Sural Nerve Splitting in Reverse Sural Artery Perforator Flap: Anatomical Study in 40 Cadaver Legs

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Background: The reverse sural artery perforator flap has been widely used in reconstruction of the lower extremity. However, along with the high rate of flap necrosis, sural nerve injury is one of the most frequent complications. This cadaveric study investigated a simple sural nerve preservation technique during reverse sural artery perforator flap surgery.

Methods: Cadaver dissection was performed on 40 cadaver lower legs, to investigate the pattern of sural nerve distribution. The points where the lateral and medial sural cutaneous nerves penetrate the deep fascia were measured. The converging point of these nerves into the sural nerve was also recorded. Furthermore, the sural nerve was split until no tethering was observed, to simulate the sural nerve–sparing reverse sural artery perforator flap.

Results: Twenty-nine legs (72.5 percent) showed the lateral and medial sural cutaneous nerves converging to become the sural nerve (combined pattern); seven (17.5 percent) and four legs (10.0 percent) demonstrated the diminished and parallel types, respectively. The distances between the lateral malleolus and the fascia-penetrating point of the lateral and medial sural cutaneous nerves were 29.9 ± 3.3 cm and 18.8 ± 5.6 cm, respectively. In the combined type, the point of convergence was 13.6 ± 4.2 cm from the lateral malleolus. Nerve splitting was successfully performed in all combined cases, without injuring the nerve fascicles.

Conclusions: The medial sural cutaneous nerve enters the deep fascia significantly more distally than does the lateral sural cutaneous nerve. Furthermore, using nerve splitting, the medial sural cutaneous nerve can be kept intact during reverse sural artery perforator flap surgery. (*Plast. Reconstr. Surg.* 140: 1024, 2017.)

The reverse sural artery perforator flap has been widely used for reconstruction of the lower extremities since the early 1980s.[1,2] This flap has a relatively consistent vascular anatomy, and can be elevated as a thin flap for reconstructing lower extremity defects, without the risk of microvascular anastomosis.[3,4]

However, the reverse sural artery perforator flap also has several drawbacks. A high risk of vascular complication and subsequent flap necrosis are serious concerns. Following wound healing, patients develop numbness, pain, or intolerance to cold, resulting from sural nerve injury during flap elevation.[4,5] The sural nerve travels from the muscle layer to the subcutaneous layer, penetrating the deep fascia in the middle third of the lower leg.

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During lower extremity reconstruction, the reverse sural artery perforator flap is elevated subfascially, to include a vascular pedicle. As a result, the sural nerve is severed during flap elevation to achieve sufficient pedicle length,[4,6,7] leading to decreased sensation on the lateral side of the foot, paresthesia, or formation of neuroma.[4,8,9] Previous studies have explored methods to preserve the sural nerve during reverse sural artery perforator flap surgery, but they are technically challenging, with reported concerns about pedicle injury.[7,10]

Our study was designed to investigate a simple and safe method for creating sural nerve–sparing reverse sural artery perforator flaps, based on the anatomy of the lateral and medial sural cutaneous nerves. These nerves, which converge to form the sural nerve, penetrate the deep fascia at different levels.[11,12] We hypothesized that the nerve-splitting technique could safely separate the two nerves while creating sufficient pedicle length to allow rotation of the reverse sural artery perforator flap.[13] We evaluated the local anatomy of the sural nerve, the fascia-penetrating locations of the lateral and medial sural cutaneous nerves, and the possibility of performing sural nerve–sparing reverse sural artery perforator flap surgery using the nerve-splitting technique.

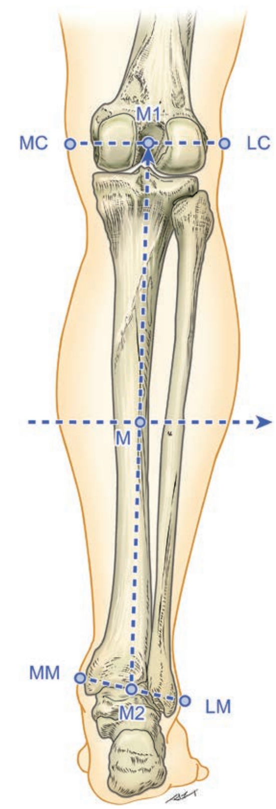

Fig. 1. Landmark coordinates used in this study. *LC*, lateral condyle of femur; *MC*, medial condyle of femur; *M1*, midpoint between the *LC* and *MC*; *LM*, lateral malleolus of the fibula; *MM*, medial malleolus of the tibia; *M2*, midpoint between *LM* and *MM*; *M*, midpoint between *M1* and *M2*.

