Perforator-Sparing Transposition Flaps for Lower Limb Defects

Anatomic Study and Clinical Application

Chin-Ho Wong, MBBS, MRCS, and Bien-Keem Tan, MBBS, FRCS

Abstract: The local fasciocutaneous flap has the advantage of low donor-site morbidity when used for the coverage of lower limb defects. However, flap reliability remains a major problem with its use. The purpose of this study was to determine the feasibility of preserving perforators to the tip of conventional local fasciocutaneous flaps to improve its vascularity. The technical considerations of raising these flaps were examined in cadaveric specimens. Twenty-one local perforator-sparing transposition flaps were raised in 12 specimens. The leg was divided into knee/proximal-third, middle-third, and lower-third/ankle regions. We raised 7 flaps in each region. Success was defined as ability to transpose flaps to cover defects without tension on the perforators. In the knee/upper-third and middle-third regions of the leg, all wounds were successfully closed. However in the lower-third and ankle region, we were unable to close wounds in 3 of 7 cases. The reasons for this were the inadequate length of the perforator and the presence of tendons in the distal leg that interfered with perforator transposition. We successfully employed this flap in 6 clinical cases. This flap represents a technical advancement over conventional lower limb skin flaps because of its improved vascularity. It can safely be performed in the knee and upper and middle-thirds of the leg and can potentially be a valuable alternative to local muscle flaps for wounds in these areas.

Key Words: augment, lower limb, leg, reconstruction, local flap, improved, perfusion, vascularity, perforator based, novel

(*Ann Plast Surg* 2007;58: 614–621)

It is generally accepted that local muscle flaps are preferred for treating difficult wounds of the lower limb, especially those associated with exposed bone or implants.[1–8] Their effectiveness in treating such wounds has been attributed to their vascularity, which improves oxygen delivery to contaminated wounds.[3,9,10] However, sacrifice of local muscle in the leg may impair function, particularly in young and active individuals. Recently, free fasciocutaneous flaps have been demonstrated to achieve equivalent healing rates as free muscle flaps. Thus, more surgeons are reverting to using fasciocutaneous flaps for such wounds.[11–25] Conventional random-pattern skin flaps are, however, fraught with problems of tip necrosis, delayed healing, and wound breakdown. We postulate that, given a better vascularity, local fasciocutaneous flaps can achieve comparable healing rates as local muscle flaps. The purpose of this study was to demonstrate the feasibility of sparing or preserving perforators supplying the tip of local fasciocutaneous flaps to improve their vascularity. Subsequently, this flap was successfully employed in our clinical cases.

Received August 23, 2006, and accepted for publication, after revision, September 28, 2006.
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The authors did not receive any funding for this work and declare no conflict of interest in this present work.
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ISSN: 0148-7043/07/5806-0614
DOI: 10.1097/01.sap.0000250839.37161.ce

METHODS AND MATERIALS

Anatomic Study

Injection studies were carried out in 12 cadaveric lower limbs using injection techniques as previously described.[26] The defects were created in the (1) knee/upper-third, (2) middle-third, and (3) ankle/lower-third regions of the leg. In each region, 7 defects were created and perforator-sparing transposition flaps were raised for coverage. Figure 1 gives a schematic illustration of the surgical technique. The following data were obtained in each dissection: The location, number, and type of perforators which could be incorporated into the flaps and their length, diameter, and origin. The configuration of a given perforator was defined by its course or direction relative to the intended movement of the flap. A favorable configuration is one in which the perforator originates from near the flap's base and runs coaxially with the flap, whereas an unfavorable configuration is one in which the perforator originates from afar and tethers the flap down. A neutral configuration is one in which the perforator runs perpendicularly downwards to its origin (Fig. 2). Finally, the success of this design in closing a wound was defined as a complete inset without tension on the perforator.

RESULTS

Table 1 gives a summary of our dissection findings. Because of the abundance of skin perforators in the leg, at least 1 perforator was successfully incorporated in all simu-

