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ARTICLE

Free neurosensory flap based on the accompanying vessels of lateral sural cutaneous nerve: anatomic study and preliminary clinical applications

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ABSTRACT

Background: The posterior aspect of the leg is an ideal donor site for flap surgery. In this study, the anatomy was investigated of the lateral sural cutaneous nerve (LSCN) and its accompanying artery, superficial lateral sural artery (SLSA), and a lateral sural neurocutaneous flap was designed.
Methods: Five fresh adult cadaver legs perfused with red latex were dissected to observe the course and relationship between LSCN and SLSA. The outer diameter of SLSA at its origin was measured. Then a lateral sural neurocutaneous flap was designed and used to repair soft tissue defects in six patients.
Results: The anatomic results showed that the SLSA gave rise to branches that followed the LSCN and ramified into terminals at the ramification of the nerve. It originated directly from the popliteal artery 4.2 ± 0.2 mm above the fibular head, where its outer diameter was 0.96 ± 0.23 mm. Several perforators penetrated from the crural fascia and anastomosed to the SLSA, creating a fine anastomotic network. The clinical results showed that the size of the flap ranged from 12 × 6 cm to 25 × 8 cm. All six flaps survived completely without complications. Follow-up ranged from 6 to 18 months with 11 months on average. The overall contour and sensory recovery of the flap were satisfied.
Conclusion: A free innervated flap may be elevated safely based on the LSCN and its accompanying vessels. It provides an alternative in reconstruction of soft tissue defects where sensory recovery is important.

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Introduction

The posterior calf region is a well-known donor site that provides several useful and reliable flaps for reconstruction of soft tissue defects. The medial sural artery perforator flap, for example, is a workhorse flap designed in the posteromedial calf region, with the virtues of thin skin paddle, minimal donor site morbidity, muscle sparing, and large-caliber vascular pedicle [1,2]. It is supplied by a sizable musculocutaneous perforator piercing through the medial head of the gastrocnemius muscle, which can be found in over 90% of patients [3–6]. Although the medial sural artery perforator flap is useful, significant attention should be paid during the tedious intramuscular dissection; any injuries to the perforator pedicle may lead to flap failure [2].

Since circulation to the cutaneous territory of the calf depends on both superficial cutaneous and deep musculocutaneous systems, some studies reported the use of the superficial sural artery to elevate flaps from the posterolateral calf [7–9]. Wolff et al. [9] dissected 42 cadaver legs and found that the superficial lateral sural artery (SLSA) existed in 36 legs. They also described a series of intraoral reconstructions using flaps from the posterolateral calf, with SLSA the pedicle. In their study, the SLSA was always found accompanying the lateral sural cutaneous nerve (LSCN). However, the relationship between SLSA and LSCN was not discussed explicitly.

The LSCN is a well-known sensory nerve in the posterolateral region of calf [10–12]. Usually, it perforates the crural fascia 5–10 cm inferior to the popliteal crease, supplying the fascia and skin of the lateral two-thirds of the leg. However, little attention has been paid to the vessels that accompany the LSCN. In this study, an anatomical study of SLSA and its association with the LSCN was performed, and a sensate flap – a free lateral sural neurocutaneous flap – based on the SLSA and LSCN was designed for sensory and soft tissue reconstruction.

Materials and methods

Anatomic study

The study was proved by Ethics Committee of the Shanghai Sixth People's Hospital. Five fresh adult cadaver legs perfused with red latex in the femoral arteries were dissected to investigate the course and branches of the LSCN and its accompanying vessels. Several sites were marked before dissection, including the flexion crease of the knee joint, the midline of the calf, the fibular head, and the junction of the middle and lower thirds of the leg. The incision started at the midpoint of the popliteal fossa and continued along the midline of the calf. The skin paddle was elevated under the crural fascia. Then, the LSCN and the peroneal communicating nerve (PCN) and their accompanying arteries were dissected above the crural fascia. The fascia around the nerve was

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incised from the underlying muscle to reveal the relationships among the cutaneous nerves, the nerve-accompanying vessels, and the perforators. The LSCN and its accompanying artery were carefully traced back to their origins, and the outer diameter of the artery was measured at its origin.