MATERIALS AND METHODS

Anatomical dissections were performed on the sural nerves of 40 legs from 20 cadavers (six women and 14 men). To begin with, a coordinate system was determined, relative to bony landmarks (Fig. 1). A vertical line was drawn from the midpoint between the medial and lateral condyles of the femur, to the midpoint between the medial and lateral malleoli. This was defined as the length of the lower leg. A perpendicular was drawn to this line at its midpoint, to constitute the coordinate system. The lateral and upper sides represented positive values, whereas medial and lower sides represented negative values.

Sural Nerve Anatomy

With each cadaver in the prone position, the coordinates were marked, as described. An incision was made above the popliteal fossa and lateral to the fibula head, extending to a level below the deep fascia. The common peroneal nerve and the origin of the lateral sural cutaneous nerve, from peroneal, was identified just medial to the fibula head. Medially, the medial sural cutaneous nerve was identified at its origin from the tibial nerve. The sural nerve pattern was classified based on the convergence pattern of lateral and medial sural cutaneous nerves. The points where lateral and medial sural cutaneous nerves penetrated the deep fascia were marked on the skin surface and designated as L- and M-points, respectively. The subfascial dissection was extended toward the lateral malleolus; the point where the lateral and medial sural cutaneous nerves joined to form the sural nerve was marked on the skin and designated as the S-point. The L-, M-, and S-points were marked on the coordinate system, and their respective distances from the lateral malleolus were measured (Fig. 2).

Reverse Sural Artery Perforator Flap Simulation Using Nerve-Splitting Technique

The reverse sural artery perforator flap was marked on the proximal third of the lower leg. A zigzag incision was made from the inferior margin of the flap, to the posterior side of the lateral malleolus, along the path of the vascular pedicle and sural nerve. This allowed elevation of the reverse sural artery perforator flap from its proximal

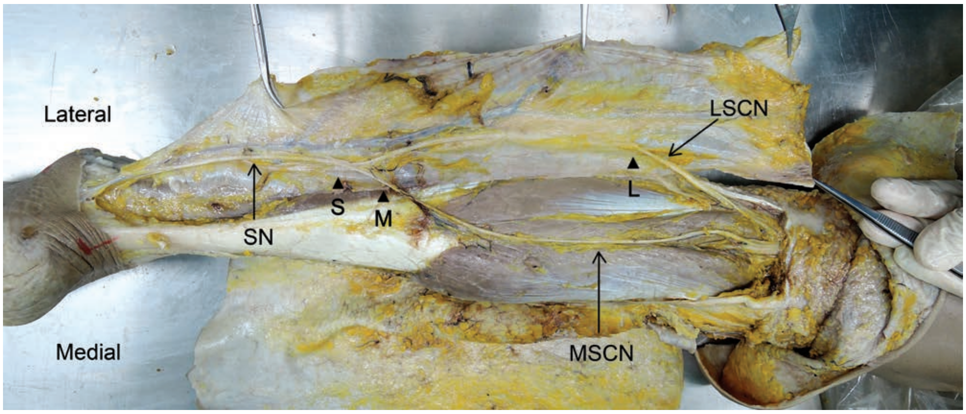

Fig. 2. Reverse sural artery perforator flap–related sural nerve (*SN*) anatomy. The lateral sural cutaneous nerve (*LSCN*) penetrates the deep fascia at the L-point (*L*). The medial sural cutaneous nerve (*MSCN*) penetrates the deep fascia at the M-point (*M*). The sural nerve arises from the convergence of medial and lateral sural cutaneous nerves as the S-point (*S*).

margin. The lateral sural cutaneous nerve, penetrating the deep fascia proximal to the reverse sural artery perforator flap, was ligated, and dissection continued distally through a plane below the deep fascia. Through this incision, a subcutaneous dissection was performed to expose the vascular pedicle, a 5-cm-wide adipofascial strip containing the small saphenous vein, superficial sural artery, and vasa nervorum of the sural nerve.