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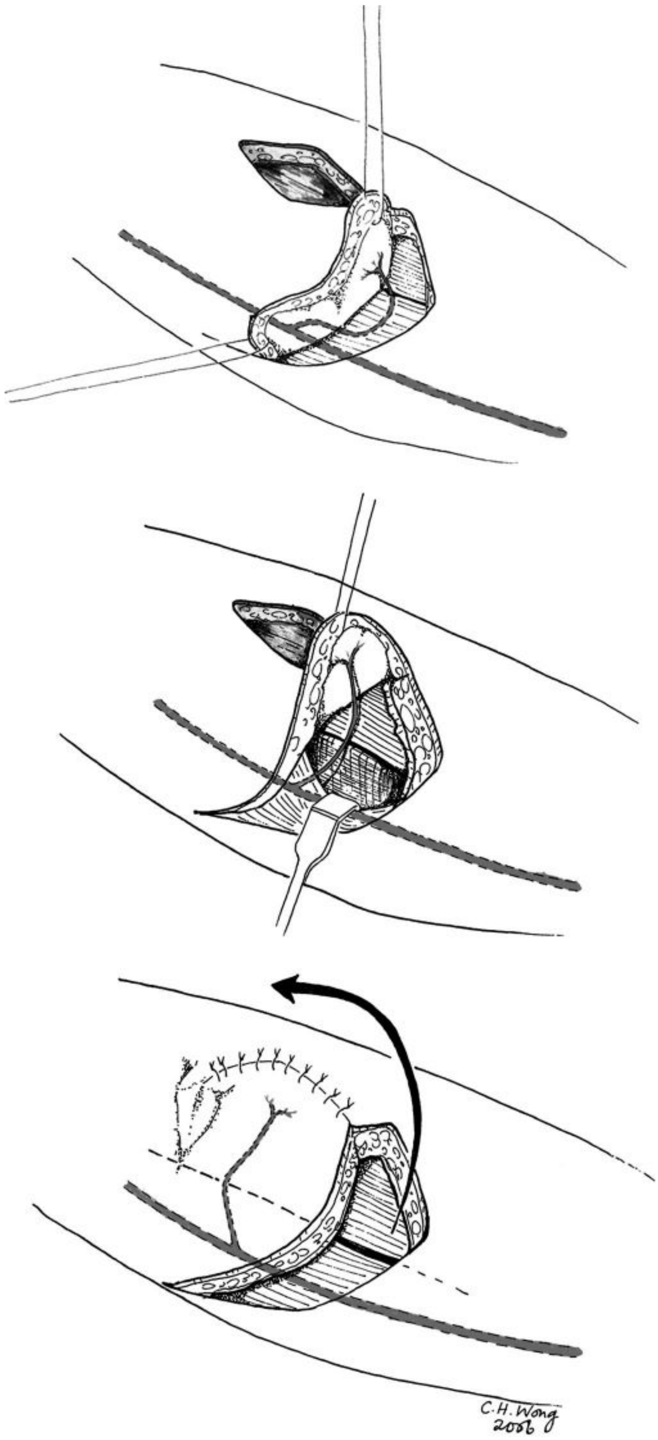

FIGURE 1. Raising a perforator-sparing local transposition flap. Above, A local transposition flap is planned and the flap is raised subfacially until a significant sized perforator (>0.4 mm) is encountered. Center, The perforator is completely mobilized to its origin. Once mobilized, the flap can be further elevated beyond the location of the perforator. Below, The flap is transposed into the defect, preserving and carrying with it the perforator to the tip of the flap. The donor site is closed by skin graft.

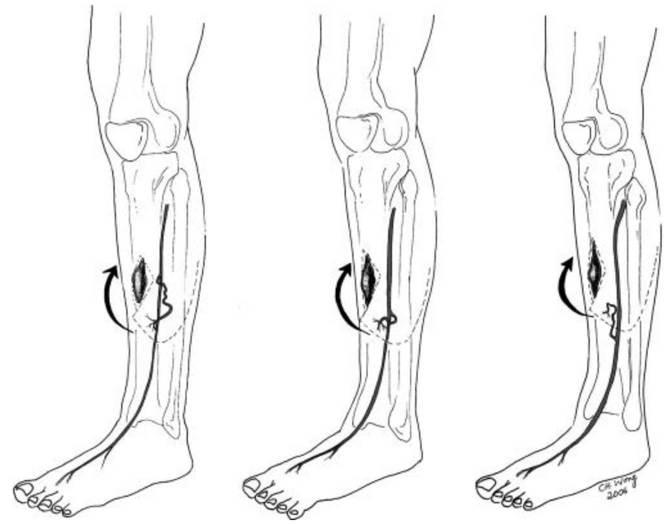

FIGURE 2. Configuration of the perforator-sparing transposition flap. (From left to right, favorable, neutral, and unfavorable configurations.)

lated flaps. Eighteen flaps had 1 perforator incorporated and 3 flaps had 2 perforators incorporated. The mean diameters of the perforators were 0.7 mm (range, 0.4 to 1.2 mm). The mean length of perforators in the knee/proximal-third, middle-third, and distal third of the leg/ankle was 4.3 cm, 4.1 cm, and 2.1 cm, respectively. We successfully closed all wounds in the knee/proximal-third and the middle-third regions of the leg. In these areas, the perforators were sufficiently long (mean length, 4.3 cm and 4.1 cm, respectively) to allow tension-free transposition. However, when flaps were raised in the lower third of the leg and ankle, we were unable to close the wounds in 3 of the 7 specimens. The reasons for this were that the perforators were short and the presence on tendons in this region interfered with perforator transposition.

