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CLINICAL ARTICLE

Reconstruction of a Distal Foot Skin Defect Using an Intermediate Dorsal Neurocutaneous Flap

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Objective: To present the use of an intermediate dorsal neurocutaneous flap for the reconstruction of defects on the distal foot.

Methods: From September 2016 to October 2018, five patients (mean age at operation 33.8 years; range, 7–70 years; female/male = 2/3) with skin defects on one of their feet caused by road-traffic accidents, electrical injury, and syndactyly correction were retrospectively reviewed. The size of the defects ranged from 2.0 cm × 1.0 cm to 5.0 cm × 3.5 cm. All patients had undergone a reconstruction surgery using intermediate dorsal neurocutaneous flap. One patient underwent a syndactyly correction, and four patients first experienced aggressive debridement. The sizes of the flaps were between 5.0 cm × 2.0 cm and 6.0 cm × 4.0 cm. The function, appearance, and pain of the injured foot were assessed using the Chinese Manchester Foot Pain and Disability Index and visual analogue scale.

Results: These five patients were systematically followed up for a mean of 15.8 months (range, 12–20 months). The donor sites were closed primarily in two cases, and skin grafts were performed in three cases. All the flaps survived with a success rate of 100%; the wounds healed well, and the color matches were excellent. Partial superficial flap necrosis occurred in one of five flaps, which was treated by dressing change using a hypertonic saline gauze. No significant problems were found at the donor site in any patient immediately afterwards or at follow-up. There were no problems in any patients associated with wearing shoes. Based on the Chinese Manchester Foot Pain and Disability Index, four patients were strongly satisfied and one was satisfied with the recovery of physical function; all the patients were strongly satisfied with the appearance of the injured foot; all five patients had an excellent score of pain intensity subscale. Except for one patient who reported mild pain, all the other patients reported no pain based on the visual analogue scale. Two typical cases are presented in this paper.

Conclusions: The intermediate dorsal neurocutaneous flap is an alternative and effective technique that can reliably cover minor- to medium-sized defects on the distal foot, toes, and web spaces. This surgical method leads to satisfactory functional recovery with minimal donor site morbidity, and no major vessels need to be sacrificed. This procedure offers an advisable option for orthopaedic surgeons to treat defects on the distal foot.

Key words: Cutaneous arteries; Distal foot defect; Neurocutaneous flap; Reconstruction

Introduction

The exposure of tendon and bone on the distal foot caused by infection, trauma, and resection of malignant skin tumor, etc. has always been a challenge for orthopaedic surgeons. Compared to a large number of local perforator-based flaps that exist on the hand, there are fewer options available for repairing small soft tissue defects of the web spaces and distal dorsum of the foot.

Some reconstructive techniques have been described in previous studies. Although skin grafting is a simple and commonly used tool for skin surface defects, unstable scar formation, contour defects, skin contracture of the dorsum of the

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Orthopaedic Surgery

toes, and generally prolonged wound-bed preparation and preparation before skin grafting are all disadvantages of skin grafting. So, it is hardly ideal. Free-flaps are an effective method to reconstruct large skin defects in most parts of the body, but they requires special instruments and microsurgical techniques and it is a highly risky and expensive process[1]. Scaglioni *et al.*[2] demonstrated a free proximal peroneal artery perforator flap which was applied in the reconstruction of distal hand and foot defects, but the flap appeared too bulky for use for hand and foot defects. El-Gammal *et al.*[3] reconstructed the dorsal foot defect in 42 children with anterolateral thigh flap. Although the defects were covered effectively because of the reliable anatomic structure of the flap, 35.7% of patients had undergone a subsequent debulking surgery after complaining of flap bulkiness. Myung *et al.*[4] presented a superficial circumflex iliac perforator flap which could also be used to reconstruct the dorsal foot defect with good postoperative symmetry and minimal donor sequelae. However, its greatest weakness is the length of pedicle (average 5 cm), which makes it difficult to apply in reconstruction of distal foot defects. Xie *et al.*[5] reported a super-thin innervated anterolateral thigh perforator flap which was applied in reconstructing defects on the anterior tibial area, dorsum of the foot, and circumference of the ankle. It achieved good results both functionally and aesthetically because of its thickness. However, it has the same problem as the flaps above: those methods involve microvascular anastomosis, operative time, and hospital stays which can be quite a degree longer than other methods, with more expenses. In short, free-flaps can potentially solve any coverage problem anywhere, but they tend to be bulky, aesthetically non-pleasing, and they can interfere with shoe wear.