The point where the medial sural cutaneous nerve penetrates the deep fascia was dissected to expose the neurovascular bundle in the subcutaneous layer. The medial sural cutaneous nerve was meticulously detached from the fascicles of the lateral sural cutaneous nerve without disturbing the vascular pedicle under surgical loupes with 2.5× magnification. The epineurium of the sural nerve was removed meticulously, using microscissors and micro-forceps, to avoid damaging the nerve fascicles. The nerve was split until a sufficient pedicle length was obtained for the flap to reach the foot defect. (**See Video, Supplemental Digital Content 1,** which demonstrates the technique of sural nerve splitting between the lateral and medial sural cutaneous nerves. Rotation arc of the flap is increased after nerve splitting, ***http://links.lww.com/PRS/C417***.)

The recovered split-nerve tissues were sent for histologic analyses, to evaluate the status of nerve fascicles and perineurium. Masson trichrome staining of the recovered tissue was performed, followed by observation using light microscopy (×40).

Video. Supplemental Digital Content 1 demonstrates the technique of sural nerve splitting between the lateral and medial sural cutaneous nerves. Rotation arc of the flap is increased after nerve splitting, ***http://links.lww.com/PRS/C417***.

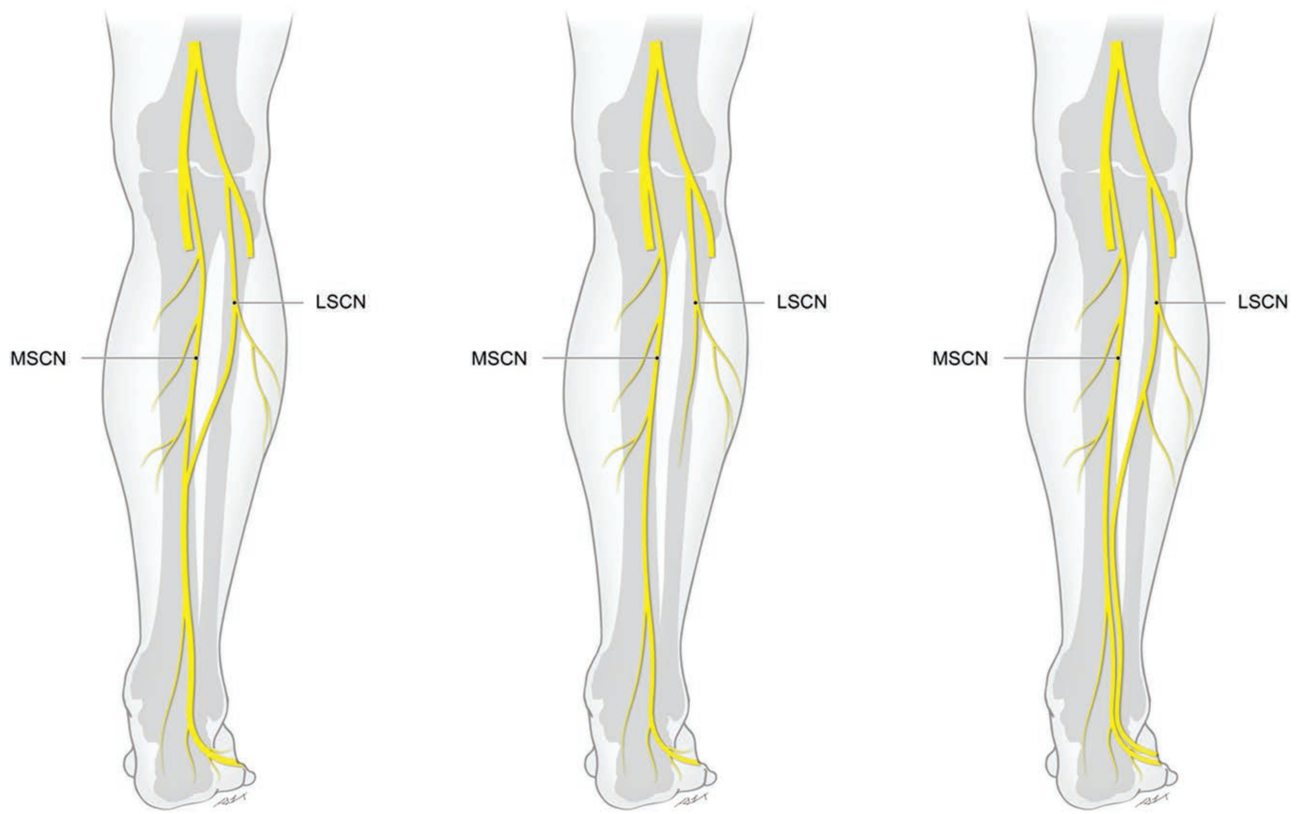

Fig. 3. Sural nerve classification: (*left*) combined type; (*center*) diminished type; and (*right*) parallel type. *MSCN*, medial sural cutaneous nerve; *LSCN*, lateral sural cutaneous nerve.

Statistical Analysis

Statistical differences between the lateral and medial sural cutaneous nerves, with respect to their coordinates and distances from the lateral malleolus, were determined by independent *t* tests. IBM SPSS Version 23 software (IBM Corp., Armonk, N.Y.) was used for statistical analyses.

