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ORIGINAL ARTICLE - PERIPHERAL NERVES

Transferring of femoral nerve motor branches for high-level sciatic nerve injury: a cadaver feasibility study

Depeng Meng [1] · Huihao Chen [1] · Yaofa Lin [1] · Haodong Lin [1] · Chunlin Hou [1]

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Abstract

Background Sciatic nerve injuries cause significant disability. We propose here a novel reconstructive procedure of transferring the motor branches of the femoral nerve as donor nerves to reconstruct both the peroneal and tibial nerve function as a novel approach to treat high sciatic nerve injury.

Methods The autopsies of donor nerves (vastus lateralis nerve branch (VLN), vastus medialis nerve branch (VMN), saphenous nerve (SAN)) and respective recipient nerves (deep peroneal nerve branch (DPN), medial gastrocnemius nerve branch (MGN), sural nerve (SN)) were conducted in six fresh-frozen lower limbs. The distance between the origin or bifurcation points of the nerves to the head of fibula and the diameter of the end at the coaptation site were measured. The feasibility of tensionless direct suturing or grafting between the donor nerves and the recipient was evaluated. Finally, the nerve end at the coaptation site was harvested for observation with toluidine blue staining and nerve fiber count.

Results The mean diameter of the VMN, VLN, MGN, DPN, SAN, and SN nerves were 1.5 ± 0.1, 1.4 ± 0.1, 1.3 ± 0.1, 2.3 ± 0.1, 2.1 ± 0.3, and 1.3 ± 0.2 mm, respectively. Histological observation showed that the abovementioned six nerve bundles had a respective nerve fiber number of 392 ± 27, 205 ± 520, 219 ± 67, 394 ± 50, 308 ± 77, and 335 ± 49. A total of 5/6 specimens needed grafting for a length ranging from 5 to 15 cm to bridge the VMN–MGN, 6/6 needed a graft length of 10–20 cm for VLN–DPN bridging, and 2/6 needed a graft length of 0–4 cm for SAN–SN bridging.

Conclusion The study demonstrated the feasibility of the transferring femoral nerve branches to sciatic nerve branches to restore the function for sciatic injury.

Keywords Nerve transfer · Sciatic nerve injury · Femoral nerve · Anatomic feasibility

Abbreviations

VMN	vastus medialis nerve branch
VLN	vastus lateralis nerve branch
MGN	medial gastrocnemius nerve branch
LGN	lateral gastrocnemius nerve branch
DPN	deep peroneal nerve branch
SPN	superficial peroneal nerve branch
SAN	saphenous nerve
SN	sural nerve
MSN	medial sural nerve
LSN	lateral sural nerve
TN	tibial nerve
CPN	common peroneal nerve
MRC	medical research council

Depeng Meng and Huihao Chen contributed equally to the manuscriptand should be considered cofirst authors.

This article is part of the Topical Collection on *Peripheral Nerves*

✉ Haodong Lin
linhaodong1978@smmu.edu.cn

[1] Department of Orthopedics, Changzheng Hospital, Second Military Medical University, Shanghai 200003, People's Republic of China

Introduction

Sciatic nerve injuries cause significant disability because of major motor division of tibial and peroneal nerve function impairment [3, 10]. Studies concerning the nerve grafting or transferring for sciatic nerve division reconstruction methods have been reported. The reported techniques included transferring tibial motor branches to the deep peroneal nerve [6], femoral motor branches to tibial motor branches [15], saphenous nerve to the sural nerve or peroneal to tibial for sensation reconstruction [11, 15], as well as transferring the obturator nerve to the gastrocnemius nerve by autogenous grafting [23].

These reported methods were limited in that both of them were only part reconstructions of single division of the sciatic nerve and the donor nerve was still insufficient. Therefore, new suitable donor nerves required to be identified. Moore et al. [15] reported transferring the femoral nerve branches to the gastrocnemius nerve branches in two cases. After the surgery, the quadricep function was not significantly affected. Inspired by this, we propose herein a novel reconstructive approach by transferring the femoral nerve motor branches for high-level sciatic nerve injury and explore the feasibility of this approach in a cadaver study.

