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ORIGINAL ARTICLE - NEUROSURGICAL TECHNIQUE EVALUATION

A cadaveric study using the ultra-minimally invasive thread transection technique to decompress the superficial peroneal nerve in the lower leg

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Abstract

Background After successful applications of the ultra-minimally invasive thread transecting technique (Guo Technique) for both thread carpal tunnel release and thread trigger finger release, we hypothesized that this technique could be used for superficial peroneal nerve release in the lower leg by selective crural fasciectomy. This study is aimed at testing the operative feasibility of performing the thread superficial peroneal nerve release (TSPNR) procedure in cadavers.

Methods The TSPNR procedure was performed on 15 fresh frozen cadaveric lower-extremity specimens under ultrasound guidance. All cadaveric specimens were dissected and visually assessed immediately after the procedures.

Results All 15 legs demonstrated a complete transection of the crural fasciae along the course of the superficial peroneal nerve (SPN) including where it penetrated and traversed the crural fascia. There was no evidence of any iatrogenic damage to the neurovascular bundle or adjacent tendons. The average operating time was less than 20 min.

Conclusion This cadaveric study demonstrated that the technique of TSPNR was accurate, reliable, and feasible while causing no injury to adjacent neurovascular structures and avoiding having to make a skin incision. Further studies are warranted to verify the results of this study before implementing this new technique in the clinical setting.

Keywords Superficial peroneal nerve entrapment release · Leg pain · Thread transecting procedure · Ultrasound-guidance · Ultra-minimally invasive procedure · Guo technique

Abbreviations

TSPNR	Thread superficial peroneal nerve release
SPN	Superficial peroneal nerve
TCTR	Thread carpal tunnel release
TTFR	Thread trigger finger release
D	Distal point
DM	Distal margin
P	Proximal point
PM	Proximal margin

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Introduction

Superficial peroneal nerve (SPN) fascial entrapment was first described by Henry in 1945 as mononeuralgia of the SPN [12]. Entrapment of the SPN as it traverses the crural fascia is an unusual cause of pain referred to the ankle and foot, and sometimes produces allodynia in the expected distribution of the nerve along the dorsum of the foot [18, 23, 24]. Styf et al. reported that SPN entrapment neuropathy had been diagnosed in 3.5% of 480 patients presenting with chronic leg pain [24, 25]. It is often underdiagnosed or misdiagnosed as a complex regional pain syndrome which can lead to inappropriate treatments [19]. After failure of conservative treatment, open surgical SPN release and fasciectomy is an effective standard treatment [3, 5, 15, 24, 25].

The ultra-minimally invasive thread transecting surgical technique, known as the Guo Technique, has been shown to be effective for several conditions. For example, it has been successfully applied to carpal tunnel release, known as thread carpal tunnel release (TCTR), and trigger finger release, known as thread trigger finger release (TTFR) [7–11, 21]. These techniques are performed under local anesthesia in a clinic-based procedure room and therefore do not require either an anesthesiologist or a tourniquet. The thread, a thin and flexible metal wire, encircles the structure to be cut via a hollow needle. The needle is first passed under and then, over the structure to be cut, under ultrasound guidance with an accuracy of 0.15 to 0.20 mm, via two small entries and exiting skin puncture sites thereby avoiding a skin incision [7–11, 21]. A special technique is necessary when performing a TTFR procedure because the thread must make a sharp curve around the structure to be cut [8]. This involves passing an additional, smaller needle from the projected exit point towards the initial needle so that the tips meet, and the thread can either be passed through both of them, or the initial needle can be guided out to the exit point by the second needle. The thread technique allows one to confirm first that only structures within the thread loop will be cut thereby minimizing damage to important surrounding structures; it allows one to check before cutting rather than check after cutting. Given these advantages of the ultra-minimally invasive thread transection technique, the specific aim is to investigate its use in performing a decompression of the superficial peroneal nerve in the lower leg without causing injury to adjacent neurovascular structures.

Material and methods

General

The TSPNR procedure was performed on 15 fresh frozen cadaveric lower legs extending from the knee to foot in the Department of Anatomy at the University of Minnesota in Minneapolis, Minnesota. The cadaveric specimens were obtained through the academic institution's anatomy bequest program. All specimens were free from signs of trauma, deformity, or prior surgery. All lower legs were insonated and confirmed to have normal anatomy.

Equipment

A GE Logiq e or Logiq S8 ultrasound machine fitted with a GE L8-18i-D18-MHz compact linear transducer (hockey stick probe) made by General Electronic (Fairfield, Connecticut) was used to perform TSPNR. Other materials included an 18-gauge 6-in. epidural Tuohy needle, a 5-ml syringe filled with 0.9% normal saline for hydrodissection of soft tissues, and a thin metal wire (Loop & Shear™, 0.009 in. in diameter and 18 in. in length; Ridge & Crest Company, Monterey Park, California) comprising the thread, encircling the tissue