RESULTS

Three sural nerve distribution patterns were identified. Of the 40 cases, 29 (72.5 percent) had a combined pattern, in which the lateral and medial sural cutaneous nerves joined to form the sural nerve. Seven cases (17.5 percent) exhibited the diminished pattern, where the lateral sural cutaneous nerves was diminished and the medial sural cutaneous nerve continued as the sural nerve. Four cases (10.0 percent) had the parallel pattern, in which the lateral and medial sural cutaneous nerves traveled parallel to one another, without joining (Fig. 3). Fourteen cadavers (70 percent) had identical patterns bilaterally, whereas six (30 percent) had different patterns in each leg. Combined and diminished types were observed in four cadavers, and the combined and parallel type and the parallel and diminished type were observed in one each (Table 1).

Table 1. Classification of the Sural Nerve

SN Pattern	No. (%)
Total	40 (100)
Combined type	29 (72.5)
Diminished	7 (17.5)
Parallel	4 (10.0)
Total cadavers	20
Same type on same cadaver	14 (70)
Different type on same cadaver	6 (30)
Combined and diminished	4 (20)
Combined and parallel	1 (5)
Parallel and diminished	1 (5)

SN, sural nerve.

The medial sural cutaneous nerve penetrated the deep fascia more distally than the lateral sural cutaneous nerve (Fig. 4). The mean length of the lower leg was 35.8 ± 2.5 cm, and the mean coordinates of the L- and M-points were 4.0 ± 1.8 cm and 10.1 ± 3.1 cm, and 1.2 ± 1.1 cm and −1.7 ± 5.4 cm, respectively. The mean distance from the lateral malleolus to the L-point (L-distance) was 29.9 ± 3.3 cm, and that to M-point (M-distance) was 18.8 ± 5.6 cm (Fig. 5). Statistical analysis revealed that the L-point was more lateral ($p < 0.001$) and