Clinical application

From January 2014 to December 2017, six patients with soft tissue defects underwent free lateral sural neurocutaneous flap transfer. Five patients were male, and one was female, with an average age of 36.7 years (range, 19–54 years). Four patients were victims of motor vehicle accidents, and two suffered from machinery trauma. The size of soft tissue defects ranged from 9 × 7 cm to 20 × 10 cm. Detailed information about these patients is summarized in Table 1.

Surgical technique

Preoperatively, a Doppler probe was used to confirm the potency of SLSA at the proximal calf level overlying the lateral head of the gastrocnemius muscle [8], because it is reported that the SLSA, as well as the LSCN, could be absent in rare cases [13]. The flap was designed on the posterolateral aspect of the calf (Figure 1(A)), with the midline of the leg as the medial border and the fibula as the lateral border; the flap length can extend from the level of fibular head to the juncture of the middle and lower thirds of the leg. The operation was performed with the patient in the lateral decubitus position. Starting at the popliteal fossa, the skin was incised in a distolateral direction, ending just below the level of the fibular neck. The LSCN and PCN were exposed with suprafascial blunt dissection (Figure 1(B)). Their accompanying arteries could easily be observed surrounding the nerves and were carefully traced back to their origins. Flap harvest was then continued from lateral to medial side on the subfascial plane. The LSCN, PCN, and accompanying arteries were elevated within the flap (Figure 1(C)). The tourniquet was deflated, and the vascularity of the flap was assessed. When the recipient site was ready, the pedicle of the flap was clipped close to the source vessels and the proximal LSCN was also cut from its origin. The distal LSCN ramified into terminals as it went down within the suprafascial plane, so it did not need concern. The distal PCN, on the other hand, was transected sharply at the flap edge or at the site where it joined the medial sural cutaneous nerve.

At the recipient site, the superficial lateral sural vessels were anastomosed to recipient vessels in an end-to-end fashion with 10/0 monofilament sutures and the LSCN was coapted to a sensory nerve in an end-to-end or end-to-side fashion using fascicular sutures (Figure 1(D,E)). The donor site was closed primarily or with a skin graft.

Posteroperatively, low molecular weight heparin was used for 7 days, and flap monitoring was conducted by special nursing staff in our microsurgery intensive care unit. The skin temperature, capillary refill, color and bleeding of the flap were monitored every 2 h for the first 2 days, and thereafter every 6 h until discharge.

Results

Anatomic results

In the anatomical dissections, the LSCN was found in all 5 specimens. It originated subfascially from the common peroneal nerve and descended between the lateral head of the gastrocnemius

Table 1. Patients' demographic data.

Patients	Sex/ Age (yr)	Cause	Location of soft tissue defect/side	Size of soft tissue defect (cm^2)	Size of free flap (cm^2)	Length of pedicle (cm)	Recipient vessels	Recipient nerve	Donor site closure	Flap Complications	Donor site Complications	Pain perception	Hot/cold distinction	SWM	2PD (mm)	Follow-up (mo)
1	Male/32	Motor vehicle accident	Sole/R	9 × 7	10 × 8	7	Medial plantar vessels	Medial plantar nerve	Skin graft	None	None	Yes	No	N/A[b]	N/A[b]	6
2	Male/54	Motor vehicle accident	Sole/L	11 × 5	12 × 6	5	Medial plantar vessels	Medial plantar nerve	Skin graft	None	None	Yes	Yes	4.74	25	12
3	Male/47	Motor vehicle accident	Heel and sole/R	20 × 10[a]	18 × 10	5	Medial plantar vessels	Medial plantar nerve	Skin graft	None	None	Yes	Yes	4.17	25	10
4	Female/42	Machinery Trauma	Dorsal hand/R	11 × 7.5	12 × 8	7	Branch of radial vessels	Superficial radial nerve	Skin graft	None	None	Yes	No	N/A[b]	N/A[b]	6
5	Male/26	Machinery Trauma	Dorsal hand/L	14 × 9	15 × 9.5	3.5	Branch of radial vessels	Superficial radial nerve	Skin graft	None	None	Yes	Yes	3.61	20	18
6	Male/19	Motor vehicle accident	Palmar Hand/R	24 × 7	25 × 8	5.5	Branch of ulnar vessels	Medial cutaneous nerve	Primary suture	None	None	Yes	Yes	3.61	20	15

