



Translocation of the soleus muscular branch of the tibial nerve to repair high common peroneal nerve injury

Huihao Chen¹ · Depeng Meng¹ · Gang Yin² · Chunlin Hou¹ · Haodong Lin²

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Abstract

Background This study was performed to evaluate the clinical effect of translocating the soleus muscular branch of the tibial nerve to repair the deep peroneal nerve.

Methods Eight patients were treated for high common peroneal nerve injury. The deep peroneal nerve was separated out from the common peroneal nerve if no injury occurred upon opening the epineurium of the common peroneal nerve. The soleus muscular branch of the tibial nerve was then translocated to the deep peroneal nerve.

Results The average follow-up duration was 21.75 months. Electromyography revealed newly appearing electric potentials in the tibialis anterior, extensor hallucis longus, and extensor toe longus muscle at 8 to 10 months postoperatively. Four patients showed good functional recovery after surgery; functional recovery was poor in other patients.

Conclusions Translocation of the soleus muscle branch is a feasible method to treat high common peroneal nerve injuries. A full understanding of the indications for this operation is required.

Keywords Nerve injury · Nerve transfer · Common peroneal nerve · Reconstruction · Tibial nerve · Sciatic nerve

Background

Most sciatic nerve injuries are caused by hip fracture and dislocation, contusion injury, compression injury, hip arthroplasty, drug injection, or gunshot injury. After the sciatic nerve has been injured, the tibial nerve components often fully or partially recover; however, the components of the common peroneal nerve often do not recover [15, 18]. High common peroneal nerve injury results in acrotarsium sensory deprivation and gait alteration, as well as muscle paralysis of the tibialis anterior, peroneus longus, peroneus brevis, peroneus tertius, extensor

hallucis longus, and extensor digitorum longus. Treatment methods for high common peroneal nerve injury include ankle orthotics correction [8], tendon transposition [31], and neural transplantation [12]; however, all of them have limitations. Currently, nerve transposition is widely used to repair upper limb nerve injuries [1, 11, 22] and has obtained good curative effects; however, it is performed less commonly to repair lower limb nerve injuries. Several anatomical studies have verified the feasibility of translocating each muscle branch of the tibial nerve to repair common peroneal nerve injuries [2, 9]. In our previous study, we identified the soleus nerve branch as the preferred donor nerve [4]. The present study was performed to evaluate the clinical effect of transferring the soleus muscular branch of the tibial nerve to repair the deep peroneal nerve.

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Huihao Chen and Depeng Meng contributed equally to the manuscript and should be considered co-first authors.

✉ Haodong Lin
linhaodong1978@smmu.edu.cn

¹ Department of Orthopedic Surgery, Changzheng Hospital, Second Military Medical University, Shanghai 200003, People's Republic of China

² Department of Orthopedic Surgery, Shanghai General Hospital, Shanghai Jiaotong University School of Medicine, Haining Road 100, Shanghai 200080, People's Republic of China

Methods

From 2013 to 2016, eight patients underwent treatment for high common peroneal nerve injury at our institution (four females and four males; average age, 37.5 years; age range, 18–66 years). The causes of their injuries were an acetabular fracture with hip joint dislocation ($n = 3$), operative complications of total hip arthroplasty ($n = 2$), an operative

complication of L4 vertebral fracture repair ($n = 1$), an operative complication of a pelvic cavity operation ($n = 1$), and a thigh gunshot injury ($n = 1$). Each patient's common peroneal nerve was injured completely, and they could not dorsiflex their ankle. However, the function of the tibial nerve was good. The ankle plantar flexor muscle force was M5 or M4+. Electromyography suggested that the dominant muscle of the injured common peroneal nerve was completely paralyzed, including paralysis of the short head of biceps femoris branch; however, the tibial nerve was normal or basically normal. Surgery was performed at an average of 7.75 months (range, 6–11 months) after the injury.

After surgery, muscle strength was evaluated according to the British Medical Research Council (MRC) marking system, which included ankle dorsiflexion and toe extension. The results were categorized as poor if the power was M2 or lower, and as good if the power was M3 or M4. This study was approved by the Hospital Ethics Committee.

