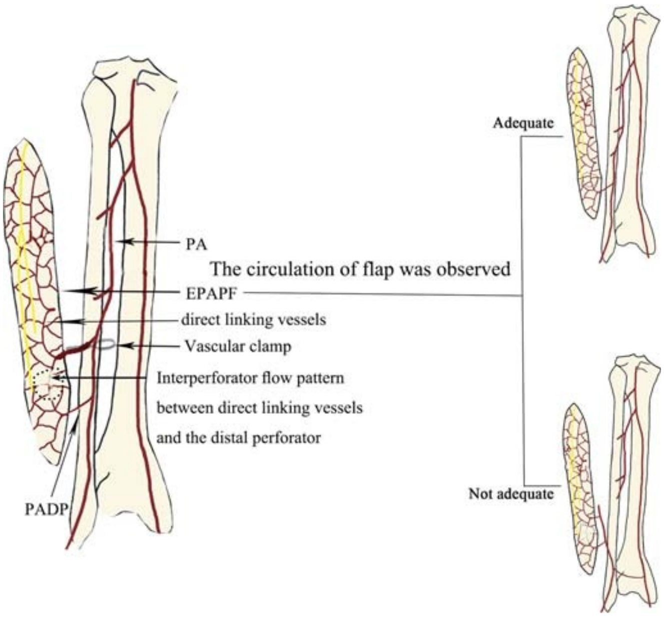

FIGURE 1. Schematic diagram of surgical technique. The middle perforator of the peroneal artery was nontraumatically occluded by a vascular clamp, and the circulation of the distal peroneal artery perforator flaps was observed (left). If the blood supply of the flap was adequate, the middle perforator was transected and ligated (top, right). If the blood supply of the flap was inadequate, the peroneal artery was transected and ligated, whereas the middle perforator was left untouched (bottom, right). EPAPF indicates the extended peroneal artery perforator flaps; PA, peroneal artery; PADP, peroneal artery distal perforator.

the lateral aspect of the leg. Through handheld Doppler ultrasonography, we found the most reliable perforators located 5 to 6 cm proximal to the lateral supramalleolar; consequently, a pivot point was located approximately 6 cm proximal to the lateral supramalleolar. The central axis of the flap was aligned with the peroneal artery or the lateral sural cutaneous nerve. The donor site of the flap was approximately 1 to 2 cm larger than the recipient site, and 2 cm was added to the pedicle length to avoid tension. In general, the size of the flap did not extend proximal to the popliteal fossa crease but could reach the distal lateral malleolus, the extensor digitorum longus anteriorly, and the medial gastrocnemius muscle in the posterior direction.

After inflating the tourniquet, the wound was first debrided and irrigated. The anterior margin of the flap, including the deep fascia, was then incised according to the outline. The deep fascia was elevated to expose and identify the perforators of the peroneal artery, lateral superficial sural artery, and lateral sural cutaneous nerve. The lateral superficial sural artery and the proximal perforators of the peroneal artery were transected and ligated. The perforators with the largest diameter located in the middle and distal zones were meticulously retained. Then, the other margins of the flap were incised. Subsequently, the middle perforator was nontraumatically occluded by a vascular clamp, and the circulation and viability of the flap were observed for half an hour. If the blood supply was adequate, the preserved middle perforators were transected and ligated. In contrast, if the blood supply of the distal flap was inadequate during the occlusion of the middle perforator, then dissection along the middle perforator to the peroneal artery was required, and the peroneal artery was transected and ligated, leaving the middle perforator uninjured (Fig. 1).

The pedicle flaps were transposed to the recipient site through a tunnel or open tunnel to avoid twisting or kinking of the pedicle. Negative suction drains were placed under the flap and pedicle to prevent hematoma formation. The donor sites were covered with split-thickness skin grafts or directly sutured. Generally, the surgical extremities were immobilized by plaster casts, and skin sutures were removed 2 weeks postoperatively.

Ethics Statement

All clinical investigations were conducted according to the principles expressed in the Declaration of Helsinki. All patients involved provided written informed consent for participation in this research. The individuals in this study have given written informed consent to publish these case details. The ethical committee of the Affiliated Hospital of Zunyi Medical College has approved this study.