[a]The soft tissue defects were covered by the free lateral sural neurocutaneous flap and skin graft. The flap was used to repair soft tissue defects around the heel, while the Skin graft was used to cover non-weight bearing area of the sole.
[b]These patients were followed up through the internet, and the results of SWM and 2PD were not obtained.

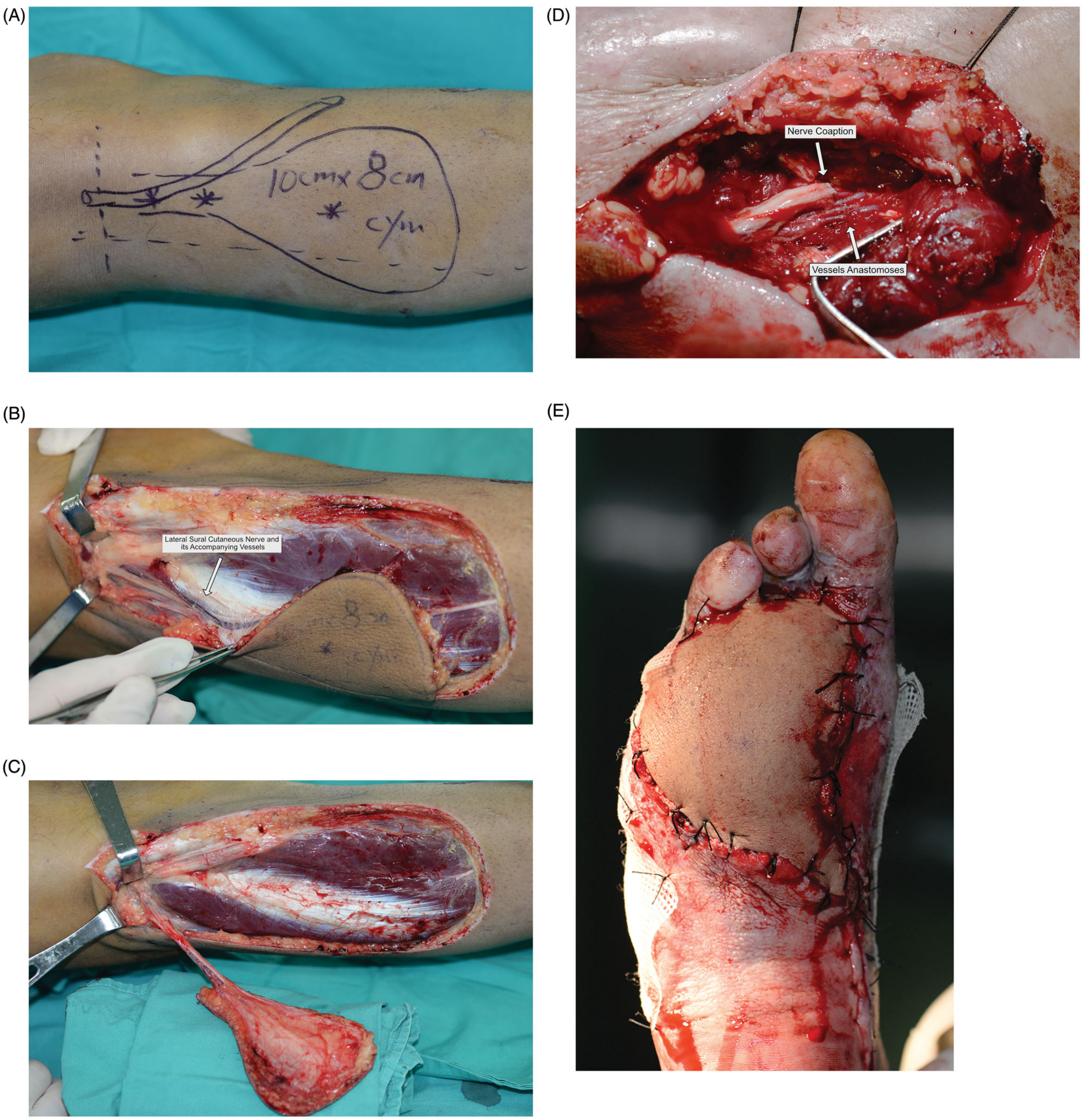

Figure 1. (A) The flap was designed on the posterolateral aspect of the calf (right leg). The asterisks were used to outline the possible course of the LSCN. (B) The LSCN was exposed with suprafascial blunt dissection. (C) The pedicle including the LSCN and accompanying vessels was exposed. (D) The anastomoses of vessels and coaptation of the nerve. (E) The free flap was transferred to cover the soft tissue defects in the plantar foot.

and the crural fascia. After penetrating the fascia near the fibular head, it ramified into its terminals supplying the skin of the lateral two-thirds of the leg. The PCN could be observed branching off the LSCN and joined the medial sural cutaneous nerve to form the sural nerve near the junction of the middle and lower thirds of the leg. The SLSA was found accompanying the LSCN in all cases. It originated directly from the popliteal artery 4.2 ± 0.2 mm above the fibular head, where its outer diameter was 0.96 ± 0.23 mm (Figure 2(A)). At the bifurcation of the LSCN and PCN, the SLSA gave rise to two branches that followed the nerves, and the artery ramified into terminals along the ramification of the nerves, supplying both the nerves and the soft tissue over them (Figure 2(B,C)). Along the course of SLSA, several perforators penetrated from the crural fascia and anastomosed with the SLSA, creating a fine anastomotic network (Figure 2(D)). Some perforators originated from the lateral sural artery, others from the peroneal artery.

Clinical results

The size of the flaps ranged from 12×6 cm to 25×8 cm, and the length of the pedicle was 5.5 cm on average. All six flaps survived completely without complications. In three patients, the superficial lateral sural vessels were anastomosed to medial plantar vessels, and the LSCN was coapted to the medial plantar nerve in an end-to-end fashion. In two patients, the pedicle vessels were anastomosed end-to-end to a branch of radial vessels, and the LSCN was coapted to the superficial branch of the radial nerve. In

