The anatomic location and importance of the tibialis posterior fascicular bundle at the sciatic nerve bifurcation: report of 3 cases

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The authors present the cases of 3 patients with severe injuries affecting the peroneal nerve combined with loss of tibialis posterior function (inversion) despite preservation of other tibial nerve function. Loss of tibialis posterior function is problematic, since transfer of the tibialis posterior tendon is arguably the best reconstructive option for foot drop, when available. Analysis of preoperative imaging studies correlated with operative findings and showed that the injuries, while predominantly to the common peroneal nerve, also affected the lateral portion of the tibial nerve/division near the sciatic nerve bifurcation. Sunderland's fascicular topographic maps demonstrate the localization of the fascicular bundle subserving the tibialis posterior to the area that corresponds to the injury. This has clinical significance in predicting injury patterns and potentially for treatment of these injuries. The lateral fibers of the tibial division/nerve may be vulnerable with long stretch injuries. Due to the importance of tibialis posterior function, it may be important to perform internal neurolysis of the tibial division/nerve in order to facilitate nerve action potential testing of these fascicles, ultimately performing split nerve graft repair when nerve action potentials are absent in this important portion of the tibial nerve.

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KNOWLEDGE of nerve anatomy is critical to anatomical localization of nerve injuries. Understanding the branching pattern and common variants is fundamental to this task. In the modern era of treatment of nerve injuries, however, this level of detail is not sufficient. Rather, neurologists, radiologists, and peripheral nerve surgeons who are evaluating and treating patients with nerve injuries must be aware of the internal fascicular topography of the nerve. This is probably most evident following the advent and popularization of nerve transfers as a treatment modality. For example, the surgeon must know the internal topography of the ulnar nerve in order to appropriately select the donor fascicle to perform a nerve transfer to the biceps motor branch for elbow flexion (Oberlin procedure).¹⁰

Patients with injury to the common peroneal nerve are challenging to treat, frequently having neuropathic pain

and poor functional recovery.^{1,2,4,6,8,9,12} One of the available treatment options is the tibialis posterior tendon transfer.^{3,4,6,7} Normally an inverter of the foot, the tibialis posterior tendon can be transferred such that it becomes a dorsiflexor of the foot. Since this muscle is innervated by the tibial nerve, this treatment remains an excellent, reliable reconstructive option in isolated common peroneal nerve injuries. We present 3 patients who sustained injuries to the common peroneal nerve who also had complete loss of inversion, despite the remainder of the tibial nerve function largely being preserved. We explain this injury pattern on the basis of the internal fascicular topography of the sciatic, common peroneal, and tibial nerves and suggest that understanding this fascicular topography may have important clinical ramifications during the treatment of this type of injury.

ABBREVIATIONS FDL = flexor digitorum longus; FHL = flexor hallucis longus; MRC = Medical Research Council; NAP = nerve action potential.

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Case Reports

Case 1

A 36-year-old man was referred for an accidental self-inflicted gunshot injury to the left peroneal nerve that occurred 8 months prior to our evaluation. The patient reported an immediate, complete foot drop following the injury. On physical examination, he had complete paralysis of the deep and superficial peroneal-innervated muscles. The tibialis posterior muscle had Medical Research Council (MRC) grade 0/5 function, whereas the flexor hallucis longus, flexor digitorum longus, and gastrocnemius muscles were graded as 3/5. Sensation was absent on the dorsum of the foot in the distribution of the deep and superficial peroneal nerves, but grossly normal on the plantar aspect of the foot in the distribution of the tibial nerve.

Electrodiagnostic testing showed fibrillation potentials in the peroneus longus, tibialis anterior, and tibialis posterior muscles. The gastrocnemius muscle was without abnormalities. Ultrasonography demonstrated a 5-cm neuroma-in-continuity in the common peroneal nerve in the distal thigh (Fig. 1A and B). Initial CT scans (Fig. 1C and D) suggested injury located at the sciatic nerve bifurcation, involving both the common peroneal nerve and the lateral portion of the tibial nerve.

Intraoperatively, a neuroma-in-continuity involving the common peroneal nerve and the lateral fascicles of the tibial nerve was found, corresponding to the preoperative imaging findings. Internal neurolysis of the sciatic nerve at the bifurcation was performed to separate the peroneal and tibial divisions, and nerve action potentials (NAPs) were absent across the injured segment of the peroneal nerve but present across the tibial nerve (Fig. 1E). The peroneal neuroma-in-continuity was resected. Graft repair was then performed to bridge the 8-cm defect with a cabled sural nerve graft (Fig. 1F).