Materials and methods

Three fresh adult cadaver specimens (two male and one female) were provided by the Department of Anatomy, Second Military Medical University, China. Vernier calipers (0.1 mm; Guilin Guang Lu Measuring Instrument Co., Ltd., China) were used in this study. The average age of the cadaver was 79.1 years (range, 77–83 years), and the average height of the specimens was 167.3 cm (range, 156–176 cm) (Table 1). A total of six lower extremities of these cadavers were dissected and measured as follows.

Dissection procedure and anatomical measurements

The cadavers were laid prone on the table. A posterior-middle long incision was made from the buttock to the calf for broad visualization of the sciatic nerve branches and the tibial, peroneal, and sural nerves, including their major subbranches: the lateral and medial gastrocnemius branch (medial gastrocnemius nerve branch (MGN)), lateral and medial sural nerve branches (sural nerve (SN)), and superficial and deep peroneal nerve branch (deep peroneal nerve branch (DPN)) (Fig. 1). Proximal epifascicular and epineurium neurolysis were performed if necessary to determine the cleavage plane between these fascicular groups. The proximal bifurcations were determined and left free as proximal as possible to provide adequate length for nerve transfer for tension-free anastomosis or to reduce the length of the grafting gap. The length from the bifurcation to fibular head was measured, and the nerve was transected at their bifurcation. The transverse and longitudinal diameters of the end were measured with a vernier caliper. After the MGN, DPN, and SN were transected proximally, they were tunneled through the medial and lateral soft tissue for latter coaptation to femoral nerve branches anteriorly.

Table 1 Transfer method and length of grafting in two sides of three cadaveric dissections

Cadaver no. and side	Height	Sex	Donor–recipient	Transfer technique	Length of grafting	Length of SN
1, left	176	Male	VMN-MGN	Graft	15 cm	44 cm
			VLN-DPN	Graft	20 cm	
			SAN-SN	Graft	4 cm	
1, right	176	Male	VMN-MGN	Graft	13 cm	46 cm
			VLN-DPN	Graft	17 cm	
			SAN-SN	Direct coaptation	0	
2, left	156	Female	VMN-MGN	Graft	10 cm	36 cm
			VLN-DPN	Graft	15 cm	
			SAN-SN	Graft	4 cm	
2, right	156	Female	VMN-MGN	Graft	7 cm	38 cm
			VLN-DPN	Graft	12 cm	
			SAN-SN	Direct coaptation	0	
3, left	170	Male	VMN-MGN	Direct coaptation	0	40 cm
			VLN-DPN	Graft	10 cm	
			SAN-SN	direct coaptation	0	
3, right	170	Male	VMN-MGN	Graft	5 cm	41 cm
			VLN-DPN	Graft	11 cm	
			SAN-SN	Direct coaptation	0	

VMN vastus medialis nerve branch, *VLN* vastus lateralis nerve branch, *MGN* medial gastrocnemius nerve branch, *DPN* deep peroneal nerve branch, *SAN* saphenous nerve, *SN* sural nerve