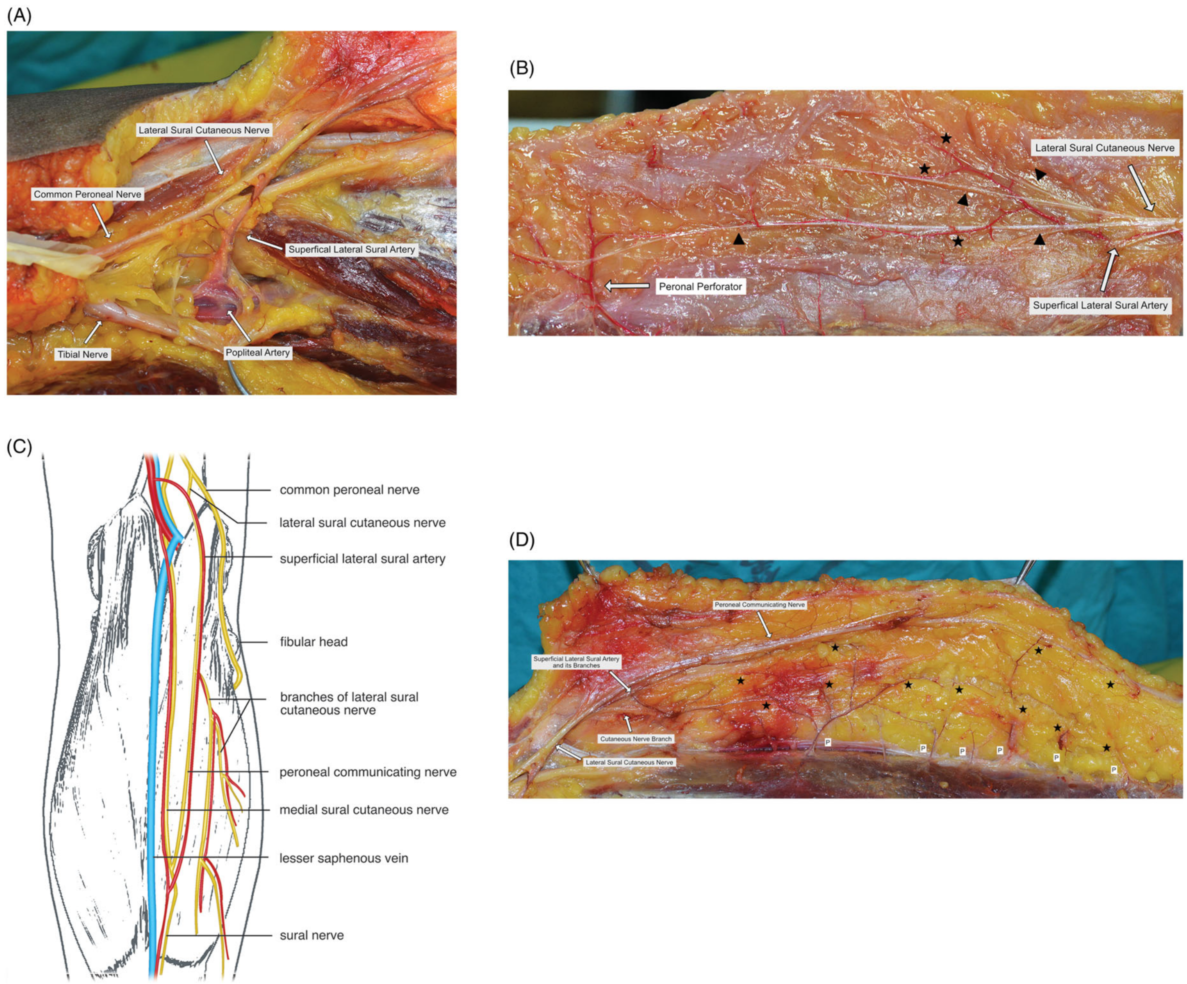

Figure 2. (A) The SLSA originated directly from the popliteal artery. (B) The SLSA gave rise to two branches following the nerves, and the artery ramified into terminals as the ramification of the nerves, supplying both nerves and soft tissue over them. The marks of triangles and stars represented the branches of the LSCN and of nerve accompanying arteries, respectively. (C) Outline of anatomic results of LSCN and SLSA. (D) Several perforators penetrated from the crural fascia and anastomosed with the SLSA, consisting a fine anastomotic network.

one patient, the vessels of the flap were anastomosed end-to-end to a branch of ulnar vessels, and the LSCN was coapted to the medial cutaneous nerve. Follow-up ranged from 6 to 18 months with 11 months in average. No additional debulking was necessary, and the overall contour after resurfacing was satisfactory. No epithelial breakdown occurred in patients with sole injuries. The donor sites healed without complications and the skin grafts healed uneventfully. The main donor site morbidity was the scar after grafting over the posterolateral leg, which can be concealed by pants. No painful neuroma of LSCN recorded.

Objective sensory recovery tests were conducted in four patients. The results of SWM test were 3.61–4.74, and the results of two-point discrimination were 20–25 mm. The other two patients were followed up through the internet. Of all the six patients, hot/cold distinction was recovered in four, and pain perception was recorded in six.

Case report

A 19-year-old man suffered from a severe motor vehicle accident resulting in multiple injuries. He was treated acutely at a local hospital. Nine months after primary treatment, his right wrist and fingers were fixed in flexion deformity without any joint mobilities (Figure 3(A)). Multiple tendon defects and segmental ulnar nerve defects were confirmed by ultrasound. In order to obtain some functions of the wrist and fingers, he came to our department.