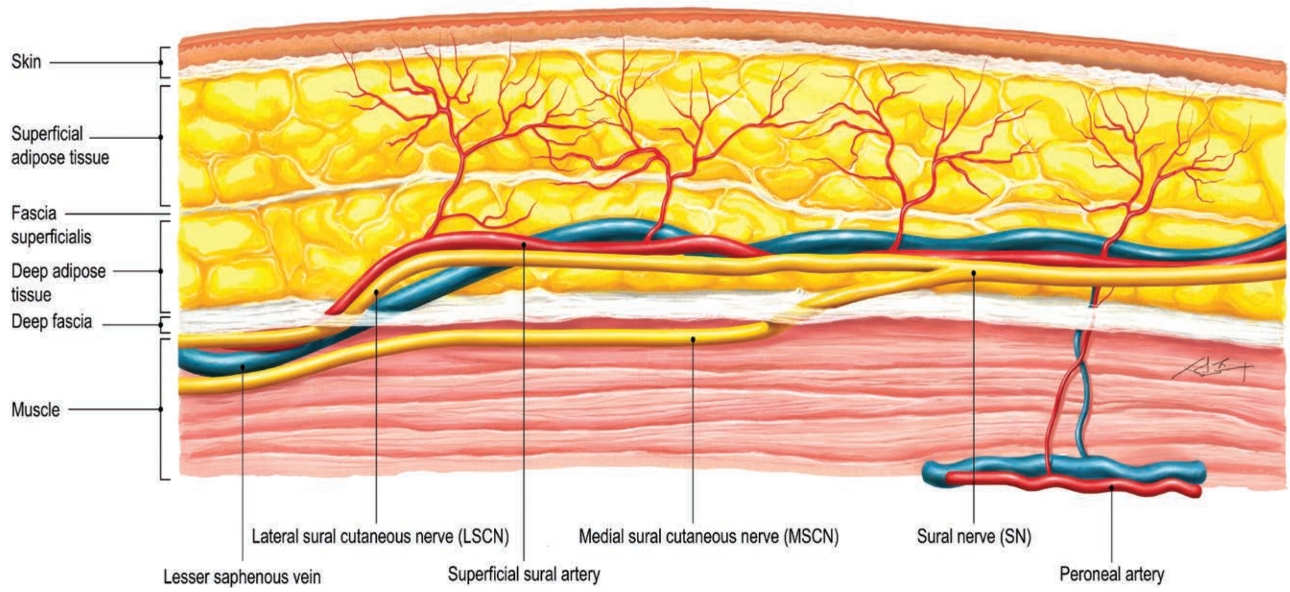

Fig. 4. Reverse sural artery perforator flap–related cross-section of the sural nerve. The medial sural cutaneous nerve penetrates the deep fascia at a more distal level than does the lateral sural cutaneous nerve, and eventually joins the lateral sural cutaneous nerve to form the sural nerve. *LSCN*, lateral sural cutaneous nerve; *MSCN*, medial sural cutaneous nerve; *SN*, sural nerve.

proximal ($p < 0.001$) than the M-point. The L-distance was also significantly longer than the M-distance ($p < 0.001$). The mean S-point coordinates (1.9 ± 1.0 cm and −7.4 ± 3.7 cm) were determined for 29 cadavers exhibiting the combined pattern, who were candidates for nerve splitting. The mean distance from the lateral malleolus to the S-point (S-distance) was 13.6 ± 4.2 cm (Table 2).

Considering the variability in length of the lower leg among cadavers, we denoted the measured values as relative ratios to the length. Corrected value of the L-distance was 0.8 ± 0.1 and that of the M-distance was 0.5 ± 0.1. They were significantly different from each other ($p < 0.001$). The corrected S-distance was 0.4 ± 0.1.

In cadavers with combined type sural nerves, nerve splitting was successfully performed from the S-point to a point sufficiently distal, to release any tethering between the lateral and medial sural cutaneous nerves (Fig. 6). The rotation length of the flap was increased because of the technique. After sufficient nerve splitting, the reverse sural artery perforator flap could cover any defect in the distal third of the lower leg. Histology of the split nerve revealed no injury to the nerve fascicles. The perineurium was preserved (Fig. 7).

DISCUSSION

The reverse sural artery perforator flap is a pedicled fasciocutaneous flap, having a reverse flow. Its pedicle consists mainly of the superficial sural artery and lesser saphenous vein. The superficial sural artery receives blood mainly from the peroneal artery through the peroneal perforator, but also receives retrograde blood supply through the venocutaneous perforator from the lesser saphenous vein and the neurocutaneous perforator from the sural nerve.[14,15] Venous blood from the flap is primarily drained to the lesser saphenous vein by reverse flow. The valves prevent reverse flow; however, the venae comitantes and their communicating branches allow backflow.[16] Another factor contributing to the backflow is decreased valve function. Torii et al. suggested that valve function might be reduced after pedicle skeletonization.[17]