The configuration of the perforator directly affected the ease by which the flaps were transposed. Of the 21 flaps we raised, unfavorable configurations were encountered in 6 flaps. Of these, 5 were distally based flaps. We were able to close all wounds in flaps with favorable and neutral configurations. In 3 specimens with unfavorable configurations, it was necessary to cut a cuff of muscle to shorten the path from the origin of the perforator to the flap. With this maneuver, we were able to successfully transpose even flaps with unfavorable configurations. This maneuver was, however, only applicable for defects in the knee and proximal and middle-third regions of the leg where muscle bulk is significant.

Surgical Technique

Our surgical technique was developed based on our experience with cadaveric dissections and our clinical cases. The patient is placed in a supine position and a tourniquet is applied. A transposition flap is designed and a handheld Doppler is used to locate skin perforators. A proximally based designed is generally preferred because perforators tend to run in a proximal to distal direction. If previous incisions or scars interfere with the design, a distally based

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TABLE 1. Summary of Our Cadaveric Dissection Findings

Specimen No.	Defect Location	Site and Base of Flap	No. Perforators Incorporated	Type of Perforator	Diameter of Perforator (mm)	Length of Perforator (cm)	Origin of Perforator	Configuration	Successful Wound Closure/Comments
1	Anterior knee	Lateral leg, distally based	1	Septocutaneous	0.4	4	Anterior tibial artery	Unfavorable	Yes/need to cut muscle
2	Anterior knee	Medial leg, proximally base	1	Septocutaneous	0.8	5	Anterior tibial artery	Favorable	Yes
3	Anterior knee	Lateral leg, distally based	1	Musculocutaneous	0.8	3.5	Anterior tibial artery	Unfavorable	Yes/need to cut muscle
4	Upper third	Medial leg, distally based	2	Septocutaneous and musculocutaneous	0.4 and 0.7	4 and 3.5	Posterior tibial artery	Neutral	Yes
5	Upper third	Lateral leg, proximally based	1	Septocutaneous	1.2	6	Anterior tibial artery	Favorable	Yes
6	Upper third	Medial leg, proximally base	1	Musculocutaneous	1.2	4	Posterior tibial artery	Neutral	Yes
7	Upper third	Lateral leg, proximally based	1	Musculocutaneous	0.8	4.5	Anterior tibial artery	Favorable	Yes
8	Middle third	Medial leg, distally based	1	Septocutaneous	1.0	6	Posterior tibial artery	Favorable	Yes
9	Middle third	Lateral leg, distally base	1	Septocutaneous	0.8	4	Anterior tibial artery	Unfavorable	Yes/need to cut muscle
10	Middle third	Medial leg, proximally based	2	Musculocutaneous and septocutaneous	0.4 and 0.6	4.5 and 2.0	Posterior tibial artery	Unfavorable	Yes/need to cut muscle
11	Middle third	Medial leg, proximally based	2	Septocutaneous	0.4 and 0.6	3 and 4	Posterior tibial artery	Favorable	Yes
12	Middle third	Lateral leg, proximally based	1	Septocutaneous	0.5	2.5	Posterior tibial artery	Neutral,	Yes
13	Middle third	Medial leg, distally based	1	Musculocutaneous	0.5	5	Posterior tibial artery	Favorable	Yes
14	Middle third	Lateral leg, proximally base	2	Septocutaneous	0.8	6	Peroneal artery	Neutral	Yes
15	Lower third	Medial leg distally based	2	Septocutaneous	0.4 and 0.6	2.0 and 2.5	Posterior tibial artery	Unfavorable	Yes
16	Lower third	Medial leg, proximally based	1	Septocutaneous	0.6	1.5	Posterior tibial artery	Neutral	No
17	Lower third	Medial leg, proximally based	1	Septocutaneous	0.7	2	Posterior tibial artery	Neutral	Yes
18	Lower third	Lateral leg, proximally base	1	Septocutaneous	1.0	2	Anterior tibial artery	Neutral	No
19	Lower third	Medial leg, proximally base	1	Septocutaneous	0.6	2.5	Posterior tibial artery	Neutral	Yes
20	Ankle	Lateral ankle, proximally based	1	Ankle perforator	0.5	2.5	Anterior tibial artery	Neutral	Yes
21	Ankle	Medial leg, distally based	1	Septocutaneous	1.0	1.5	Posterior tibial artery	Unfavorable	No