The reconstructive procedures were performed in multiple stages. In the first stage, it was planned to incise the scar of the wrist and set the wrist in the functional position with an external fixator. After removing the scar, the soft tissue defects in the palm and forearm were measured at 24×7 cm (Figure 3(B)), and a segmental defect of the ulnar nerve was found from the middle forearm to the middle palm. A free lateral sural neurocutaneous flap was designed in his left leg to cover the soft tissue defects (Figure 3(C,D)), and the medial sural nerve was also elevated within the flap to repair the ulnar nerve (Figure 3(E)). The flap was 25×8 cm in size. The superficial lateral sural vessels were anastomosed to the branches of ulnar vessels, and the LSCN was anastomosed to the medial cutaneous nerve of the forearm. The proximal medial sural nerve and an additional segment of sural nerve obtained distal to the flap were coapted proximally to the ulnar nerve, and distally to the 4th common palmar digital nerve and proper palmar digital nerve. The donor site was closed primarily. Postoperatively, the flap survived uneventfully without complications. In second stage, tendon transfers were performed to restore flexor function of wrist and fingers. At 15-months of follow up, the flap retained a good contour (Figure 3(F)), and the

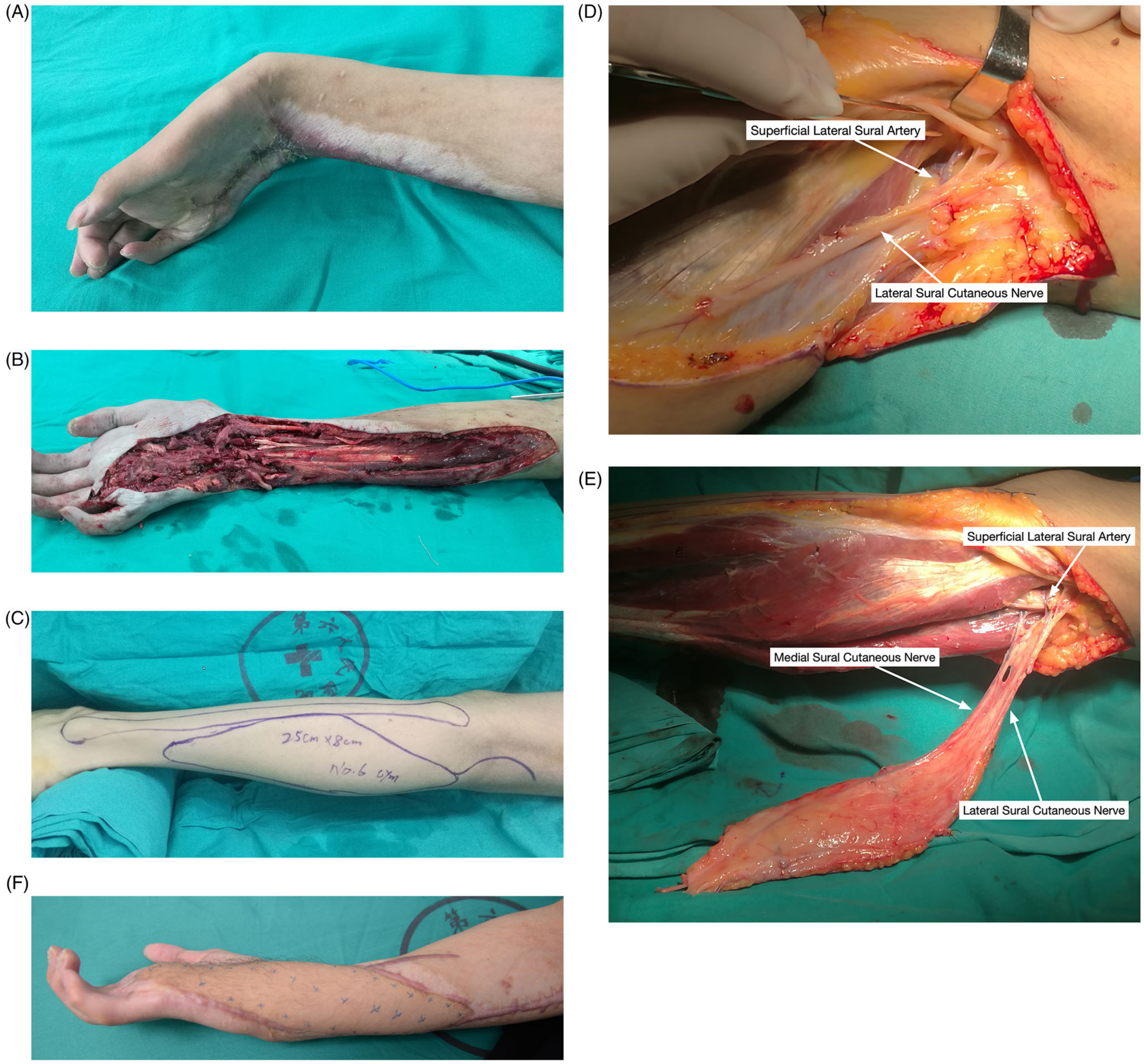

Figure 3. (A) Flexion deformity of wrist and fingers suffered from a severe trauma. (B) After scar was incised, a large soft tissue defects over forearm and palm were encountered. (C) A lateral sural neurocutaneous flap was designed in his left lower leg. (D) SLSA was exposed and traced back to its origin. (E) Flap was elevated and ready to transfer. (F) Flap appearance at 15-months follow-up.

donor site healed uneventfully. The sensory recovery of the flap was determined with SWM test 3.61 and 2PD 20 mm.

Discussion

It is known that the superficial cutaneous nerves of the extremity are paralleled by a vascular axis that not only supplies the nerves but also gives off branches supporting the skin [14–17]. In the leg, for example, the well-developed vascular axes followed the medial sural cutaneous, the saphenous, and the superficial peroneal nerves were described by Masquelet et al. [14], who also introduced the neuroskin island flaps based on their anatomical findings. The neurocutaneous flaps then gradually become popular in reconstruction of soft tissue defects in extremities [18]. In this study, further evidence was provided of the accompanying neurovascular axis related to the lateral sural cutaneous nerve by the anatomical study and clinical cases; the LSCN was accompanied by the SLSA and several perforators along its path, and a flap can be raised based on the neurovascular axis.