Surgical technique

The operations were performed under general anesthesia using an operating microscope ($\times 10$ magnification). The patient was placed in the supine position. An "S"-shaped incision was made in the popliteal fossa, and its distal end stopped at the bottom of the fibular head. Dissection was performed to find the main trunk of the tibial nerve and the common peroneal nerve at the top of the popliteal fossa. The common peroneal nerve was separated at the distal end of the fork of the common peroneal nerve and tibial nerve. The epineurium was opened, and the deep peroneal nerve and superficial peroneal nerve were dissected. Separation was carefully continued along the main trunk of the tibial nerve toward the distal end, and the gastrocnemius lateral and medial head muscle branches and soleus muscle branch of the tibial nerve were then identified. The diameter and length of the tibial nerve soleus muscle branch and deep peroneal nerve were observed. Intraoperative electrical stimulation was used to confirm the function of the tibial nerve branch. When the function was normal, the deep peroneal nerve was cut at the proximal end and the tibial nerve soleus muscle branch was cut at its entrance point. Under microscopy, the soleus muscle branch and deep peroneal nerve were anastomosed without tension using 9-0 nylon (Fig. 1). Plaster immobilization of the injured lower limb was performed in a conventional manner for 3 to 4 weeks postoperative; the patients also underwent physiotherapy, including exercise training and intensive training.

Results

No patients were lost to follow-up. The average follow-up duration was 21.75 months (range, 19–24 months). No

postoperative complications occurred. The hospital stay ranged from 8 to 10 days. During surgery, all patients' tibial nerve soleus muscle branches and deep peroneal nerves were directly anastomosed, and no patients developed a decrease in their ankle plantar flexor muscle force after surgery. Electromyographic examination revealed newly appearing electric potentials in the tibialis anterior, extensor hallucis longus, and extensor toe longus at 8 to 10 months postsurgery, illustrating that the tibial nerve soleus muscle branch had regenerated to the deep peroneal nerve. Two to 3 months later, electromyography showed new potentials, and the muscles of the tibialis anterior, extensor hallucis longus, and extensor toe longus began to contract. Initially, the patients showed co-contraction of the dorsiflexion and plantar flexion muscles; they could only perceive muscle contraction without dorsal extension of the ankle joint and toe. After about 3 months of rehabilitation exercises, this co-contraction changed, and the patients could control the dorsal extension and plantar flexion of the ankle joint.

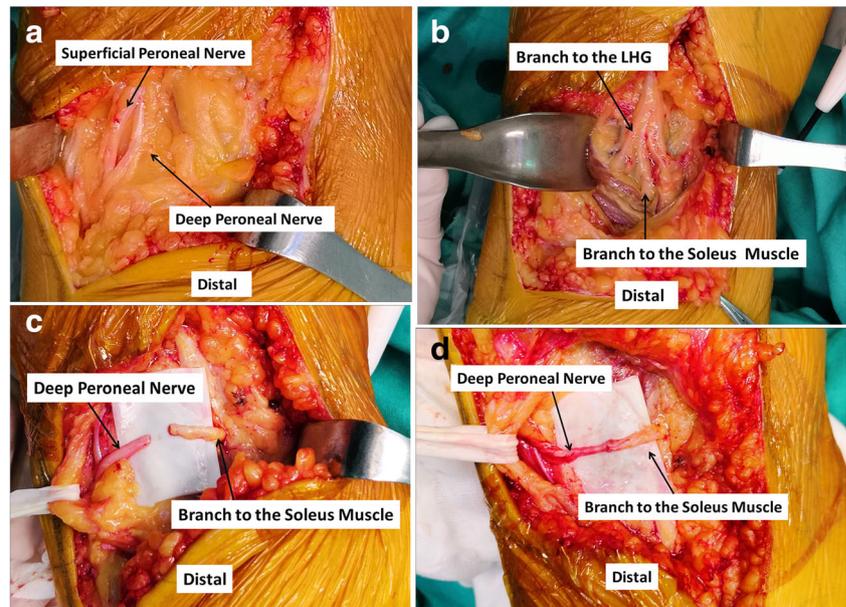
Four patients developed good functional recovery after surgery (two patients achieved M4 (Fig. 2) with ankle dorsiflexion against partial resistance, and two patients achieved M3), one patient achieved M2, two patients achieved M1, and the remaining patient showed no recovery (Table 1). Three patients still needed external orthosis after rehabilitation.

Discussion

The sciatic nerve consists of two nerve components: the tibial nerve and common peroneal nerve, which are loosely wrapped by the same connective tissue and are easily distinguished from each other [34]. In a high sciatic nerve injury, the common peroneal nerve component tends to be more severely injured [7, 18]. The tibial nerve component usually recovers wholly or partially, while the peroneal nerve component often fails to recover, causing the foot to drop [9, 14, 15, 18, 19, 23, 27, 28].