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TABLE 2. Clinical Cases

Case	Age, Years	Comorbidities	Location and Type of Injury	Structures Exposed	Defect Size (cm)	Flap Size (cm)	Outcome/ Complications
1	24	Nil	Middle third anterior tibial defect. Gustillo type IIIB open tibial fracture	Bone	6 × 3	14 × 8	Complete flap survival Follow-up 6 months
2	70	Diabetes mellitus, hypertension	Anterior knee defect Right tibia plateau fracture	Patella tendon, tibia bone and implant	4 × 7	8 × 14	Complete flap survival Follow-up 7 months
3	34	Nil	Upper and middle third defect Tibial plateau and midshaft tibia fracture	Bone and implant	14 × 4	6 × 17	Complete flap survival Follow-up 4 months
4	26	Nil	Middle third anterior tibial defect; Gustillo type IIIA open tibial fracture	Bone	6 × 4	6 × 12	Complete flap survival Follow-up 8 months
5	47	Diabetes	Middle third anterior tibial defect Gustillo type IIIB open tibial fracture	Bone	6 × 3	7 × 14	Complete flap survival Follow-up 12 mo
6	38	Hypertension	Middle third anterior tibial defect Gustillo type IIIB open tibial fracture	Bone and implant	5 × 3	7 × 16	Complete flap survival Follow-up 11 months

design is used instead. There is a higher possibility of encountering a flap with an unfavorable configuration in such a situation. In planning the flap, 2 sets of perforators should be marked: those at the (1) tip of the flap and (2) at the base of the flap. The former marks the perforators that should be spared to augment the tip's blood supply. The latter marks the pivot point of the flap as advocated by Ponten.[27]

Under tourniquet, subfascial flap elevation is performed. Care should be taken to elevate the flap in the loose areolar tissue plane while preserving the paratenon to allow for skin grafting at the donor site. The saphenous vein and superficial nerves when encountered should be included with the flap. Guided by preoperative markings, elevation proceeds until significant-sized perforators (>0.4 mm) are encountered. The initial selection of perforators would depend on their size and location. Further considerations include the length of the perforator and its configuration. The longer the perforator, the easier it would be for the flap move without tension. At this juncture, without committing oneself, the tourniquet is released and the selected perforator is traced to its origin (anterior tibial, posterior tibial, or peroneal arteries), and its configuration and length are assessed. Dissection is performed with 2.5× loupe magnification. Dissection is straightforward if the selected perforator is a septocutaneous perforator. In instances where the selected perforator is a musculocutaneous perforator, intramuscular dissection is more technically demanding but, as previously shown, can be performed precisely and safely using perforator flap techniques.[28] Once the adequacy of the chosen perforator is confirmed, other perforators (if present) are divided. If desired, more than 1 perforator can be incorporated. Flap elevation beyond the location of the perforator can then proceed. Undermining should stop when perforators at the base are encountered, and this serves as the pivot point of the flap. The flap is then transposed into the defect, and fine sutures are used to coapt the skin (Fig. 1). Care should be taken to avoid tension on the perforator. If necessary, a cuff of muscle can be cut to provide a more direct path for the perforator. The muscle can later be repaired over the perforator. Some dog-ear is usually present at the pivot point, and this usually settles down with time. This should not be trimmed to preserve the subdermal plexus. The donor site can be covered immediately with skin graft.

Clinical Cases

We performed this flap for coverage of lower-limb defects in 6 patients (Table 2). All patients were men, with age ranging from 24 to 70 years. Our selection criteria for the use of this design included small- to medium-size defects (mean area, 27 cm^2) with no complex 3-dimensional loss and defects located in the knee and upper third and middle third of the leg. In general, defects that can be adequately covered by local muscle flaps are well suited for closure with perforator-sparing transposition flaps. From our experience with cadaveric dissections, we avoided this design in the distal third of the leg and ankle.

All wounds were successfully closed. The mean follow-up was 8 months (range, 4 to 12 months). All flaps survived completely, with no complications. Bone healing was achieved in all patients. At follow-up, handheld Doppler assessment confirmed the patency of the incorporated perforators in all patients.