The anatomy of the SLSA has been described in a few studies. Li et al. [7] dissected 20 legs and found that the SLSA existed in all specimens and that in 85% of cases, it originated from the popliteal artery. The artery descended along the LSCN and the posterolateral aspect of the leg with two venae comitantes. Wolff et al. [9] reported that the SLSA was present in 85.5% of their 42 specimens. The artery originated from the popliteal artery in 69% and from the lateral sural artery in 31%. An SLSA with a diameter > 1 mm was only found in 69.4% of the legs. Of the specimens, 59.5% of the SLSAs had two vena comitantes, while 40.5% had only one. In this study, the SLSA was found present in all the cadaveric dissections and clinical cases. More importantly, it was observed there was an intimate relationship or 'dance' between the SLSA and LSCN; the SLSA adhered to the LSCN and ramified along with the LSCN, both when the LSCN gave off PCNs and when it gave off terminals. This finding complements Masquelet's anatomical study, further describing the vascular basis of neurocutaneous flaps [14].

Distally, the neurovascular axis of the LSCN was reinforced by several perforators issuing either from the lateral sural artery or the peroneal artery [19]. These artery branches not only connected longitudinally to the adjacent perforators but also anastomosed to the SLSA, forming a longitudinal vascular network that ran parallel to the LSCN. Similar anatomical findings were also reported for other cutaneous nerves [14,15]. For example, the artery accompanying the sural nerve receives blood from peroneal perforators [4,18–21], and the perineural artery of the saphenous nerve connects to posterior tibial perforators [22]. These perforators connect with the perineural artery sequentially by true anastomoses, forming a low-resistance longitudinal arterial system or 'freeway' in the subcutaneous plane, enabling to survive a long neurocutaneous flap that spans more than two anatomical angiosomes [22–24]. Thus a flap as large as 25×8 cm can survive without complications in this series, even though the caliber of the SLSA was approximately 1 mm. Although the conclusion cannot be drawn easily of the maximal size of the lateral sural neurocutaneous flap, the flap that is designed along the course of the LSCN and over the lateral half of gastrocnemius muscle would generally be known to be safe.