RESULTS

The DSA images of 12 patients seen from 2010 to 2012 showed that all the peroneal arteries were present and unobstructed. The peroneal artery generated grades I to IV perforator vessels in different layers of the lateral leg and formed a perforator vascular tree. Approximately 2 to 7 grade I perforators originated from the peroneal artery, and the grade I perforators located on the proximal third were lesser than those of the middle and distal thirds. The ascending and descending branches from grade I perforators formed grade II perforator vessels, which generated direct linking vessels. The linking vessel was especially prominent in the proximal and middle zones of the leg, whereas it was faintly visible in the distal zones, and it traveled a similar path to the peroneal arteries. Then, the grades III or IV perforators formed a reticular vascular network through a large number of chock and potential anastomoses (Fig. 2).

The data gained from these 12 patients were then used to design distally based extended peroneal artery perforator flaps to repair nonhealing wounds located on the ankles and feet of 14 patients. All flaps and skin grafts in these 14 patients survived, and the wounds healed by primary intention. The flap areas ranged from 22 × 4 to

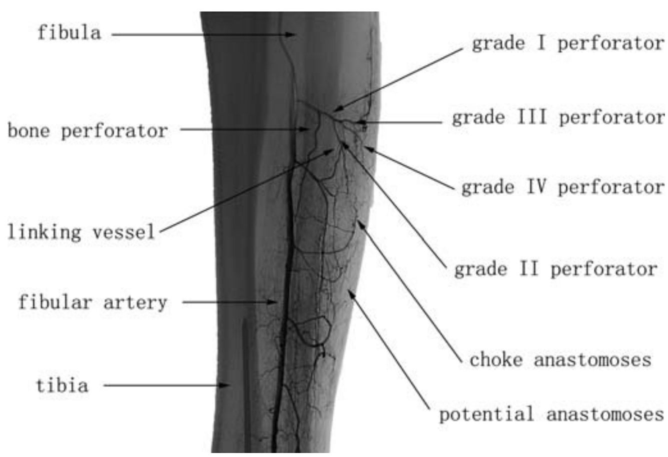

FIGURE 2. Digital subtraction angiography images. The peroneal artery generated grades I to IV perforator vessels in different layers of the lateral leg and formed a perforator vascular tree. The ascending and descending branches from grade I perforators formed grade II perforator vessels, which generated a direct linking vessel. The grade III or IV perforators then formed a reticular vascular network through a large number of chock and potential anastomoses.