CASE REPORTS

Case 1

A 24-year-old fireman sustained a Gustillo type IIIA open fracture of the left tibia. Intramedullary nailing was performed, and the anterior shin wound was primarily closed. This was complicated by postoperative wound-edge necrosis and wound infection. The wound was debrided and closed with a perforator-sparing fasciocutaneous flap (Fig. 3A). A distally based design was used because of the presence of a previous incision extending from the inferior aspect of the

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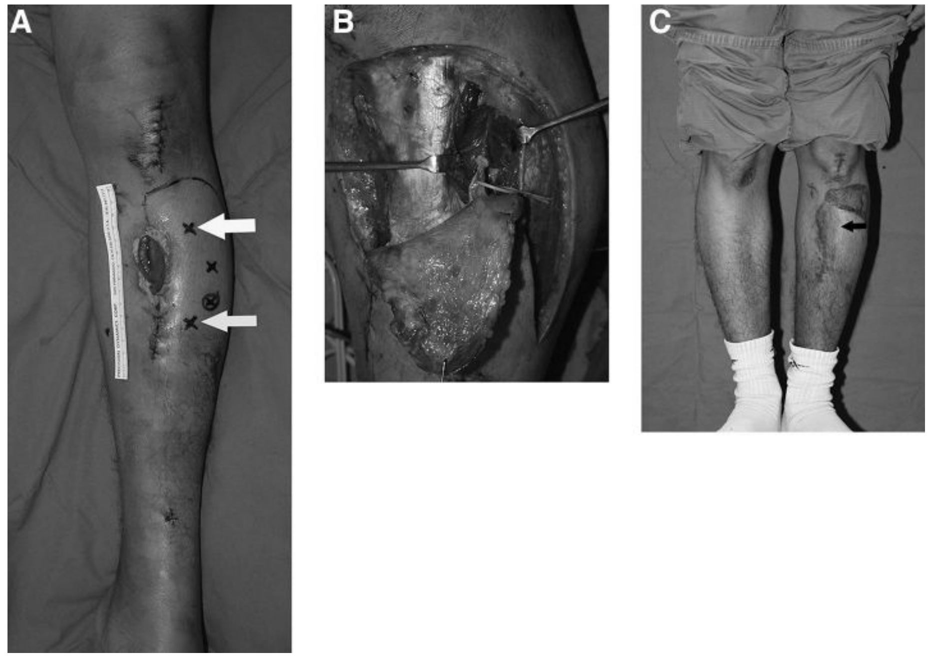

FIGURE 3. Patient of case 1. A, A perforator-sparing transposition flap was planned for coverage of a middle-third defect of the leg. Preoperative Doppler assessment identified the location of cutaneous perforators. The top arrow indicates the perforator to be mobilized and the bottom arrow indicates the perforator at the base of the flap to be preserved. B, Intramuscular dissection of the musculocutaneous perforator to its origin at the anterior tibial artery. C, Patient at 6-month follow-up. Doppler assessment confirmed the patency of the preserved perforator (arrow).

wound. A musculocutaneous perforator at the tip of the flap was selected. Intramuscular dissection to its origin at the anterior tibial artery was performed, and this was noted to have a neutral configuration (Fig. 3B). The flap was transposed to close the defect without tension on the perforator. He healed uneventfully, and at 6 months' follow-up, the patency of the incorporated perforator was confirmed by Doppler (Fig. 3C).

Case 2

A 70-year-old man with a history of diabetes mellitus sustained a right knee tibial plateau fracture in a road traffic accident. Open reduction internal fixation was performed. Knee wound infection and breakdown resulted in exposed patella tendon, tibial bone, and titanium plate. After 2 wound debridements and negative-pressure therapy (V.A.C. dressing; Kinetic Concepts, Inc, San Antonio, TX), the wound was clean and ready for closure. Guided by handheld Doppler, a lateral-leg, proximally based, perforator-sparing, fasciocutaneous flap was planned (Fig. 4A). Intraoperatively, a septocutaneous perforator was selected. When traced to its origin at the anterior tibial artery, an unfavorable configuration with the perforator running distally was noted. To facilitate flap transposition without tension on the perforator, the tibialis anterior muscle was partially cut and the wound was successfully closed (Fig. 4B). The muscle was repaired over the perforator and the donor-site skin grafted. Healing was uneventful. He started ambulating 2 weeks after the operation. At 7-month follow-up, he was well, with good bony union. Doppler assessment confirmed the patency of the incorporated perforator (Fig. 4C).