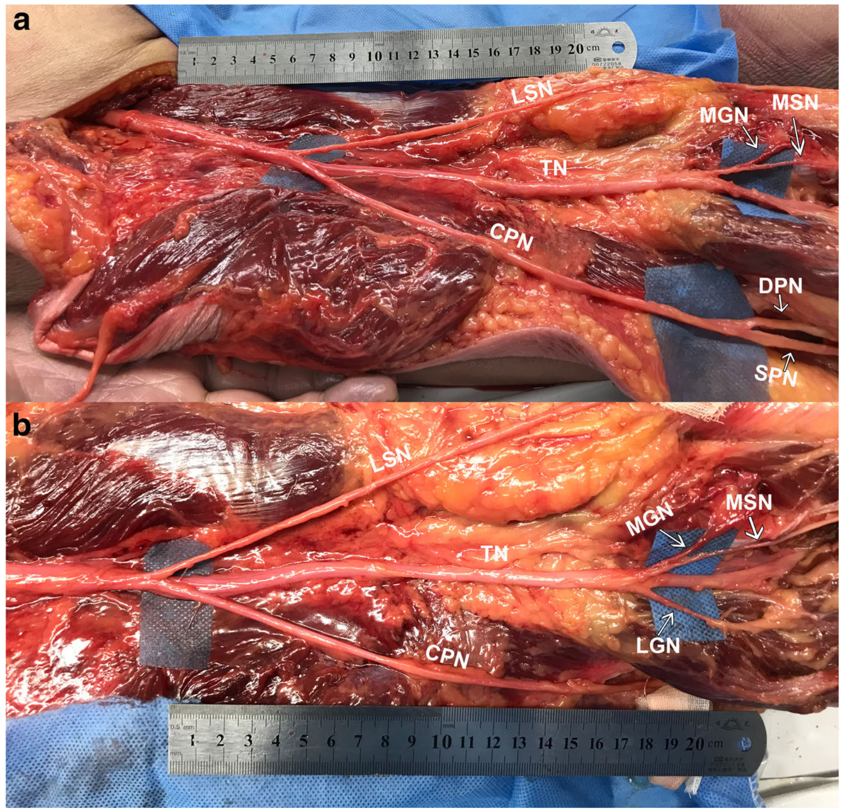

Fig. 1 Posterolateral (**a**) and posterior (**b**) views of dissection in the thigh. The cadaver was laid prone. The MGN, LGN, and MSN that originated from the tibial nerve and the DPN, SPN, and LSN that originated from the peroneal nerve were identified

Next, we turned the cadavers to the supine position, and a 30-cm vertical incision was made in the thigh, extending proximally from the inguinal ligament to the patella for broad visualization. The trunk and major branches of the femoral nerve was free and indentified. The target motor nerves to the vastus medialis (vastus medialis nerve branch (VMN)) and lateralis muscles (vastus lateralis nerve branch (VLN)) were dissected in the thigh (Figs. 2 and 3). The target sensory branch (saphenous nerve (SAN)) was the terminal branch of the femoral nerve, and it was indentified for splitting off from the main trunk medially. The length from the terminal branch (> 1 mm) of femoral nerve branches to the fibular head was measured, and the transverse and longitudinal

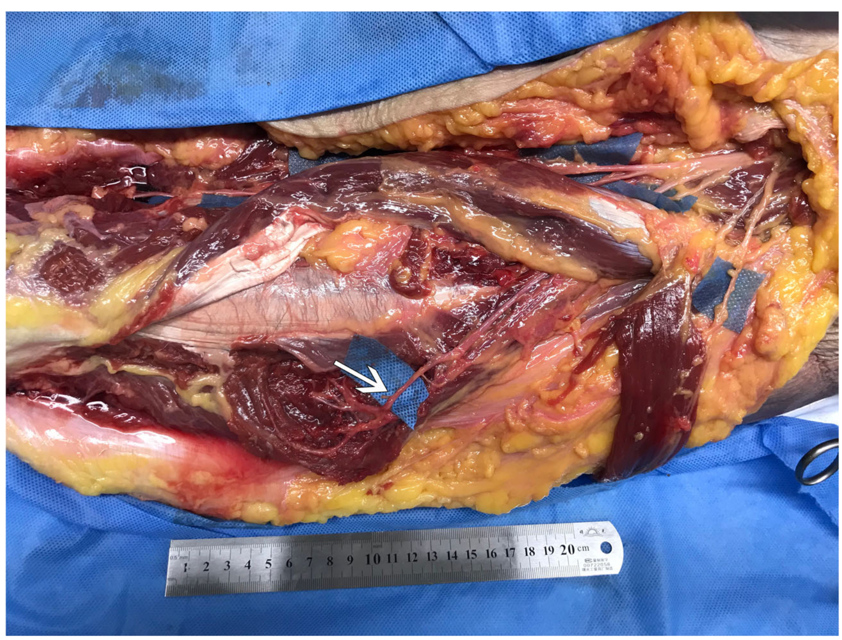

Fig. 2 Lateral view of cadaver dissection in the thigh demonstrating VLN (white arrow) to the vastus lateralis muscle

Fig. 3 Medial view of dissection of the thigh demonstrating VMN and SAN

diameters of the end of the terminal branch were measured with a vernier caliper.