Eight months after the surgery, the patient recovered MRC grade 4/5 tibialis posterior muscle function, without any clinical or electrophysiological improvement of the peroneal nerve-innervated muscles. A tendon transfer reconstruction was offered for the treatment of the foot drop.

Case 2

A 32-year-old man presented 6 months after a knee dislocation with injury to both the anterior cruciate and lateral collateral ligaments. Immediately after the injury, the patient noted a complete foot drop, moderate weakness of inversion, and mild weakness of plantar flexion and toe flexion, and subsequently developed neuropathic pain on the dorsum of his foot. Over the ensuing 6 months, he noted some recovery of plantar flexion and inversion. On physical examination, he had paralysis of deep and superficial peroneal-innervated muscles. Toe flexion, tibialis posterior, and gastrocnemius function were MRC 4+/5. He had decreased sensation on the dorsum of the foot, with only subtle changes on the plantar aspect.

Electrodiagnostic testing showed a severe peroneal nerve lesion distal to the short head of the biceps femoris, without conduction block and without signs of reinnervation. A mild tibial neuropathy without active denervation was also found. Initial MR images after the acute knee

dislocation did not include the proximal calf, limiting evaluation of the tibialis posterior muscle (Fig. 2A–C); however, the popliteus muscle was included and showed edema and denervation changes. The tibial nerve could only be well seen on the coronal images and showed enlargement and T2 hyperintensity within the distal sciatic nerve, extending into the tibial nerve at and below the knee. Severe damage to the peroneal nerve was also seen, including the peroneal division of the sciatic nerve at the sciatic nerve bifurcation. Repeat MR imaging 6 months later showed that the abnormal signal within the popliteus muscle had resolved (Fig. 2D and E). Fatty atrophy of the tibialis posterior muscle in addition to the anterior and lateral compartments was seen. There was very prominent subacute denervation of the tibialis anterior, in addition to the more chronic changes seen as prominent edema within the muscle.

Intraoperatively, a long-segment (20 cm) injury of the peroneal nerve injury was found, with mild scarring of the tibial nerve at the bifurcation. NAPs were absent across the peroneal nerve lesion, but present across the tibial nerve lesion. A cabled nerve graft repair was performed (Fig. 2F and G), primarily to address the neuropathic pain. A tibialis posterior tendon transfer was also performed concomitantly.

At the 4-year follow-up, the patient had continued pain. He wore boots but no brace. He had 5° of active dorsiflexion.

Case 3

A 22-year-old man presented 4 months after a knee dislocation for evaluation of an associated right peroneal nerve injury. At the time of the injury, he noted a complete foot drop, with no improvement since the injury. On physical examination, peroneal-innervated muscle function was MRC grade 0/5, as was the tibialis posterior. Flexor hallucis longus and flexor digitorum longus muscles were MRC grade 3/5 and the gastrocnemius muscle grade was 4/5.

Electrodiagnostic testing showed fibrillation potentials in the tibialis anterior, peroneus longus, and gastrocnemius muscles. The tibialis posterior was not included in the study. Reinnervation was found in the tibial-innervated muscles (gastrocnemius and flexor digitorum longus) but not for the peroneal nerve distribution. Ultrasonography of the peroneal nerve showed nerve enlargement and complete loss of normal fascicular architecture commencing at the sciatic nerve bifurcation. A gap in the common peroneal nerve was visualized. Hypoechoic, enlarged fascicles were also seen in the lateral portion of the tibial nerve near the sciatic nerve bifurcation (Fig. 3A). MR imaging showed hyperintensity at the sciatic nerve bifurcation involving the common peroneal nerve and the lateral portion of the tibial nerve.

Intraoperatively, the common peroneal nerve was found to be ruptured, with a 7-cm gap between the nerve ends initially (Fig. 3B). After resecting the nerve stumps back to healthy, viable fascicles, the gap was 15 cm. A cabled sural nerve graft was used for nerve graft repair. The tibial nerve was in-continuity but with some scarring involving the lateral aspect of the tibial division at the level of the sciatic nerve bifurcation and knee region (Fig. 3C). There