Case 3

A 34-year-old man was involved in a road traffic accident and sustained a right tibial plateau and midshaft tibial fracture. Open reduction and internal fixation with titanium plates were performed. Postoperatively, however, wound infection resulted in loss of soft tissue over the entire anterior compartment of the shin, with exposed tibia and metal plate. Coverage with a free anterolateral thigh musculocutaneous flap failed because of thrombosed recipient vessels. He declined a second free-flap attempt. The wound was treated with negative-pressure therapy (V.A.C. dressing; Kinetic Concepts, Inc) for 2 months. This effectively reduced the size of the wound, but a 14- × 4-cm area in the upper and middle thirds of the leg with exposed plate and bone remained (Fig. 5A). We performed a perforator-sparing transposition flap raising a 17- × 6-cm flap for closure on the defect. Two perforators (1 musculocutaneous from the anterior tibial artery and 1 septocutaneous from the peroneal artery) were preserved to augment the flap's tip (Fig. 5B). This successfully covered the exposed bone and plate, with the remaining granulating wound and donor-site skin grafted. He healed uneventfully and was given antibiotic coverage for a further 6 weeks after wound closure. He started gradual ambulation 1 month after surgery and was well at 4-month follow-up. Doppler assessment confirmed the patency of the incorporated perforator (Fig. 5C).

DISCUSSION

Early local flaps in the leg were raised in the subcutaneous plane, and they relied solely on the subdermal plexus for blood supply. Hence, their dimensions were constrained by strict length-to-width ratios.[29] In 1981, Ponten[27] introduced the fasciocutaneous "superflaps," which were longer and had greater reach. These flaps included the deep fascia and were nourished by perforators located at the base of the flap. Additionally, sensory nerves and superficial veins included gave a measure of axiality to the flap because of their

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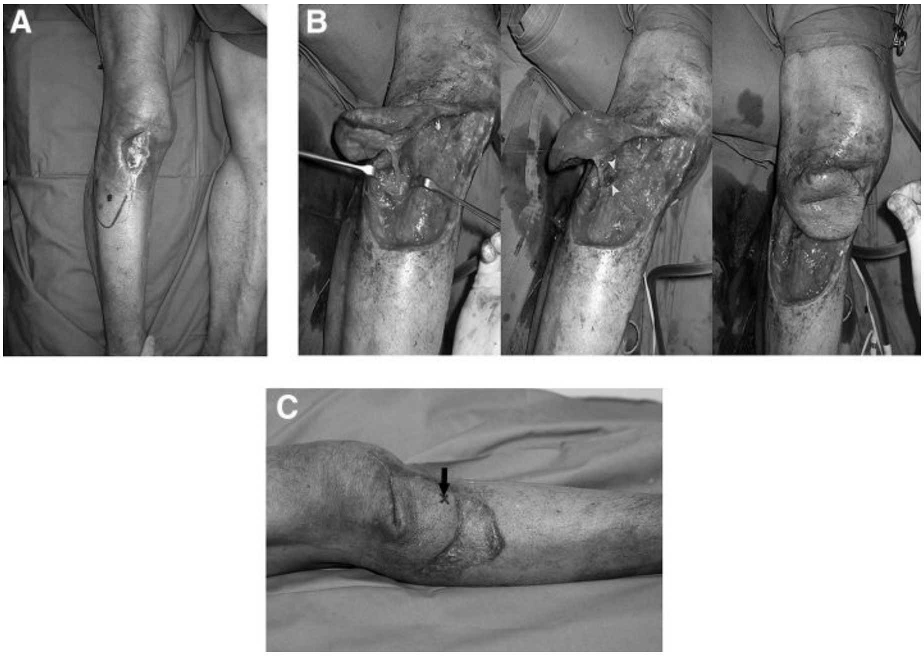

FIGURE 4. Patient of Case 2. A, Right knee wound. Preoperative markings of a perforator-sparing transposition flap. B, Left, Intraoperatively the selected perforator was a septocutaneous perforator, and this was mobilized to its origin at the anterior tibial artery. An unfavorable configuration with the perforator running away from the center of transposition was noted. Middle, To facilitate transposition without tension of the perforator, approximately 40% of the tibialis anterior muscle (arrowheads) was cut to create a more direct path from the origin of the perforator to the flap. Right, Wound closed with the perforator-sparing transposition flap. C, Patient at 6-month follow-up. Doppler assessment confirmed the patency of the preserved perforator (arrow).