Finally, the cadavers were turned and fixed in the lateral position. In the anterior approach, the VMN, VLN, and SAN were mobilized further posteriorly to determine if a tension-free coaptation can be created with the recipient nerve (VLM to DPN, VMN to MGN, or SAN to SN). If that was not feasible, a section of grafting was used to bridge the donor and recipient nerve with tension-free coaptation (Fig. 4). Generally, the contralateral or ipsilateral SN or SN branches (e.g., lateral sural nerve, LSN) was used as an autogenous graft in the clinic. For convenience, we used the ipsilateral tibial nerve and peroneal nerve trunk as a graft instead of SN or a cable for length measuring in this cadaver study (Fig. 5). The length of the nerve grafting was measured.

Neuromorphometric Analysis

An approximately 1-cm segment of both the donor and recipient nerves at the coaptation site were harvested for neuromorphometric analysis. The tissues were postfixed overnight in 4% paraformaldehyde, subsequently dehydrated in a graded series of ethanol, embedded in paraffin, and cut into transverse sections measuring 1 μm thick. Sections were stained with toluidine blue (toluidine blue (TB)) and photographed under a microscope (DWLB2, Leica). A computer-based image analysis system (Image-Pro Plus 6.0, Media Cybernetics) was used to measure the myelinated fibers. For each section, the number of myelinated fibers was recorded from five random fields under × 400 magnification (Fig. 6).

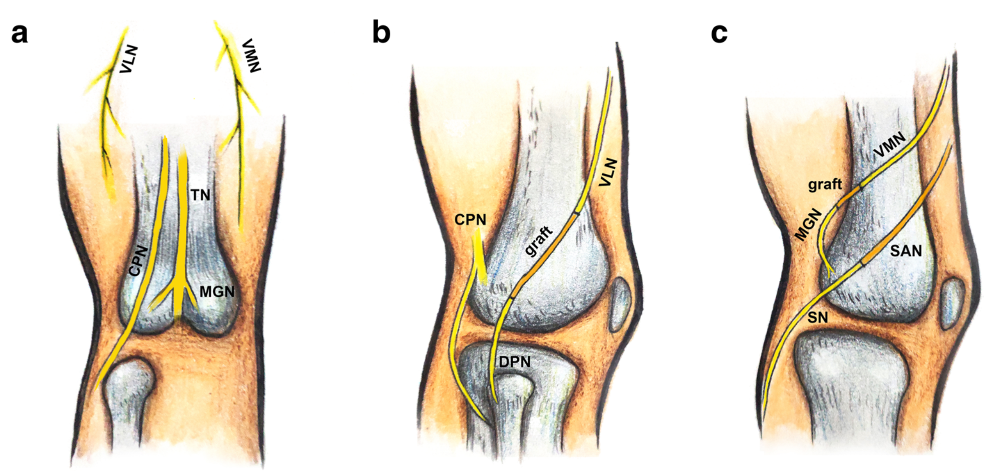

Fig. 4 Schematic drawing demonstrating the proposed procedure. **a** Schematic representation of the coronary projection location of anatomic structures at the level of lower thigh and upper calf. **b** Lateral view of the nerve transfer procedures: VLN to DPN. **c** Medial view of the nerve transfer procedure: VMN to MGN, SAN to SN