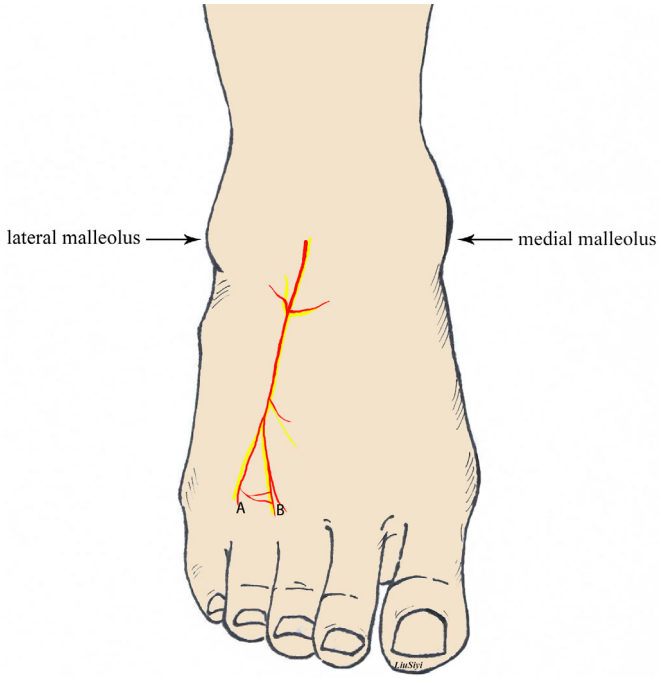

Fig. 1 Intermediate dorsal cutaneous nerve of the foot and its nutrient vessels. Intermediate dorsal cutaneous nerve and its branches are in yellow and nutrient vessels are in red. A and B are both constant nutrient vessels. A located at 1.5 ± 0.3 cm proximal to the fourth web space. B located at 1.6 ± 0.3 cm proximal to the third web space.

Localized flap transfer with regional tissue has been widely used in reconstruction of defect on dorsal foot. A traditional distally-based dorsalis pedis flap has been successfully applied for the reconstruction of a defect on the distal foot[6–10]. Its vascular anatomy was first described by McCraw and Furlow[11] in 1975. However, when the trauma involves the toes, the vascular pedicle based on the deep plantar branch is limited[12]. The reversed dorsal metatarsal artery flap[13–20] and distally-based medial plantar flap[21] were extensively reported for the reconstruction of defects on the distal foot. The flaps above are based on the dorsal metatarsal artery and its distal communicating branch or the deep plantar branch of the dorsalis pedis artery. On the other hand, the neurocutaneous vascular flap does not include the dorsal metatarsal artery or dorsalis pedis artery within the flap, and it completely relies on the cutaneous artery. Since the first reports of Bertelli[22] and Masquelet[23], neurocutaneous vascular flap has been widely used in clinical applications because the operation is simple and safe and does not require sacrificing the main vessels. However, there have been few reports about the application of neurocutaneous flaps on the distal foot since Bharathwaj *et al.*[24] first demonstrated that the cutaneous arteries in the first web space alone allowed the formation of a distally-based reverse flap in 1997.

In the cadaver study by Xu *et al.*[21], it was found that intermediate dorsal cutaneous nerve, which originate from superficial peroneal nerve, is located 1.3 ± 0.6 cm lateral to the midpoint of the line with a diameter of 2.05 ± 0.56 mm crossing the intermalleolar line. The nerve stem divides into branches 2.8 ± 1.3 cm distal to the line, which mainly distributes the dorsal skin of the second, third, and fourth metatarsal and toe. At least three nutrient vessels are constant around the intermediate dorsal cutaneous nerve and its branches. These nutrient vessels perforate both sides of the intermediate dorsal cutaneous nerve and its branches, showing segmental distribution and anastomosing with each other into a longitudinal vascular network which not only nourish the cutaneous nerves, but also the neighboring skin. They perforate the deep fascia 4.3 ± 0.4 cm proximal to the middle point of the line between the tip of the lateral and medial malleolus, 1.6 ± 0.3 cm proximal to the third web space and 1.5 ± 0.3 cm proximal to the forth web space (Fig. 1). These nutrient vessels originate from the anterior tibial artery and the dorsalis pedis artery in the proximal end and the dorsalis metatarsal artery in the distal end.