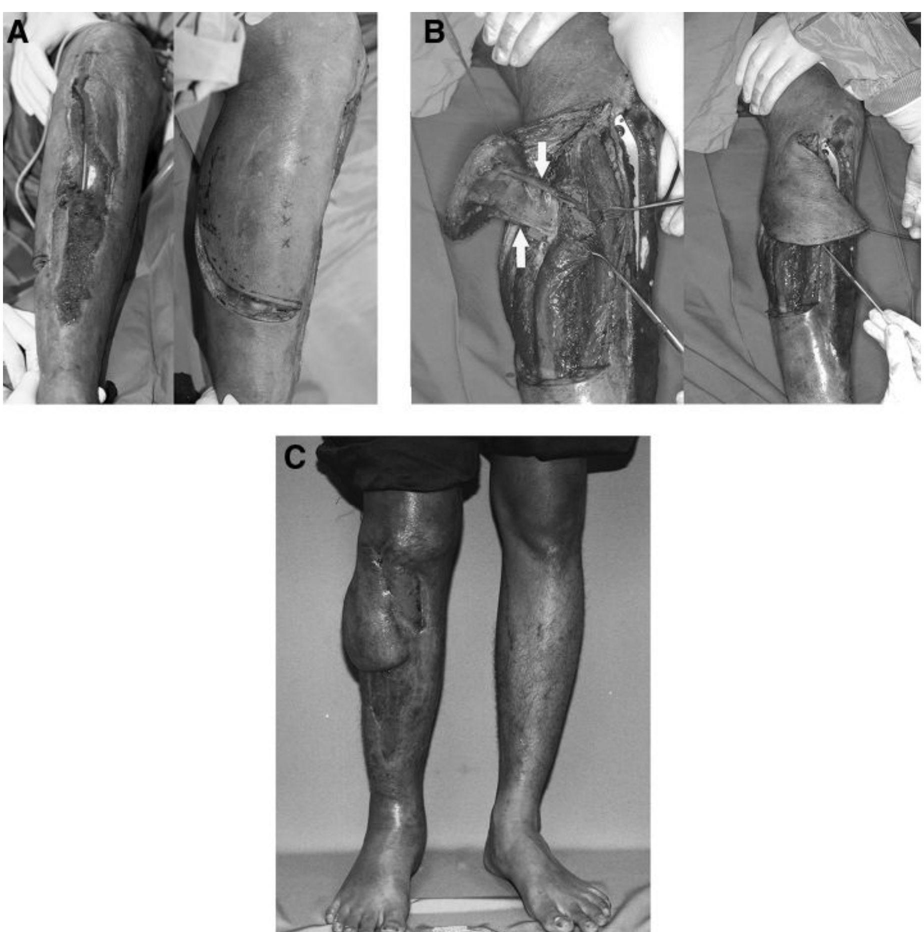

FIGURE 5. Patient of Case 3. A: Left, Right-leg traumatic wound after 2 months of V.A.C. therapy. The patient has a 14- × 4-cm area in the upper and middle thirds of the leg, with an exposed plate and bone. Right, Coverage with a perforator-sparing transposition flap was performed. B, Left, Intraoperatively 2 perforators supplying the tip of the flap were preserved and dissected to their respective origin. One was a musculocutaneous perforator from the anterior tibial artery (top arrow) and the other was a septocutaneous from the peroneal artery (bottom arrow). Right, Complete coverage of the plate with the flap. C, The patient at 4 months' follow-up, showing complete survival of the flap. The patency of the 2 perforators was confirmed by handheld Doppler.

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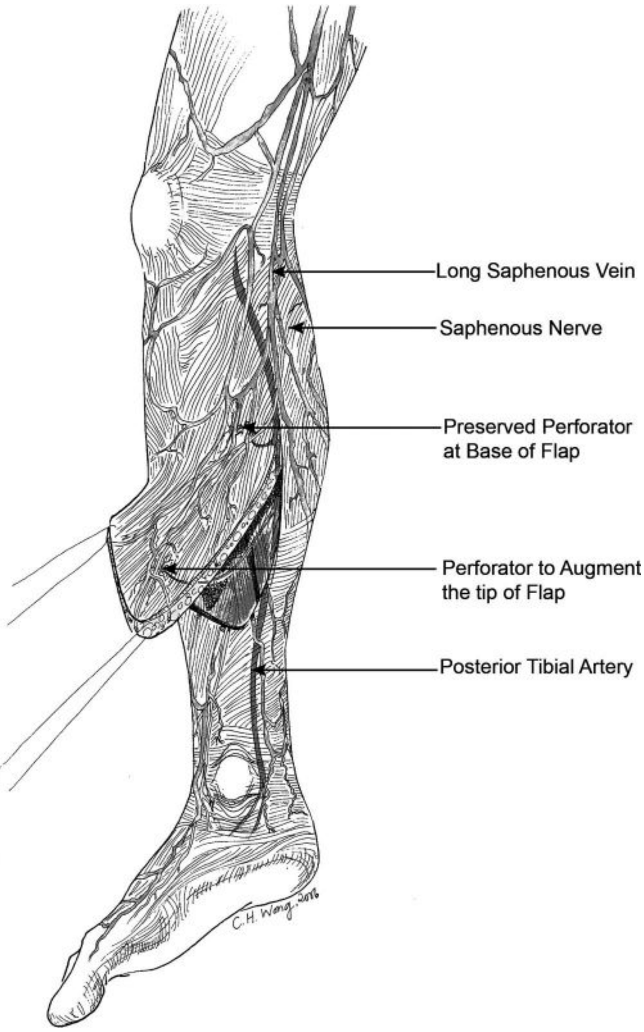