FIG. 1. Case 1. A 36-year-old man underwent evaluation for a left peroneal nerve injury 8 months after a gunshot injury. **A:** Short-axis ultrasound image of the sciatic nerve, demonstrating intact hypoechoic fascicles of the enlarged tibial division of the sciatic nerve (arrows). Fusiform, hypoechoic enlargement of the peroneal and lateral tibial components of the sciatic nerve, with loss of the normal fascicular architecture, consistent with a neuroma-in-continuity (arrowheads). **B:** Long-axis ultrasound image of the sciatic nerve, demonstrating hypoechoic enlargement and loss of the normal fascicular architecture consistent with a neuroma-in-continuity (arrowheads). Normal fascicles of the tibial component can be seen superficially (arrows). **C:** Axial image from a CT angiogram of the lower extremities, demonstrating enlargement and loss of fascicular architecture of the left peroneal division and lateral aspect of the tibial division of the left sciatic nerve (long arrow). The tibial (short arrow) and peroneal (arrowhead) divisions can be seen as 2 separate structures on the right. **D:** Coronal maximum intensity projection image from CTA, showing bullet fragments within the peroneal component of the left sciatic nerve (arrow), with thinning of the tibial division (arrowhead), indicating injury to the lateral aspect of the tibial division. **E:** Intraoperative photograph showing the neuroma (*) involving the peroneal division and the lateral fascicles of the tibial division. **F:** An 8-cm cabled sural nerve graft, comprising 6 cables, was used to repair the common peroneal nerve. dP = distal peroneal nerve; dT = distal tibial nerve; NG = nerve graft; pP = proximal peroneal nerve. Figure is available in color online only.

was good muscular contraction when stimulating the tibial nerve. External neurolysis of the scarred fascicles was performed.

Discussion

We present 3 cases in which patients suffered a complete injury to the common peroneal nerve and a partial injury disproportionately affecting the tibialis posterior fi-

bers of the tibial nerve (i.e., despite the remainder of tibial nerve function largely being preserved). The loss of inversion in these cases has profound clinical significance and eliminates as an option, arguably the best surgical treatment for foot drop, a tibialis posterior tendon transfer.^{3,4,6,7} We predicted that this injury may be accounted for by the internal fascicular topographical organization of the sciatic, common peroneal, and tibial nerves.

In these 3 cases, while the nerve injury was predomi-

FIG. 2. Case 2. A 32-year-old man underwent evaluation for a left peroneal nerve injury associated with a knee dislocation 6 months prior to presentation. **A:** Coronal T2-weighted, fat-suppressed MR image obtained shortly after the injury, showing enlargement and hyperintensity of the sciatic nerve at the bifurcation, with extension into the tibial nerve at the knee (arrows). Significant soft-tissue edema is present and related to the acute injury of the knee. **B:** Axial T2-weighted, fat-suppressed MR image showing marked abnormality, irregularity, and edema of the peroneal nerve (arrowhead) distal to the sciatic nerve bifurcation just above the joint. The tibial nerve is also enlarged with surrounding edema (arrow). **C:** Axial T2-weighted, fat-suppressed MR image showing edema within the popliteus muscle, consistent with denervation. **D:** Axial T1-weighted MR image obtained 6 months after the initial injury, showing fatty atrophy of the tibialis posterior muscle (TP) and the anterior and lateral compartments of the calf, including the tibialis anterior muscle. **E:** Axial fat-suppressed, fast spin echo T2-weighted MR image showing prominent subacute denervation in the tibialis anterior muscle (TA). The previously seen edema in the popliteus muscle has resolved. **F:** Intraoperative photograph showing a 20-cm gap in the peroneal nerve. **G:** A 22-cm cabled sural nerve graft repair of the common peroneal nerve was performed concomitantly with a tibialis posterior tendon transfer. T = tibial nerve (in blue vessel loop). Figure is available in color online only.

FIG. 3. Case 3. A 22-year-old man underwent evaluation 4 months after a knee dislocation. **A:** Short-axis ultrasound image of the sciatic nerve, showing abnormal fascicular enlargement of the lateral portion of the tibial nerve (*short arrows*) and abnormal soft tissue interposed between the peroneal and tibial nerves at the sciatic nerve bifurcation (*long arrow*). **B:** Intraoperative photograph showing a 7-cm gap in the common peroneal nerve. **C:** Intraoperative photograph showing scarring around the lateral aspect of the tibial nerve. Figure is available in color online only.