Venous congestion of the flap and flap necrosis are considered as the most serious complications of the reverse sural artery perforator flap, especially in cases with extended flap dimension or in patients with comorbidities such as diabetes or peripheral vascular disease.[18,19] Modifications of the reverse sural artery perforator flap have been suggested to overcome the high rate of flap compromise from poor perfusion. Staged reconstruction with a delayed reverse sural artery perforator flap, or anastomosis of the vein at the proximal end of the flap with a subcutaneous vein at the recipient site, had better results for flap survival.[20,21] The peroneus brevis flap could be another good option for reconstruction of the foot or ankle, but the

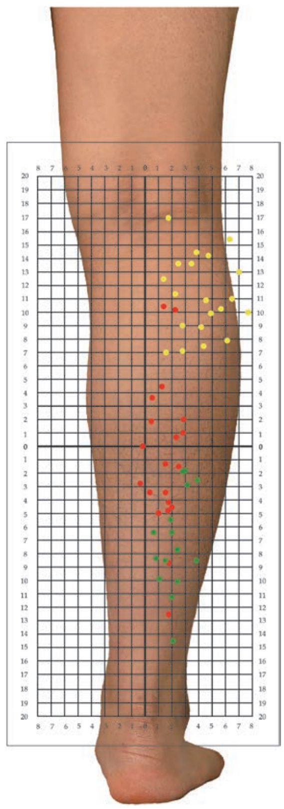

Fig. 5. Distribution of the L- (*yellow dots*), M- (*red dots*), and S-points (*green dots*) on the coordinate system. The L-point is the point where the lateral sural cutaneous nerve penetrates the deep fascia, as marked on the skin surface. The M-point is the point where the medial sural cutaneous nerve penetrates the deep fascia, as marked on the skin surface. The S-point is the point where the lateral and medial sural cutaneous nerves join to form sural nerve, as marked on the skin surface.

Table 2. Coordinate System and Distances from the Lateral Malleolus of the Medial Sural Cutaneous, Lateral Sural Cutaneous, and Sural Nerves in Cases Demonstrating Combining Type Sural Nerves

	No.	*x* Coordinate (cm)	*y* Coordinate (cm)	Distance from LM (cm)
L-point	40	4.0 ± 1.8	10.1 ± 3.0	29.9 ± 3.3
M-point	40	1.2 ± 1.1	−1.7 ± 5.4	18.8 ± 5.6
S-point	29	1.9 ± 1.0	−7.4 ± 3.7	13.6 ± 4.2

L-point, point where lateral sural cutaneous nerve penetrates the deep fascia, marked on the skin surface; M-point, point where the medial sural cutaneous nerve penetrates the deep fascia, marked on the skin surface; S-point, converging point where median and lateral sural cutaneous nerves combine to become SN, marked on the skin surface; LM, lateral malleolus.

reverse sural artery perforator flap is preferred for a large defect, wherein a larger arc of rotation is required.[22]

The rotation arc of the flap is determined by pedicle length. For maximal pedicle length, dissection can be continued to the point where the peroneal perforator anastomoses with the superficial sural artery, 4 to 7 cm proximal to the lateral malleolus.[23,24] During this process, the sural nerve is included in the pedicle and is sacrificed from the donor site.

This study was designed to attempt preservation of the sural nerve during flap elevation. The lateral and medial sural cutaneous nerves, the two components of the sural nerve, originate from a common peroneal nerve and tibial nerve, respectively. After penetrating the deep fascia, the lateral sural cutaneous nerve travels parallel to the lesser saphenous vein above the deep fascia, and meets the medial sural cutaneous nerve, which penetrates the deep fascia more distally. Ortigüela et al. suggested that the point where the lateral and medial sural cutaneous nerves join to form the sural nerve is 11 to 20 cm from the lateral malleolus.[25] In addition, Mojallal et al.[26] reported that the sural nerve crossed the deep fascia 17.1 cm proximal to the heel. In our study, the L- and M-distances were, 29.9 cm and 18.8 cm from the lateral malleolus, respectively. The distances had a statistically significant difference ($p < 0.05$). The S-point, located 13.6 cm proximal to the lateral malleolus, was not far from the vascular pivot point.[23,24] We hypothesized that the medial sural cutaneous nerve could be preserved during reverse sural artery perforator flap elevation, if nerve splitting is immaculately performed from the S-point to the vascular pivot point, without damaging the nerve fascicles.