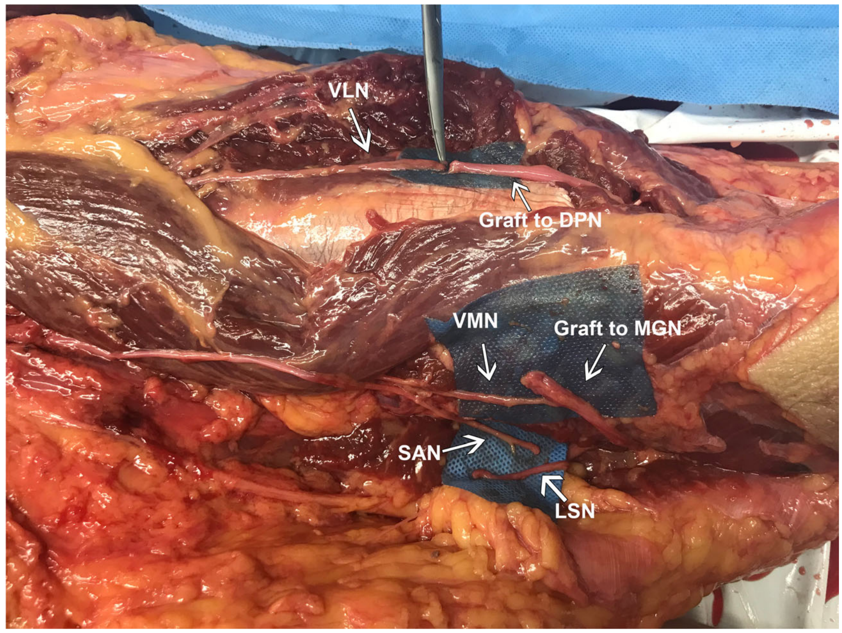

Fig. 5 The anterior view of the proposed procedure in a cadaver. Two interpositional nerve grafts were used to bridge the end of VMN to that of MGN, VLN, to DPN. Then, the length of the nerve grafting was measured. The SAN was tension-free coapted to SN

Results

As measured in cadaveric specimens, the average distance from the mobilized ends of the donor nerves to the head of the fibula was 167 ± 10 mm for VLN, 143 ± 10 mm for VMN, and 28 ± 13 mm for SAN. The average distance from the mobilized bifurcation points of the recipient nerves to the head of the fibula was 62 ± 9 mm for DPN, 49 ± 6 mm for MGN, and 183 ± 54 mm for SN. A total of 5/6 specimens, 6/6 specimens, and 2/6 specimens required interpositional grafting to bridge the VMN–MGN, VLN–DPN, and SAN–SN, respectively. The length of the grafting nerves ranged from 0 to 15 cm for VMN–MGN, 10–20 cm for VLN–DPN, and 0–4 cm for SAN–SN. In all specimens, the total length of the three grafts used was shorter than that of the contralateral SN, which is clinically generally considered as the autogenous graft (Table 1). The nerves had a mean diameter of 1.5 ± 0.1 mm, 1.4 ± 0.1 mm, 1.3 ± 0.1 mm, 2.3 ± 0.1 mm, 2.1 ± 0.3 mm, and 1.3 ± 0.2 mm for VMN, VLN, MGN, DPN, SAN, and SN, respectively. This shows that all the donor nerves had similar diameter as that of the recipient nerves. Histological findings showed that the abovementioned six nerve bundles had a nerve fiber number of 392 ± 27, 205 ± 52, 219 ± 67, 394 ± 50, 308 ± 77, and 335 ± 49, respectively. The number of nerve fibers in the donor nerve were sufficient to innervate that of the recipient bundles (Table 2).