The free lateral sural neurocutaneous flap used in this study has several advantages. First of all, as the flap is raised based on the SLSA that runs along the superficial cutaneous nerve, there is no need to dissect perforator vessels as a pedicle through the gastrocnemius muscle – a time-consuming procedure which is essential to elevate a sural perforator flap. Second, it contains only the lateral sural cutaneous nerve, sparing the medial sural cutaneous nerve; this may minimize donor site morbidity to a certain degree.

The potential for sensory reconstruction is regarded as another virtue of the flap. Innervated flaps have been reported to enable better sensory recovery in comparison to non-innervated flaps [25]. It is especially useful at recipient sites where sensation is a critical determinant of successful use, such as hand [26], weight-bearing area of foot [27], female breast [28], and penis [29]. The commonly used sensory flaps include lateral arm flaps, radial forearm flaps, dorsalis pedis flaps, anterolateral thing flaps, and transverse rectus abdominus muscle flaps [25]. By coapting the LSCN to the recipient sensory nerve, the lateral sural neurocutaneous flap can also serve as an innervated flap and a better sensory recovery of the recipient site can be anticipated.

Some potential disadvantages of the flap are worth noting. Experienced microsurgery techniques are required for this free flap transfer because the diameter of the SLSA is approximately 1 mm. The donor site morbidity, though minimal, should be carefully considered. Meticulous hemostasis before closure of the donor site is always kept in mind. When a split-thickness skin graft is required, the wound can be partially closed with simple sutures to reduce the demand for grafting. In addition, the vacuum assisted closure device is often used for securing skin grafts with improved overall graft survival [30].

Another drawback is the possible anatomical variations of the SLSA and LSCN. Although the SLSA was found in all the specimens and clinical cases included in this study, it has been reported that the artery could be missing or unreliable for anastomosis [9]. To overcome this disadvantage, we recommend checking the vessel by Doppler preoperatively and tracking the artery following the LSCN and the PCN in the elevation. Even if the accompanying artery of the LSCN is too small or absent, the accompanying artery of the medial sural nerve is reliable for backup [8]. Another strategy is to elevate the flap based on the muscle perforator of the lateral sural artery or the septocutaneous perforator of the peroneal artery, although the dissection of these perforators is more time-consuming [9].

Several studies have addressed the anatomical variations in LSCN and PCN [10–12,31]. In Huelke's study [13], the LSCN was absent in 22% of 159 cadaver legs, while in Riedl and Frey's [11] study, 93% of 28 specimens had an LSCN. Ramakrishnan et al. [10] conducted a systematic review of the anatomical variations of the sural nerve complex, and the results showed that the PCN originated directly from the LSCN in 84.5% of 227 limbs, and 15.5% shared a common trunk with the LSCN. Despite these anatomical variations, we focused mainly on the accompanying artery and not on the origins or branches of the nerves. Both the LSCN and the PCN serve as markers that help us locate the accompanying artery during the flap design and elevation.

The main limitation of this study is the small sample size in both anatomical and clinical studies. With the increased sample size, anatomical variations of the SLSA and LSCN may come across as reported in the literature. Another limitation is that the objective data of sensory recovery was not obtained in two of our early patients who were followed up through the internet.

Conclusion

The SLSA accompanies the LSCN and gives rise to branches as the nerve ramifies. It not only supplies the nerve but nourishes the skin over the nerve. Based on the SLSA and LSCN, a free neurosensory flap may be elevated for reconstruction of soft tissue defects where sensory recovery is critical. Future work concerning the anatomical variations of SLSA and long-term follow-up of the neurosensory flap is planned.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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