Three types of sural nerves were identified in this study: combined (72.5 percent of cases), diminished (17.5 percent), and parallel (10.0 percent) types. The combined type, which accounts for almost three-quarters of sural nerves, is suitable for the nerve-splitting technique. Mahakkanukrauh and Chomsung analyzed the anatomical variations of the sural nerve in 76 cadavers,[11] and reported that 67.1 percent of sural nerves were formed by the union of the lateral and medial sural cutaneous nerves; others were direct continuations of the medial sural cutaneous nerve.

Some earlier reports described sural nerve preservation during reverse sural artery perforator flap surgery. Nakajima et al. noted that even if the artery accompanying the sural nerve is injured, the blood supply is maintained by the superficial sural artery and venocutaneous perforators.[15] In addition, Mojallal et al. suggested that the blood supply to the vasa nervorum was

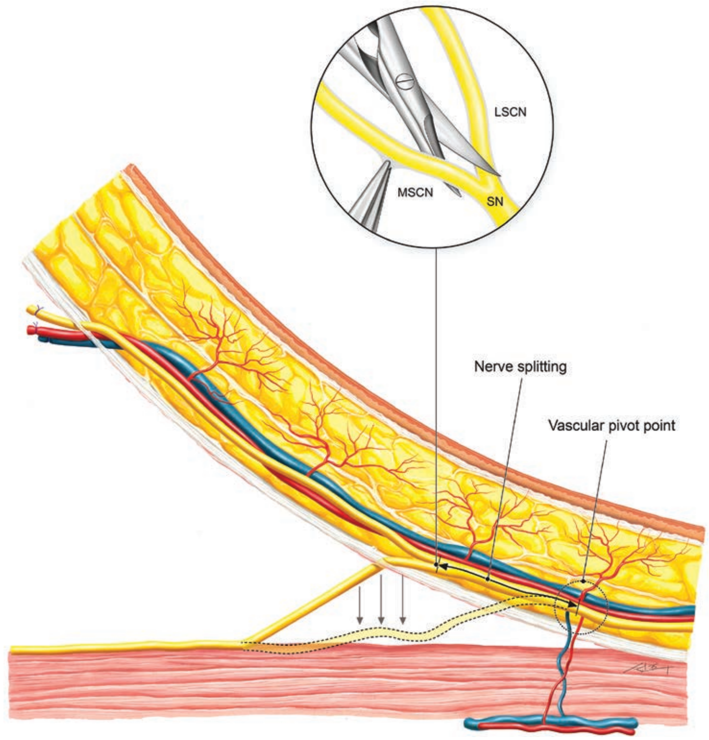

Fig. 6. Nerve-splitting technique. The epineurium between the lateral and medial sural cutaneous nerves is split using microscissors. The medial sural cutaneous nerve is preserved at the donor site, after flap rotation. *MSCN*, medial sural cutaneous nerve; *LSCN*, lateral sural cutaneous nerve; *SN*, sural nerve.

minimal, compared with that of the superficial sural artery and lesser saphenous vein, in a cadaveric model of the venoadipofascial sural flap.[26]

Previous clinical studies suggested that, despite sural nerve exclusion from the flap, the entire flap remained well perfused.[27,28] However, these studies involved only a small number of case reports. Many articles have indicated that dissection of the sural nerve from the entire flap and pedicle is challenging, leading to prolonged surgery, and carries a risk of pedicle injury and congestion, because of the close proximity of the