The routine treatment of foot drop caused by common peroneal nerve injury is the transfer of the posterior tibial tendon [5]. Generally, tendon transplantation is more effective than nerve transfer to treat foot drop [25]. However, after the transfer of the posterior tibial tendon, the muscle strength of the transposed tendon decreases, accompanied by tunnel entrapment [26]. In addition, the transfer can also lead to some long-term complications, such as valgus deformity of the hind foot and flat foot [33]. In contrast to tendon transplantation, successful nerve transplantation can achieve synchronous physiological movement and restore muscle function similar to the pre-injury levels [17]. Leclère stated that nerve transplantation provides muscle balance between the anterior tibial muscle and the remaining intact triceps surae muscles, and there is no need for orthopedic shoes after reinnervation [20].

Fig. 1 Intraoperative photographs of the soleus muscle branch of the tibial nerve to the deep peroneal nerve. **a** The superficial and deep peroneal nerve branches were exposed. **b** The branch to the soleus muscle and lateral head of the gastrocnemius (LHG) were exposed. **c** The branch to the soleus muscle and the deep peroneal nerve was isolated for a tensionless suture. **d** The branch to the soleus muscle was coapted to the deep peroneal nerve



The neuroplasticity of nerves, which refers to the ability of the CNS to reorganize and adapt to internal changes or environmental stimuli, and thus optimize the functional outcome, makes it possible to revive nerve function via surgery [32]. Nerve remodeling in infants and young children is active, while Mohanty emphasized in adult brain after nerve injury [24]. Modern concepts of plasticity must be considered when performing simultaneous agonistic and antagonistic muscle reinnervation during surgery on the brachial plexus [32]; however, it has been confirmed that the transfer of the flexor muscle innervated by the median and ulnar nerves can repair the extensor function after radial nerve injury [6]. In addition, transfer of the branches of the median nerve repaired the dorsal

extension function of the radial nerve [21, 22]. These results proved that an antagonist muscle can have a transforming function, and a single agonist muscle reinnervated by an antagonist nerve usually obtains a discernable function.

Several anatomical studies have been conducted to explore the feasibility of using the tibial nerve proximal muscular branch to repair the deep peroneal nerve. In a study by Bodily et al. [2], the gastrocnemius lateral head muscular branch and the soleus muscle branch of the tibial nerve could be directly translocated to the common peroneal nerve after dissection of the nerves of these muscles. Flores [9] also performed a study in patients with high common peroneal nerve injuries. After anatomical separation of the deep peroneal

Fig. 2 Postoperative results from the soleus muscle branch for the treatment of high peroneal nerve injury of the left side. **a** Bilateral feet in a neutral position. **b** Bilateral feet in a dorsiflexion position. **c** Bilateral feet in a standing position. **d** Bilateral feet in a dorsiflexion anti-resistance position



Table 1 Result of transferring the nerve of soleus muscle to the deep peroneal nerve in 8 patients

Case No.	Age/gender	Preoperative ankle plantar flexion (MRC)	Interval (months) ^a	Follow-up (months)	Postoperative EDX	Ankle dorsiflexion (MRC)	Toe extension (MRC)
1	66 M	m4+	11	22	TA(-), EHL(-), ETL(-) LG(+), MG(+), So(-)	M0	M0
2	18 M	M4+	9	25	TA(-), EHL(-), ETL(-) LG(+), MG(+), So(-)	M1	M0
3	24 F	M5	6	20	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M4	M3
4	53 F	M5	7	24	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M4	M4
5	32 M	M5	6	19	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M3	M2
6	28 F	M4+	8	23	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M1	M1
7	33 F	M5	7	20	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M3	M2
8	46 M	M4+	8	21	TA(+), EHL(+), ETL(+) LG(+), MG(+), So(-)	M2	M2

MRC, Medical Research Council; EDX, electrodiagnostic study; TA, tibialis anterior; EHL, extensor hallucis longus; ETL, extensor toe longus; LG, latissimus Gastrocnemius; MG, medial gastrocnemius; So, soleus; (-), no activity; (+), acquired new action potentials

^a Between injury and surgery

nerve from the common peroneal nerve, the gastrocnemius medial and lateral head muscular branches and the soleus muscle branch of the tibial nerve were used to directly repair the deep peroneal nerve. Our previous anatomical studies [3] indicated that three motor nerve branches in the popliteal space of the tibial nerve could be directly translocated to match the deep peroneal nerve. The diameter of the soleus muscle branch and the total number of fibers of the motor nerve were similar to those of the deep peroneal nerve, and the soleus nerve branch may be the preferred donor nerve.