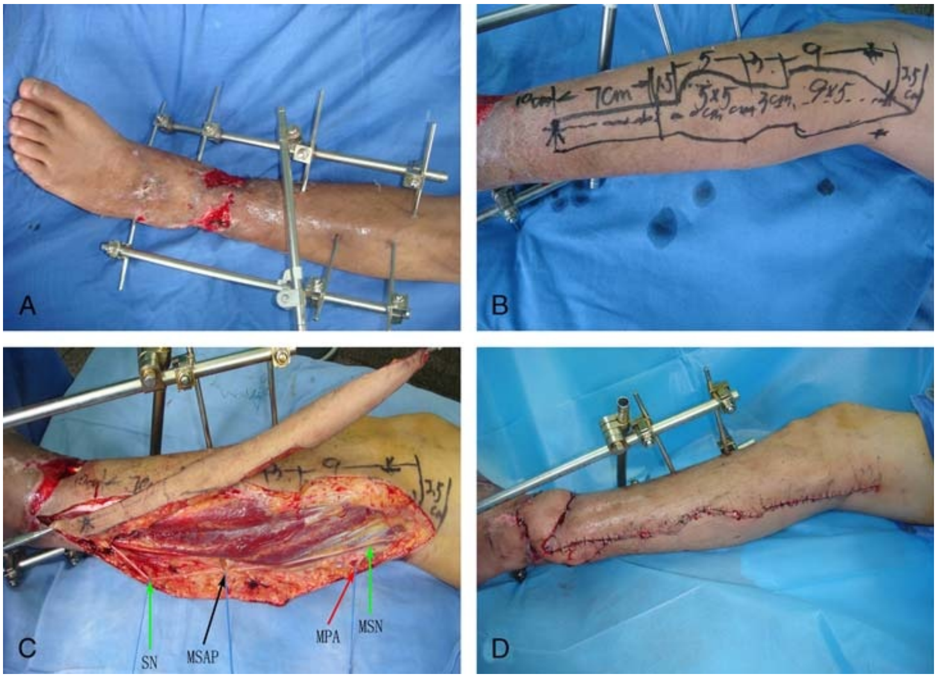

FIGURE 3. A, Preoperative view. The wound wrapped around the left ankle joint. The sizes of the wound medial and lateral to the ankle were 8 × 5 and 4 × 4 cm, respectively. B, Preoperative design. C, Elevation of the flap. MPA indicates medial popliteal artery; MSAP, medial sural artery perforator; MSN, medial sural cutaneous nerve; SN, sural nerve. D, Early postoperative view of the flap placement and the donor site after direct suturing.

26 × 12 cm, with the longest flap being up to 28 cm. Follow-up for all patients ranged from 6 to 36 months, with an average follow-up period of 14 months. The flaps all had excellent appearance and texture at follow-up.

Case Reports

Patient 1

A 40-year-old man was referred to our department with an open fracture of the left tibia due to a traffic accident. On admission, he underwent 1 surgical debridement because of tissue necrosis, and the wound was covered with vacuum-sealed drainage on day 7 after injury. One week later, a flap surgery was performed under continuous epidural anesthesia. The wound wrapped around the left ankle joint, and the sizes of the wound on the inside and outside ankle were 8 × 5 and 4 × 4 cm, respectively (Figs. 3 and 4).

The distally based extended peroneal artery perforator flap was designed to cover the defect, measuring 28 × 5 cm, and the donor site was directly sutured. The flap survived, and the wounds healed by primary intention. The patient was followed up for 22 months. At the end of follow-up, the flap had an excellent appearance and texture, and the patient could walk normally.

Patient 10

A 40-year-old man with a wound located on the left ankle from a machinery injury was referred to our department. On admission, surgical debridement and vacuum-sealed drainage were performed because of lots of tissue necrosis. Three weeks later, a flap surgery was performed under continuous epidural anesthesia. The wound was 16 × 6 cm. The distally based extended peroneal artery perforator flap was designed to cover the defect and exposed tendon, measuring 18 × 7 cm. The donor area was closed with a split-thickness skin graft. The flap and skin graft survived, and the wounds healed by primary intention. The patient was followed up for 15 months. At the end of follow-up, the flap had an excellent appearance and texture, and the patient could walk normally (Figs. 5 and 6).

DISCUSSION

In our study, we found that the peroneal artery generated a few reliable grade I perforators, including perforators nourishing the bone, tendon, muscle, nerve, and skin. Approximately 2 to 7 grade I perforators subdivided into grade II perforators, including ascending and descending branches, which formed direct linking vessels. Grade III perforators originated from ascending and descending branches of grade II perforators, pierced the superficial fascia, and gave off grade IV perforators, which entered into the dermal layer and formed a subdermal vascular network of perforator angiosomes. The results found with DSA were consistent with the angiosome territory of a cutaneous perforator proposed by Taylor et al.[14,15] We also found that the grade I perforators located on the proximal third of the leg were lesser than those of the middle and distal thirds. This may possibly be why the middle and distal thirds were more suitable donor sites for a pedicle perforator flap.[13] The DSA images showed that the grade II perforator vessels generated a direct linking vessel through some true anastomoses between adjacent grade II perforators, which is consistent with results described by Chubb et al,[16] who revealed through thermal imaging that interperforators were linked by true anastomotic vessels. In addition, the direct linking vessels accompanying the lateral sural cutaneous nerves were found intraoperatively, verifying that true anastomotic vessels are often found in parallel with cutaneous nerves and/or accompanying veins.[16,17] However, the linking vessel was especially prominent in the proximal and middle zones of the leg and was only faintly visible in the distal zones. Further observation showed that the proximal end of the linking vessel anastomosed with the lateral cutaneous perforator of

FIGURE 4. Appearance 22 months after the operation. The flaps had an excellent appearance and texture, and the patient could walk normally (A–D).