Based on the anatomic study above, the intermediate dorsal neurocutaneous flap technique was presented in our study. The purpose of this retrospective study was to: (i) investigate the therapeutic effect of reconstructing distal foot defects using an intermediate dorsal neurocutaneous

flap; (ii) summarize the indications and contraindications of this flap; and (iii) explore the key points of clinical application of this flap.

Patients and Methods

This was a retrospective review, and the analysis was approved by Wuhan University institutional review board.

Inclusion and Exclusion Criterial

The inclusion criteria were: (i) skin defect on distal dorsum foot, toes or web spaces skin with exposure of tendon or bone; (ii) patients with dorsal foot defect who have undergone reconstruction with an intermediate dorsal neurocutaneous flap; (iii) single defect of 2.0–7.0 cm in width; (iv) proximal tissue of the defect uninjured; and (v) postoperative follow-up term of at least 1 year. The exclusion criteria were: (i) defect less than 2.0 cm or more than 7.0 cm in width; (ii) severe damage on the same limb (affecting the blood supply); (iii) previous flap surgery has failed; and (iv) patients with diabetes or smoking history.

Patient Data

From September 2016 to October 2018, five patients (three male and two female subjects) were included in this retrospective study. Patient characteristics are shown in Table 1. One patient was subjected to syndactyly correction, one patient experienced a local infection after open reduction and internal fixation of fractures, two patients suffered electrical injuries, and one patient suffered from skin necrosis after a crushing injury. Two cases of skin defects were located on the dorsal distal foot, and three were in the toes. The sizes of the skin defects ranged from 3.0 cm × 1.0 cm to 5.0 cm × 3.5 cm. The dimensions of the flaps ranged from 5.0 cm × 2.0 cm to 6.0 cm × 4.0 cm. There was no long-term history of smoking or vascular disease in any of the cases.

Preoperative Treatments

Aggressive debridement was conducted first in four cases. Devitalized tissue and infected tissue were removed until normal tissue was visualized, and the wounds of these four cases were covered by negative pressure dressings. The dressing changes were performed every 5 to 7 days. Blood C-reactive protein levels, erythrocyte sedimentation rates, and bacterial culture data were examined to determine infectious status. When the infection was eliminated, the negative pressure device was removed.

Surgical Techniques

Anesthesia and Position

The patient was placed in a supine position, and routine combined spinal and epidural anesthesia was performed. The operation was performed under tourniquet control without limb exsanguination. The aseptic surgical area was prepared using polyvinylpyrrolidone (1%).

Approach and Flap-Raising

The size and location of the defects were carefully evaluated before the surgery. The flap was designed on an anatomical basis. Number of the nutrient arteries of intermediate dorsal cutaneous nerve is usually five, and at least three are always found[21]. They originate from anterior tibial artery, dorsal pedal artery, third dorsal metatarsal artery, and fourth dorsal metatarsal artery. The location of the proximal nutrient artery was 4.3 ± 0.4 cm to the middle point of the line between the tip of the lateral and medial malleolus. The location of the distal nutrient artery was 1.6 ± 0.3 cm to the third web space and 1.5 ± 0.3 cm to the fourth web space according to Xu[21]. Therefore, at least 2.0 cm of the proximal end of the third or fourth toe-web was used as the pivot point, and the connection between this point and the midpoint of the line between the tip of the lateral and medial malleolus is the axis of the flaps (Fig. 2A, B). The maximum width of the flap is 4 cm if one cutaneous nerve branch is included, or 7 cm if two are included. The deep fascia of the dorsal foot was included during the flap-raising, and the aponeurosis was retained at the donor site. While *in situ*, the vascular supply was checked after the tourniquet was released, and the bleeding was stopped completely.

Reconstruction

If the flap perfusion was adequate, flap rotation was completed, and the flap was inserted into the defect without tension. If superficial veins appeared hyperperfusion, they were ligated near the pedicle. The donor site of the flaps was sutured or covered with a skin graft. It is not necessary to confirm the nutrient artery is always present at the pivot point during the surgery. The cutaneous nerves within the flaps were not anastomosed to the nerves at the recipient site.