There is still no clear consensus on which tibial nerve muscular branch is the ideal donor nerve. Giuffre et al. [13] reported that 4 of 11 patients benefited from translocation of different branches of the tibial nerve to repair the deep peroneal nerve; however, only one patient regained grade 4 ankle dorsiflexion, and three patients regained grade 3. Flores et al. [10] used the soleus muscle branch to repair the deep peroneal nerve, and 3 of the 13 patients withdrew from the study. Among the remaining 10 patients, only two patients' ankle dorsiflexion reached M3 or M4, and two achieved dorsiflexion of the toes.

In the present study, we used the tibial nerve soleus muscle branch to translocate the deep peroneal nerve. In terms of ankle dorsiflexion, two patients reached M4 and two patients reached M3. The results were better than those of Flores et al. [10]. The difference between the study by Flores et al. and our study may be related to the choice of patients. In our study, the ankle plantar flexion function of four patients without high-energy injuries reached M5 before the operation and recovered well. The ankle dorsiflexion of the three patients with preoperative M4+ ankle plantar flexion and the patients with bullet wounds showed poor recovery. For patients with high common peroneal nerve injury with ankle plantar flexion that fails to reach M5, the axons and branches of their tibial nerves may have already been damaged. Nerve injury can cause apoptosis of many motor neurons of the anterior angle, and the Nissl bodies in the neuron may also be damaged. In patients with high-energy injuries, the common peroneal nerve may sustain a stretch injury in the fibular head at the time of injury, leading to partial deep peroneal nerve injury, which affects nerve translocation. Finally, in patients with bullet wounds, the tibial nerve may sustain a burn injury, which has an adverse effect on the recovery of ankle dorsiflexion function. In the study by Flores et al., they did not report the level of injury to the common peroneal nerve. Therefore, the deep peroneal nerve of some patients maybe injured before surgery, which may affect functional recovery. The results of the present study suggest that this procedure requires a strict grasp of the operative indications. To achieve better clinical effects, we suggest choosing patients with low-energy injuries whose preoperative ankle plantar flexion muscle force reaches grade 5. Preoperative electrophysiological examination showed that the short head of the biceps femoris was not recovered, which

indicated that the common peroneal nerve might be located at a high level. During surgery, we recommend conducting electrical stimulation to ensure the integrity of the donor nerve. Functional exercise should be performed in the early postoperative period.

Generally, both the gastrocnemius muscle and the soleus muscle contract at the same time, which makes it difficult for the brain to distinguish each nerve separately. The transposition of gastrocnemius muscle flaps is sutured with the soft tissue of the knee extensors, such as the residual patellar ligament and quadriceps femoris, which can partly replace the function of these soft tissue structures in knee extensors [16, 29, 30]. This suggests that after the gastrocnemius and soleus muscles are separated, the brain can differentiate the functions of the two muscles, and the gastrocnemius muscle can be transformed into the extensor muscle. Therefore, the brain should be able to distinguish the function of the soleus muscle branch from that of the gastrocnemius muscle after the transfer of the soleus muscle branch. We have conducted animal experiments in rats to prove that the proximal tibial nerve branch can actively extend the ankle joint and open the toes after repairing the deep peroneal nerve, which indicates that the brain can distinguish the functions of the soleus and gastrocnemius muscles [4]. In the present study, during the recovery course, the patients showed co-contraction of the dorsiflexion and plantar flexion muscles at first; however, after about 3 months of rehabilitation exercises, this co-contraction changed: The patients could control the dorsal extension and plantar flexion of the ankle joint. The results indicated that the brain has the ability to distinguish the contraction of the gastrocnemius muscle from that of the soleus muscle.

Conclusions

We believe that translocation of the soleus muscle branch is a feasible method to treat high common peroneal nerve injuries. However, this method requires a deep understanding of the operative indications. To achieve better clinical effects, we suggest choosing patients with low-energy injuries whose preoperative ankle plantar flexion muscle force reaches grade 5. Preoperative electrophysiological examination showed that the short head of the biceps femoris had not recovered, which indicated that the injury to the common peroneal nerve might be located at a high level. During surgery, we recommend conducting electrical stimulation to ensure the integrity of the donor nerve. Functional exercises should be performed in the early postoperative period.

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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 participants were in accordance with the ethical standards of the institutional and/or national research committee (Guilan University of Medical Sciences) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from the patients.

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Comments

This article describes a technique using a nerve transfer using a tibial branch to the soleus muscle to restore peroneal nerve function mediating the important function of foot dorsiflexion. This transfer is particularly useful in the setting of proximal peroneal nerve injuries where tibial nerve function is 5/5. Although such a transfer involves activating antagonistic muscles in terms of function, over time the patient learns to selectively activate the muscles so as to produce useful foot dorsiflexion. This technique is another useful addition to the peripheral nerve's toolkit box.

Michel Kliot
California, USA