FIGURE 6. Anatomy of the perforator-sparing fasciocutaneous transposition flap. This design, with multiple sources of blood supply, maximizes the flap's reliability. These include the (1) subdermal plexus at the base of the flap, (2) the neurovenocutaneous circulation (based on the superficial veins and nerves within the flap), and (3) the preserved perforator.

intrinsic and extrinsic neurocutaneous and venocutaneous circulation.[30] In essence, the local flap has evolved from a random-pattern-type flap into one which is now termed *neurovenocutaneous flap*. However, even in Ponten's[27] series, complete flap survival was only noted in 74% of cases. Could we improve the reliability of local flaps in the lower limb? This was the question that motivated this study.

The perforator-sparing local transposition flap as described in this paper is built on the virtues of the fasciocutaneous flap, with attempts to augment its vascularity by strategically preserving cutaneous perforators supplying the tip of the flap (Fig. 6). Often, this is the part that covers the critical portion of the defect, such as an exposed plate or bone, and therefore a partial tip necrosis is as good as complete loss. Compared with the conventional design of a fasciocutaneous flap, ours represented a technical advancement for the following reasons: First, the vascularity of the flap, especially that of the tip, is improved. Second, flap mobilization is no longer restricted by the location of the perforators. In the conventional fasciocutaneous flap, when the perforator is encountered, flap elevation had to cease and this served as the pivot point of the flap.[31] If reach was insufficient, the perforator would have to be cut to mobilize the flap further, which may potentially compromise the flap's blood supply. With the perforator-sparing flap, however, when a perforator is encountered, it can be mobilized to its origin and preserved. Further undermining can then be performed beyond the location of the perforator, affording this design equal mobility without compromising its vascularity.

The medial and lateral leg are richly supplied by cutaneous perforators, which allow the raising of perforator-sparing transposition flaps from virtually any area in the lower limb. In general, a proximally based design is preferred because lower-limb perforators, be they septocutaneous or musculocutaneous, tend to travel in a proximal to distal direction. This increases the likelihood of encountering a favorable configuration where the perforator runs coaxially with the flap. Perforators in the proximal and middle thirds of the leg are inherently longer because of the presence of muscle through which they traverse. In these areas, even perforators with an unfavorable configuration may be transposed with minimal tension. This is because all perforators have some inherent redundancy after they are mobilized. In cases where length is still lacking, cutting the intervening muscle to create a groove provides a more direct path for the perforator. In the distal third of the leg and ankle, perforators are short and the surrounding tendons cannot be divided to facilitate perforator transposition. Furthermore, vital structures such as the Achilles tendon may become exposed. Dissection is also more difficult as the deep fascia fuses with the ankle retinaculum. The use of this technique is thus recommended for coverage of defects above the lower leg.

Several authors have reported the use of local island-type perforator flaps for coverage of lower-limb defects.[32,33] The island-type design relies solely on its perforator, which may be unreliable in trauma cases because of degloving injury. The handheld Doppler can evaluate arterial inflow adequately but may not confirm the integrity of the venous perforators draining the flap. In such cases, we prefer using the transposition-type design as the intact skin at the base of the flap provides an additional channel for venous drainage via the subdermal plexus.[34]

Limitations of this design include the technically more demanding dissection, unpredictable perforator anatomy, and increased length of surgery. Defects that are appropriate for this flap are small- to medium-size defects. The defects covered in our clinical cases ranged from 5×3 cm^2 to 14×4 cm^2. As a guide, defects that cannot be covered by local muscle flaps will generally not be suited for coverage with perforator-sparing transposition flap. Free flaps, either muscle or fasciocutaneous, are indicated for larger defects.[19]

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ACKNOWLEDGMENTS

The authors thank Mr. Robert Ng and Mr. Kok-Heng Kum for specimen preparation and laboratory assistance.

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