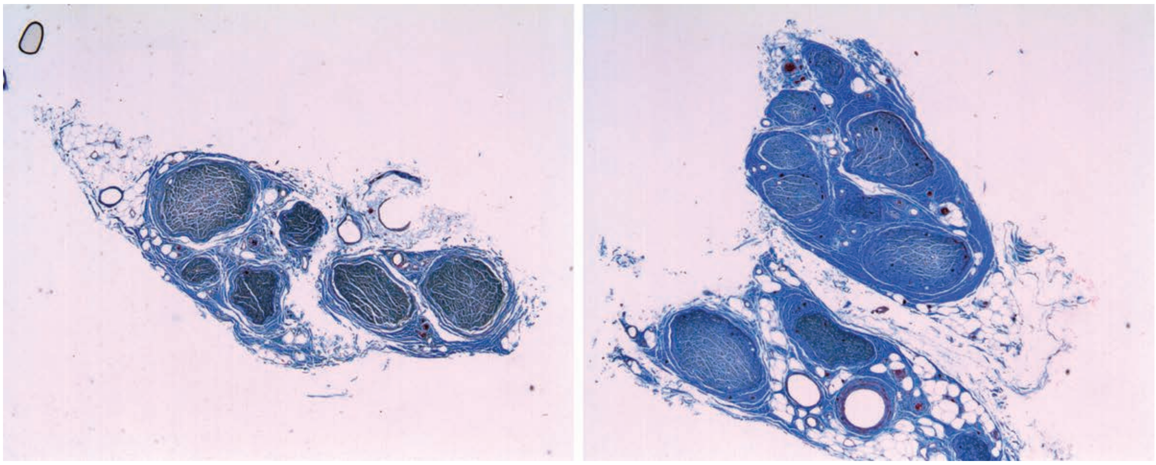

Fig. 7. Histologic specimens showing intact nerve fascicles, after nerve splitting, 1 cm (*left*) and 4 cm (*right*) distal to the point where the lateral and medial sural cutaneous nerves converge to form the sural nerve (Masson trichrome; original magnification, × 100).

nerve to vascular structures.[7,29] Jeng et al. suggested a flap model that preserves the medial sural cutaneous nerve during flap elevation, and includes the lateral sural cutaneous nerve, allowing it to be coapted to the distal common sural nerve or medial plantar nerve.[30–32] This minimizes donor-site morbidity and helps in sensory recovery of the flap. However, the detailed description of the methods to preserve the medial sural cutaneous nerve and to secure a sufficient rotation arc was not recorded.

In a previous study by Kwon et al., a nerve-splitting technique for pedicled latissimus dorsi musculocutaneous flaps was suggested.[13] The authors performed interfascicular nerve splitting of the thoracodorsal nerve using microsurgery instruments to preserve the horizontal branch at the donor site. In our study, nerve splitting was performed in a manner similar to the method described by Kwon et al., and the intact perineuria were confirmed histologically.

The procedure took an additional 7 to 15 minutes, depending on the length of splitting. Previous studies of complete sural nerve preservation[27,28] did not indicate additional operative time for nerve preservation, but it is not difficult to assume that detaching the sural nerve throughout the flap and pedicle would have required considerable time. Complete sural nerve preservation, although it can minimize donor-site morbidity, could increase the anesthesia risks from longer operative time and the risk of vascular compromise of the flap, compared with our partial nerve-splitting procedure. The range of nerve splitting was limited from the point of convergence of the lateral and medial sural cutaneous nerves, to the pivot point distally; therefore, the risk of vascular compromise of the flap could be mitigated. Furthermore, the nerve-splitting procedure preserves the medial sural cutaneous nerve and is expected to reduce the risks of sensory morbidity, pain, and neuroma formation.

The limitation of our study is that it was performed exclusively on Asian cadavers, and did not investigate racial differences. The data indicate that the anatomy is conducive for performing this relatively simple method for preserving the sural nerve during reverse sural artery perforator flap surgery. The results of this study, however, do not indicate the feasibility of the procedure in clinical situations. Issues regarding donor-site morbidity and surgical safety, including vascularity of the flap after nerve splitting, should be investigated in future clinical studies.

CONCLUSIONS

The reverse sural artery perforator flap is a useful option for reconstruction of soft-tissue defects in the distal third of the lower leg. In this study, we simulated nerve splitting as it applies to the reverse sural artery perforator flap, and preserved the medial sural cutaneous nerve at the donor site. To the best of our knowledge, this is the first study that has investigated the feasibility of the nerve-splitting technique to preserve donor-site sensation following reverse sural artery perforator flap surgery. The data from this cadaveric study might be clinically useful to plastic surgeons.

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