FIGURE 5. A, Preoperative view. The wound was 16 × 6 cm. B, Preoperative design. C and D, Early postoperative view of the flap placement and the donor site. The donor site was covered with a skin graft.

FIGURE 6. Appearance 15 months after the operation. The flaps had an excellent appearance and texture, and the patient could walk normally (A, B).

the popliteal artery; the distal end could potentially anastomose with the distal perforator of the peroneal artery, supporting an interperforator flow pattern and survival theory within a distally based extended peroneal artery perforator flap. In the event that the distal end of the linking vessel anastomosed with the distal perforator of the peroneal artery through a choke anastomosis or potential anastomosis, then necrosis of the distally based extended peroneal artery perforator flap would occur. Therefore, the middle perforator, together with the peroneal artery, should be included in the flap to ensure complete flap survival. Based on these findings, we designed distally based extended peroneal artery perforator flaps to restore soft tissue defects around the ankle and forefoot of 14 patients.

Complicated soft tissue defects located on the distal lower extremity, in particular around the ankle and foot, epitomize tricky reconstructive problems because of exposure of bone, joint, and/or tendons. Clinically, several reconstructive procedures have been developed to repair soft tissue defects in these regions, including local pedicled perforator flaps from the ipsilateral leg, cross-leg fasciocutaneous flaps, and microsurgical flaps. Depending on the degree of surgical difficulty and possibility of patient benefit, local pedicled perforator flaps may be the best repair procedure, despite distally based peroneal artery perforator flaps being the most widespread pedicled flaps.[18,19] However, the use of pedicled flaps is restricted by their limited reach and reduced amount of soft tissue that can be transported.[20] It is not uncommon for the distal flap to undergo necrosis, exposing the bone or tendon. Using the concept of perforator angiosome territory and ignoring possible complications related to surgical technique and postoperative management, necrosis of a flap results when the area of the flap extends beyond the scope of the perforator angiosome. In our series, the distally based extended peroneal artery perforator flaps were designed to repair ankle and foot wounds in 14 patients. All of the flaps survived. The flap areas ranged from 22×4 to 26×12 cm, with the longest flaps reaching up to 28 cm. These areas of cut flap are significantly larger than those previously reported[8,21,22] and support the findings from Sur et al,[13] which indicated a single peroneal artery perforator can perfuse approximately 40% of the entire surface of the leg. We hypothesized that our encouraging results were due to our understanding of perforator angiosomes and previous angiography analysis showing the condition of the anastomosis between direct linking vessels and distal perforators of the peroneal artery. During flap surgery, nontraumatic occlusion of the middle perforator by a vascular clamp allowed for direct observation of blood circulation in the distal cutaneous part of the flap. If the blood supply was adequate, suggesting that the anastomosis was a true anastomosis, the preserved middle perforators were transected and ligated. In contrast, if the blood supply of the distal flap was inadequate, suggesting the anastomosis was a choke anastomosis or potential anastomosis, then the peroneal artery must be transected and ligated, whereas the middle perforator was left uninjured.

Our study was not without limitations. During angiography, we attempted to extend the guide wire into the distal perforator of the peroneal artery to observe the developing range of the contrast agent in vivo. Unfortunately, as soon as the guide wire touched the perforator, the perforator underwent vasospasm. If this evidence was available, it may be able to better support our research. In addition, the peroneal artery sometimes needed to be sacrificed when the distally based peroneal artery perforator flaps were elevated. Therefore, preoperative angiography was required, and the donor site was monitored for postoperative ischemia-related complications.

CONCLUSIONS

Distally based extended peroneal artery perforator flaps are reliable for repairing wounds located on and around the ankle and forefoot. Whether the middle perforator of the peroneal artery needs to be maintained depends on the condition of the anastomosis between direct linking vessels and the distal perforator.

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