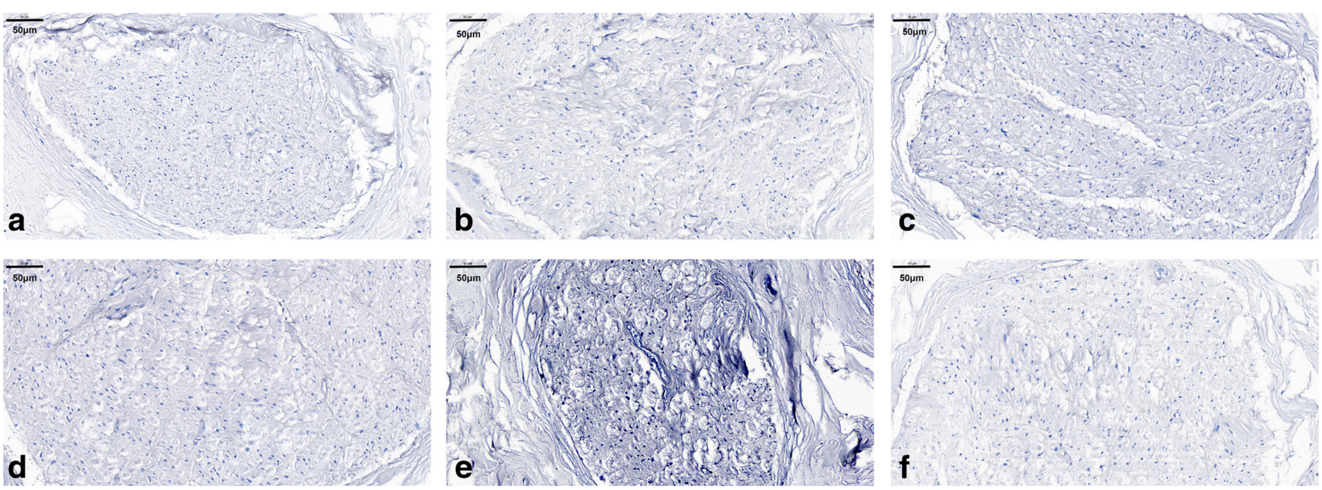

Fig. 6 Images of cross section of the myelinated fibers of the donor and recipient nerves at the coaptation site (TB stain, magnification × 400). **a** VLN. **b** VMN. **c** SAN. **d** DPN. **e** MGN. **f** SN

Table 2 Histological and morphometric data of six cadaver specimens

Nerve	Total fiber counts	Length from origin or bifurcation to fibular head	Diameter of terminal end for coaptation
VMN	392 ± 27	143 mm ± 10 mm	1.5 mm ± 0.1 mm
VLN	205 ± 52	167 mm ± 10 mm	1.4 mm ± 0.1 mm
SAN	308 ± 77	28 mm ± 13 mm	2.1 mm ± 0.3 mm
MGN	219 ± 67	49 mm ± 6 mm	1.3 mm ± 0.1 mm
DPN	394 ± 50	62 mm ± 9 mm	2.3 mm ± 0.1 mm
SN	335 ± 49	183 mm ± 54 mm	1.3 mm ± 0.2 mm

VMN vastus medialis nerve branch, *VLN* vastus lateralis nerve branch, *MGN* medial gastrocnemius nerve branch, *DPN* deep peroneal nerve branch, *SAN* saphenous nerve, *SN* sural nerve

Discussion

Traumatic, oncologic, or iatrogenic lesions frequently caused debilitating lower-limb activities secondary to injuries of the sciatic nerve and its division, presenting lower leg atrophy, foot drop, plantar sensation loss, and absent plantar and dorsiflexion [3, 7]. The reported reconstruction approaches consisted of tendon/muscle transfer, nerve grafting, and transferring [14, 20]. The outcome of a controlled study has demonstrated that tendon transfer lead to 30% risk of complication, wherein satisfactory results could not be achieved [20]. Encouraged by the high success rate of nerve transfer in upper brachial plexus injuries [21], there was a steady rise in research regarding nerve reconstruction approaches for lower limb nerve injuries [5, 6, 17]. Yin et al. [23] reported the results of transferring the obturator nerve to motor the branch of the tibial nerve, by using more than 20-cm-long nerve grafts. Moore et al. [15] introduced a novel motor nerve transfer using femoral nerve terminal branches to the vastus medialis and lateralis muscles in the distal thigh to the medial and lateral gastrocnemius branches of the tibial nerve. They also implemented a sensory transfer using a saphenous nerve to tibial nerve with an intermediary sural nerve graft to reconstruct protective foot sensation. Flores et al. [5] used the proximal motor branches from the tibial nerve as a direct donor to the deep peroneal nerve, which is suitable for only peroneal nerve injury cases in which the tibial nerve is normal. However, all these reported methods only restore the function of the tibial nerve or peroneal nerve and are not suitable for high level sciatic nerve lesion with both the tibial and peroneal nerve function impaired. Hence, more efficient and practical donor nerve and surgical methods are required to be identified. Inspired by Moore et al. [15], we conducted this cadaver feasibility evaluation of femoral motor branches transfer for deep peroneal branch as well as tibial motor branches.