TABLE 1 Patient characteristics

Case	Age	Sex	Cause	Defect	Flap size (cm)	Complications
1	70	F	Traffic accident	Dorsum	5.0 × 2.5	No
2	18	M	Syndactyly correction	4th toe	6.0 × 3.5	No
3	42	F	Crush injury	1st toe	5.0 × 3.0	Superficial necrosis
4	32	M	Electric injury	Dorsum	5.5 × 4.0	No
5	7	M	Electric injury	1st toe	6.0 × 4.0	No

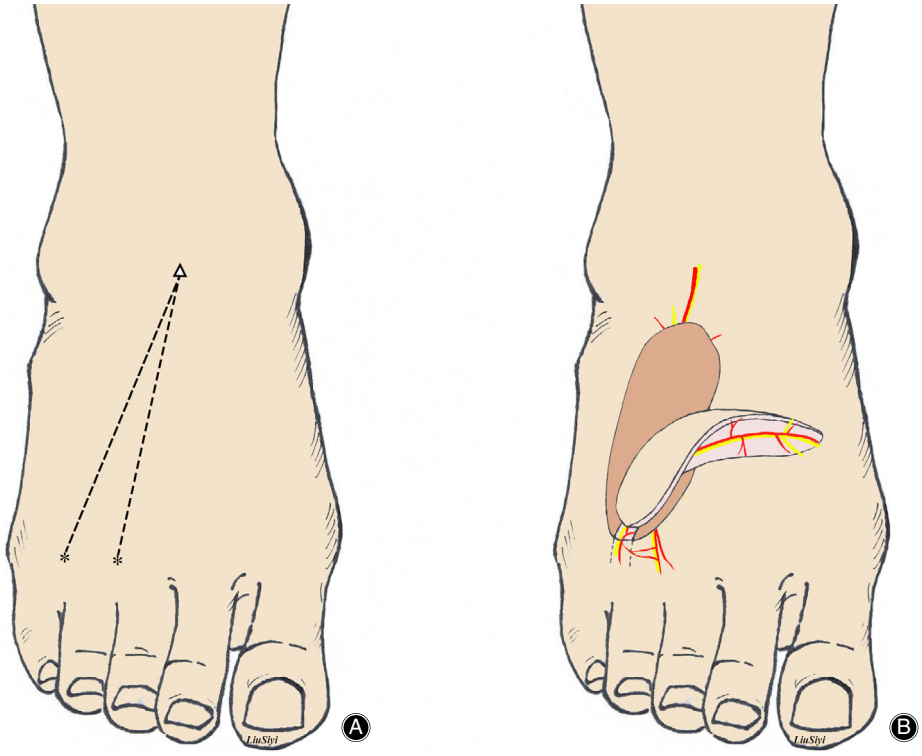

Fig. 2 A: Intermediate dorsal neurocutaneous flaps: the axes and pivot points. △: The midpoint of the line between the tip of the lateral and medial malleolus. *: The pivot points, which should be located at least 2.0 cm of the proximal end of the third or fourth toe-web. The dotted lines between △ and * are taken as the axis of the flaps. B: The diagram shows that the intermediate dorsal neurocutaneous flap includes one or more branches of intermediate dorsal cutaneous nerve and its nutrient vessels. Yellow: Intermediate dorsal cutaneous nerve and its branches. Red: Nutrient vessels.

Postoperative Treatments

Postoperative care included antibiotic usage, anticoagulant and anti-vasospasm treatment, and smoking was prohibited. The circulation of the flap was monitored for at least 24 hours after the operation by visual inspection of the color of the flap and capillary refilling.

Evaluation of Complications and Outcomes

Complications

Complications at both recipient site and donor site were carefully recorded, including flap necrosis, infection, nerve injury, vascular injury, and delayed wound healing.

Chinese Manchester Foot Pain and Disability Index[25,26] *(C-MFPDI)*

The C-MFPDI was used to evaluate the foot health and function of these patients at the final follow-up. There were three basic domains which contained 17 items evaluated by the C-MFPDI, including physical limitation (10 items), personal appearance (two items), and pain intensity (five items). The C-MFPDI subscale scores were calculated: none of the time (score = 0), some days (score = 1) and on most/every day(s) (score = 2).

Visual Analogue Scale (VAS)

A 10-cm-line VAS was used to evaluate pain sensations of the injured foot, which could be categorized into painless (0 cm), mild (1–3 cm), moderate (4–6 cm), and severe (7–10 cm).

Results

Demographics

These five patients (two female and two male) were systematically followed up for a mean of 15.8 months (range, 12–20 months). The average age at the operation was 33.8 years (range, 7–70 years).