nantly to the common peroneal nerve, both preoperative imaging and visual inspection of the sciatic nerve bifurcation intraoperatively demonstrated injury at the level of the sciatic nerve bifurcation that included the lateral aspect of the tibial division/nerve. A single longitudinal stretch of the peroneal nerve back to the sciatic nerve bifurcation could be hypothesized as the mechanism of injury.¹² With this clinical observation, we then referred back to Sunderland's original maps of the fascicular architecture of the sciatic nerve and Gustafson and colleagues' later study, hypothesizing that the fascicles subserving the tibialis posterior muscle would be located in the lateral aspect of the tibial division at the level of the sciatic nerve bifurcation. The original topographical maps from Sunderland, as well as the later maps from Gustafson, suggest exactly that (Fig. 4).^{5,13,14} This is important to recognize, as the close juxtaposition of the fascicles to the tibialis posterior and the common peroneal nerve suggests that loss of inversion is likely to be more common than loss of other tibial nerve function in predominantly peroneal nerve stretch injuries. The clinician should always assess inversion in patients with common peroneal nerve injury due to its importance as a potential treatment option via tendon transfer, but this serves to point out that one cannot assume inversion is intact based on preserved tibial nerve function to the so-

leus and gastrocnemius and maintenance of strong plantar flexion. Similarly, electrodiagnostic testing should assess the tibialis posterior preoperatively. (Note it was only needed preoperatively in 1 of our 3 patients.)

A richer awareness of the topographical layout of the tibial division at the sciatic nerve bifurcation will lead us to evaluate and potentially treat patients with a similar injury pattern differently in the future. In each case presented, we performed a nerve graft repair of the peroneal nerve but performed only external neurolysis of the proximal tibial nerve and the tibial division at the level of the sciatic nerve bifurcation. Understanding the importance of tibialis posterior function and the internal topography, we believe that in future similar cases, if tibialis posterior function does not recover spontaneously, it may be worthwhile to perform internal neurolysis of the lateral fascicles of the tibial division in order to separate out the fascicles subserving the tibialis posterior. These fascicles could then be tested for the presence of NAPs across the injured segment. If NAPs are absent, nerve graft repair for those specific fascicles could then be performed, with the goal being restoration of tibialis posterior function sufficient enough to allow tendon transfer. Given better outcomes with tibial nerve grafting compared with peroneal nerve grafting, this may be realistic.

FIG. 4. Gustafson and colleagues' maps of the fascicular architecture of the sciatic nerve, showing the fascicles subserving the tibialis posterior located in the lateral aspect of the tibial division at the level of the sciatic nerve bifurcation. EDL = extensor digitorum longus; EHL = extensor hallucis longus; FB = fibularis brevis; FDL = flexor digitorum longus; FHL = flexor hallucis longus; FL = fibularis longus; LG = lateral gastrocnemius; LSC = lateral sural cutaneous; MG = medial gastrocnemius; MSC = medial sural cutaneous; TA = tibialis anterior; TP = tibialis posterior. Figure is reprinted from Gustafson KJ, Grinberg Y, Joseph S, Triolo RJ: Human distal sciatic nerve fascicular anatomy: implications for ankle control using nerve-cuff electrodes. *J Rehabil Res Dev* 49:309–321, 2012. Publication is in the public domain. Figure is available in color online only.

Some centers perform nerve transfer of tibial nerve branches to branches to the tibialis anterior in cases of peroneal nerve injury.^{2,11} Understanding the topographical organization of the tibial nerve is also important in these cases. These nerve transfers are typically performed at the level of branches of the tibial nerve, typically using branches to the flexor digitorum longus, flexor hallucis longus, or soleus. Branches to the tibialis posterior are avoided. However, if internal neurolysis is performed in order to lengthen the branch of the tibial nerve to be used as a donor, care must be taken to avoid injury to the fascicles to the tibialis posterior. Injury to these fascicles would eliminate the possibility of tibialis posterior tendon transfer in case the nerve transfer is not successful. The fascicles to the flexor digitorum longus and flexor hallucis longus are intimately related to the fascicles to the tibialis posterior. Thus, when using the branches to the flexor digitorum longus or flexor hallucis longus, the theoretical risk to the tibialis posterior fascicles is higher. It is not clear what the actual risk is, but this should be considered when choosing which branch to utilize for transfer.

For peripheral nerve surgeons, neurologists, and radiologists who evaluate patients with nerve injuries, an understanding of the segmental innervation of a nerve and its neuroanatomical course through the body to its ultimate targets is not sufficient any longer. Rather, we must have a deep understanding down to the level of the fascicular or-

ganization of a given nerve. These cases highlight the importance of specifically recognizing the location of the fascicles subserving the tibialis posterior. This understanding will change our approach to patients presenting with this pattern of injury and may, by addressing the loss of inversion, increase our ability to improve dorsiflexion function.

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Disclosures

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Author Contributions

Conception and design: Spinner, Wilson. Acquisition of data: all authors. Analysis and interpretation of data: Spinner, Wilson, Maldonado, Amrami. Drafting the article: Wilson, Maldonado. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Spinner. Study supervision: Spinner.

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