In our study, we observed that the diameter and nerve fiber number of the end of the targeted donor nerve corresponded well to those of the recipient nerve. The length of the contralateral SN is sufficient to bridge all the donor–recipient nerve pairs. The results confirmed the feasibility of the procedure and demonstrate that transferring of VMN to MGN, VLN to DPN, and SAN to SN are a practical and reasonable reinnervation option to treat sciatic nerve injury.

However, the morphometric data found in our autopsy study was not consistent with other reported studies. Unlike the results of Moore et al. [15], who reported a direct coaptation in 1/2 specimens, our study revealed a total of 5/6 samples that needed grafting, ranging from 5 to 15 cm to bridge the VMN to MGN. This may be due to the small sample size and difference in the body mass index between populations in difference geographic regions.

Besides, we found that in the VMN to MGN anastomosis, three of the anastomoses were 7 cm or less. The other three of the anastomoses were 10 cm or more. In the VLN to DPN anastomoses, all of the grafts were more than 10 cm. Some authors reported that grafts with length greater than 9 cm have a rather low rate of being successful [8, 19]. However, other authors found that in cases with large nerve gap greater than 9 cm, the repair using sural nerve autograft would still benefit the patients. Lee et al. [12] reported the results of a research repairing the radial nerve large defect of more than 9 cm length and 83% of the patients obtained an MRC 4 or better recovery. Yin et al. [23] reported the clinic and electrophysiological results of five patients who presented with sacral plexus injury and received the operation of transferring the obturator nerve branch to the motor branch of the tibial nerve, by using long nerve grafts greater than 20 cm. Functional evaluation showed that three patients (60%) recovered to MRC grade 3 or better and the electrophysiological investigation showed the indicative of reinnervation of gastrocnemius. In Fisher et al. [4] and Bosnjak et al. [1] series, they used the nerve autografts to repair the radial nerve large defects ranging from 9 to 14 cm and found that up to 75% of the patients recovered to MRC 4 or MRC 5. In our previous study, a sural nerve graft with 30-cm length was used to bypass the T12 ventral root to S2 ventral root and it succeed in establishing an abdomen-to-bladder reflex pathway to restore controllable micturition in the atonic bladder [13]. These results indicated that even the nerve defect is greater than 10 cm, repairing the defect with autograft would have the chance to restore function. Therefore, we believe that when there were no better means to treat high sciatic nerve injury, transferring femoral nerve branches to sciatic nerve branches with long nerve graft provides an alternative to traditional means.

Our novel procedure has some advantages. First, this is an intact treatment strategy for high-level sciatic nerve injury with impairment of both motor and sensation functions. We were able to restore the dorsiflexion and plantar flexion by transferring VMN to MGN, and VLN to DPN. Simultaneously, sensation was restored by suturing the SAN to the SN nerve, which is an essential step to further restore protective foot sensation by transferring the distal sural nerve to the tibial nerve at the tarsal tunnel, as per Moore's report. Both of these aspects are important in the intact stance-wing procedure of walking. Second, in the case of foot drop, we demonstrated, for the first time, the treatment feasibility of transferring femoral nerve motor branch to the deep peroneal nerve. This is a practical alternative to traditional treatment such as the tibial nerve branch or tendon transfer method, both of which depend on the intact function of the tibial nerve. Because the end of femoral nerve branches run nearer with the recipient nerve than other donor branches reported [23], this procedure is supposed to be a better alternative in case of high-level sciatic nerve injuries with an abnormal tibial and peroneal nerve function.