Surgery and Complications

Five intermediate dorsal neurocutaneous flaps were performed, and all the operations were successful. The mean length of the surgery was 62 min (range, 45–85 min) and average blood loss was 70 mL (range, 60–90 mL). Partial superficial flap necrosis occurred in one of the five flaps, which was healed by dressing change using a hypertonic saline gauze. No significant problems were found at the donor site in any patient immediately afterwards or at follow-up.

Outcomes

The donor sites were primarily closed in two cases, and skin grafts were performed in three cases. All the flaps survived with a success rate of 100%, the wounds healed well, and the color matches were excellent. There were no problems associated with wearing shoes in any of the patients.

Based on the Chinese Manchester Foot Pain and Disability Index, four patients were strongly satisfied (score 0–5) and one patient (case one) was satisfied (score 6–10) with the recovery of physical function because she suffered a phalangeal fracture of her left big toe and a fracture of the left third metatarsal bone at the mean time. The average score of the physical limitation subscale based on the Chinese Manchester Foot Pain and Disability Index was 2.4. As for the personal appearance subscale, all the patients were strongly satisfied with the appearance of the injured foot (score 0–1). All five patients had an excellent score (score 0–2) of pain intensity subscale based on the C-MFPDI.

According to the VAS, except for one patient (case one) who reported mild pain at the injured foot, all the other patients reported no pain.

Case Report

Case One

A 70-year-old woman was transferred to our department with a local infection after the open reduction and internal fixation of fractures. One month prior, she had suffered a phalangeal fracture of her left big toe and a fracture of the left third metatarsal bone caused by a road-traffic accident. The internal fixation was performed in a local hospital (Fig. 3A), but an infection occurred at the site of surgery, the incision did not heal, and necrosis developed around the incision with exposure of the extensor tendon of the toes (Fig. 3B). Extensive scar tissue formed on the back of the left foot, so the donor site could not be closed directly.

After debridement, the wound was covered by a negative pressure dressing for 7 days, until the infection and necrotic tissue were eliminated. The axis of this flap was the connection between the fourth toe-web and the midpoint of the ankle, and the size of the flap was approximately 5.0 cm × 2.5 cm (Figs 3C and 1D). The donor site of this flap was covered with a skin graft. Four days after the surgery, the color and temperature of the flap were normal, but the incision was slightly red and swollen (Fig. 3E), so bigeminal application of antibiotic was used until the inflammation was eliminated. The grafted skin survived after 12 days (Fig. 3F), and then the patient was discharged from the hospital. Two months post-operation, all wounds had healed, and the appearance of both donor site and recipient site were satisfactory (Fig. 3G). There were no problems associated with wearing shoes.

Fig. 3 A: A 70-year-old woman suffered a phalangeal fracture of her left great toe and a fracture of the left third metatarsal bone caused by a road-traffic accident. B: There was a 2.5 cm × 2.0 cm skin defect on her dorsal foot. C, D: An intermediate dorsal neurocutaneous flap was designed for reconstruction. The donor site could not be closed directly. E: Four days after the surgery, the incision was slightly red and swollen. F: Twelve days after the surgery, the flap and skin grafts at the donor site survived uneventfully. G: Two months after the surgery, all wounds had healed, and the appearance of both donor site and recipient site was satisfactory.

Fig. 4 A, B: An 18-year-old man was diagnosed with a complete syndactyly. C, D: After the separation of two toes, an intermediate dorsal neurocutaneous flap was designed for the reconstruction of the defect on the fourth toe. The donor site was sutured directly. E: One week after the surgery, the color and temperature of the flap were normal, and there were no problems with the incisions. F: Two months after the surgery, the appearance of both donor site and toes was satisfactory.

Case Two

An 18-year-old man was admitted to our department with complete syndactyly of the third and fourth toes of his left foot (Fig. 4A and B). He had not undergone any treatment for his syndactyly in the past 18 years.