Other technical issues of these method that merit mention are as follows: First, the branches of the vasti played a role as the donor nerve for the following reasons: there are four terminal motor branch candidates, when one part of which was chosen as the donor and the other parts could provide residue extension function of the knee joint [15]. Based on our observation, the ends of VLN and VMN run nearer to the target recipient nerve and are thus better donor options than the other two branches of the femoral nerve (branches to the vatus rectus and internus). Second, if the nerve graft is not long enough, reconstructive priority is given to the motor nerve to restore the flexion strength and improve the ambulation, without affecting the sensation dominance area of the donor sensation nerve [15, 16]. The gastrocnemius and tibialis anterior play important roles in dorsiflexion and plantar flexion of the ankle and had the priority to be reinnervated [2, 9, 16]. Third, the femoral-tibial nerve is a synergistic donor-recipient nerve pair to provide complementary functions in the stance phase of walking and provides explosive force to propel the body forward at toe-off [22]. On the contrary, the femoral-peroneal nerve is an antagonistic donor-recipient nerve pair [2, 9]. For this consideration, the whole transfer procedure is recommended to be implemented by stages in clinical practice. The rehabilitation program including motor re-education would be necessary to establish a new motor pattern and facilitate the brain adaption [15]. Fourth, we think these types of high sciatic nerve injuries should be repaired using the femoral nerve transfer approach rather than attempting a direct repair with grafting: particularly in the clinical setting of partial lumbosacral plexus avulsion or long defects of the sciatic nerve trunk in the gluteal region involving either the tibial and/or peroneal nerve components when femoral nerve function is preserved [15].

Our study has some limitations. First, this is an anatomic feasibility research. The theoretical and basic effects should be confirmed by clinical trial in future. Second, the transfer of terminal of femoral nerve and deep peroneal nerve only succeeded by means of proximal neurolysis and intaneural dissection, which would lead to unnecessary sacrifice of more proximal motor branches and increase the potential of scarring. Additionally, the side effect of donor morbidity by severing two femoral nerve branches should be taken into consideration in future study. Third, unlike the adjacent nerve transferring, our study needs an autogenous graft to bridge the donor and recipient. The latter requires two coaptation sites and longer regeneration distance than adjacent nerve transfer. The regenerating axons have to traverse two suture lines that will make the functional outcome variable [18]. Last, the sample size is small which could have biased the results. These questions should be evaluated in future studies.

Conclusion

Our study demonstrated the feasibility of transferring femoral nerve branches to sciatic nerve branches to restore motor function and sensation after sciatic nerve injury. However, the results need to be confirmed in future clinical trials.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human specimens were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent This article does not contain any studies with human participants performed by any of the authors.

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Comments

Dr. Meng and his colleagues at the Second Military Medical University in Shanghai have provided us with a beautiful cadaver dissection demonstrating the feasibility of using nerve transpositions from the femoral nerve to restore function in a patient with an irreparable high sciatic nerve injury. The anatomy of those transpositions is very nicely demonstrated in the accompanying figures.

While I remain sceptical about the efficacy of sural nerve grafts more than seven centimetres, the authors have provided us with reference of cases in which longer sural nerve grafts have restored function. I am very interested in reading about the authors' results applying this technique to patients.

Allan Friedman

NC, USA

An interesting proximal femoral nerve to distal sciatic nerve transfer option in the setting of proximal injuries to the lumbosacal plexus and/or proximal sciatic nerve. It will require further validation in animals and if successful eventually in patients.

Michel Kliot

CA, USA