During the syndactyly correction surgery, we firstly accomplished the separation of two toes and sutured the wound on his third toe. There was a 3.0 cm × 1.0 cm skin defect on his fourth toe that could not be sutured directly. Therefore, an intermediate dorsal neurocutaneous flap was designed for the reconstruction of the skin defect. The size of the flap was approximately 6.0 cm × 3.5 cm, and the pivot point was 2.0 cm of the proximal end of the third toe-web (Fig. 4C). The donor site was sutured directly (Fig. 4D). After the surgery, a piece of gauze was placed between the two toes to prevent the flap from being pressed. One week after the surgery, the color and temperature of the flap were normal, and there were no problems associated with the incisions (Fig. 4E). Two months post-operation, all incisions healed, and the patient was satisfied with the appearance of his foot (Fig. 4F). There were no problems with the functioning of the toes.

Discussion

Reconstruction options for defects of the distal foot are limited because of the tension of the skin and a lower number of optional local and random flaps[27]. This surgery always represents a difficult problem for orthopaedic surgeons, especially when the defect is on the toes or the web spaces. In addition, one of the most important concerns is that the reconstruction of the distal foot should provide a good contour and thin and pliable tissue to allow for the wearing of a shoe[28]. Therefore, there is still a need for continued improvement.

Skin grafting is most commonly used because it is simple and risk-free, but it cannot be used where a bone or a tendon are exposed. A cross-leg flap is an option for reconstruction, but it requires a two-stage operation in which the patient must be placed in a very uncomfortable position for at least three weeks[28]. Compared to amputation and closure[28–30], which was used in the past, limb salvage surgeries are more commonly used when facing complex wounds now. These include transplantation of free anterolateral femoral flap, sural nerve pedicled island flap and cross-leg flap[1], all of which involve a longer recovery time, higher cost, and have an increased incidence of complications. A common

limitation of these procedures above is that the flaps are too bulky and interferes with shoe wear. A reversed or islanded first dorsal metatarsal artery (DMtA) flap can be thin, good in contour, and provide adequate coverage, but it involves dividing the pedis artery, often requiring additional surgeries to cover the donor site[6,13–15,24,29]. Besides, the first DMtA may be absent or inadequate in 9.4% to 18% of subjects; when the first DMtA lies within or deep to the dorsal interosseous muscle, the flap surgery would be more complicated[15,31–33].

It has been reported that the best age to correct syndactyly is from 1 to 2-years-old[34], which is good for a child's mental health, as well as for foot morphology and development. The traditional method of syndactyly correction includes skin grafts and local flaps, and many reconstruction techniques have been described over the years[35–42]. However, skin grafts are used on the web and a lateral side, or part of a lateral side, of the toe in most of the methods described above, which might result in a poor pigmentation match of the skin grafts and remaining scars on the dorsal side. Although some of the surgery techniques are applied without skin grafts, the incisions required are extensive which could also cause postoperative complications such as scar contracture. In this study, an 18-year-old patient with complete syndactyly underwent syndactyly correction. The size of the skin graft would have been too large if we had used traditional techniques. Therefore, an intermediate dorsal neurocutaneous flap seemed appropriate for reconstruction. In fact, it was successful in correcting the morphology and function of the foot.

The advantages of the intermediate dorsal neurocutaneous flap are obvious. First, it is expected to provide sufficient options for flap designs compared to the abovementioned flaps because of the rich nutrient artery network. Second, it presents a satisfactory postoperative contour and wide rotation arc. Third, complications are rare at both the donor and recipient sites. Finally, it is aesthetically pleasing and would not interfere with shoe wear (Fig. 3G and 4F). However, one of the limitations of intermediate dorsal neurocutaneous flap is that it is not suitable for large defects and the direct donor site closure can be also problematic. In addition, at least one cutaneous nerve of the flap should be sacrificed.

The key points of clinical application of intermediate dorsal neurocutaneous flap include: (i) the deep fascia of the dorsal foot should be included during the flap-raising to ensure the blood supply; (ii) the aponeurosis should be retained at the donor site for skin grafting; (iii) the pedicle should be kept at a width of at least 2cm to protect the nutrient vessels; (iv) the nutrient arteries at the pedicle need not to be separated to prevent the injury of nutrient vessels; and (v) the flap should be transferred without tension, the donor area should be larger than the recipient area in design, and the pedicle should not be twisted or squeezed too much to ensure the blood supply.

Conclusions

The intermediate dorsal neurocutaneous flap is an alternative and effective technique that can reliably cover minor- to medium-sized defects on distal foot, toes, and web spaces. This surgical method is able to obtain a satisfactory functional recovery with minimal donor-site morbidity without the need for sacrificing major vessels. It offers an advisable option for orthopaedic surgeons to treat defects on the distal foot.

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