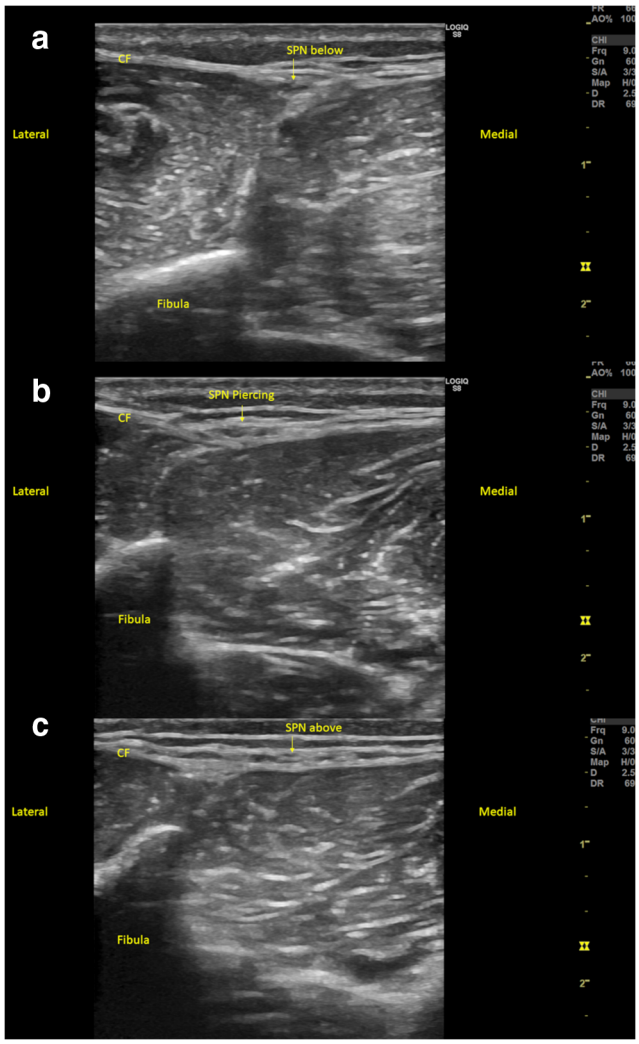

Fig. 1 In image **a**, the superficial peroneal nerve (SPN) is below the crural fascia in the lower limb. Image **b** shows the superficial peroneal nerve as it pierces the crural fascia in a sonographic short-axis view. Image **c** shows the superficial peroneal nerve above the crural fascia in a sonographic short-axis view

targeted to be cut (e.g., crural fascia overlying the superficial peroneal nerve and through which it passes).

Anatomy and surgical procedure

Many anatomical and surgical studies have shown great variability in the course and branching pattern of the SPN [1, 6, 20, 22]. SPN entrapment occurs where the nerve penetrates the crural fascia transitioning from its subfascial location to a more superficial subcutaneous plane [14, 26]. Sonographic imaging can clearly visualize the course of the SPN from the neck of the fibula proximally, where it branches from the common peroneal nerve to the dorsum of the foot distally (Figs. 1 and 2). In this study, the distal margin of the SPN was defined as the point where it penetrated through the crural fascia, and the proximal margin as a point 10 cm proximal [2, 17, 25, 26].

Surgical procedure

The knee, leg, and foot were positioned with the lateral malleolus of the foot and lateral aspect of the knee facing up towards the ceiling. First, skin marks were made along the sonographically visualized course of the SPN (Fig. 3). The line demarcating where transection of the crural fascia was to be performed along the course of the SPN was confirmed sonographically and drawn on the skin surface with a marker. The proximal margin "PM" and the distal margin "DM" of the SPN were also marked on the line demarcating crural transection. DM was marked at the point where the SPN pierced through the crural fascia and PM was marked 10 cm proximal to this point on the crural transection line. We selected a distal to proximal approach for looping the transecting thread around the crural fascia. The distal needle skin entry site "D" and the proximal skin exit site "P" were marked on the transecting line 3 cm distal to DM and 3 cm proximal to PM respectively. The distal to proximal approach is shown in a step-by-step schematic diagram (Fig. 4) and is described in greater detail below.

The entire procedure was guided by real-time sonographic visualization. Initially, a 27-gauge 1.5-in. needle connected to a 5-ml syringe filled with normal saline was inserted through the skin at entry point D and advanced carefully beneath the crural fascia to lie in the space above the SPN. This 27-gauge needle was advanced for approximately 4 cm under sonographic guidance using hydrodissection to separate the soft tissues surrounding the SPN thereby creating additional space for safely inserting a larger and longer needle as described in the next step. An 18-gauge 6-in. epidural Tuohy needle, connected to a 5-ml saline-filled syringe, was prepared as follows. While holding the needle with the distal concave bevel tip facing up, the distal shaft was gently bent to give it a gradual 15° upward curve thereby making it easier to enter the skin and advance along the course of the SPN. Under real-time sonographic guidance, this 18-gauge needle was inserted through the skin and into the subcutaneous tissues at entry point D. The needle tip was carefully advanced more deeply so that before reaching the level of DM, the nerve entrapment point, the needle was deep to the crural fascia and superficial to the SPN (Figs. 5 and 6). After checking and adjusting the needle's correct position and orientation in short axis relative to the SPN, the needle continued to be advanced proximally towards position PM while using gentle hydrodissection to separate any adherent soft tissue surrounding the SPN. Once the 18-gauge needle reached point PM, another 22-gauge needle was inserted at point P and advanced to enter the opening at the tip of the 18-gauge needle using the needle tip-to-tip technique under ultrasound guidance as previously described [8]. The flexible metal thread was then passed through the 22-gauge needle and the 18-gauge needle allowing it to enter and exit the skin while coursing superficial to the SPN and deep to the crural fascia. This procedure was repeated with the 18-gauge needle inserted into the same entry "D" point but was not advanced proximally deep to the crural fascia but instead was advanced proximally in the subcutaneous layer above the crural fascia. This time, the 22-gauge needle inserted in point

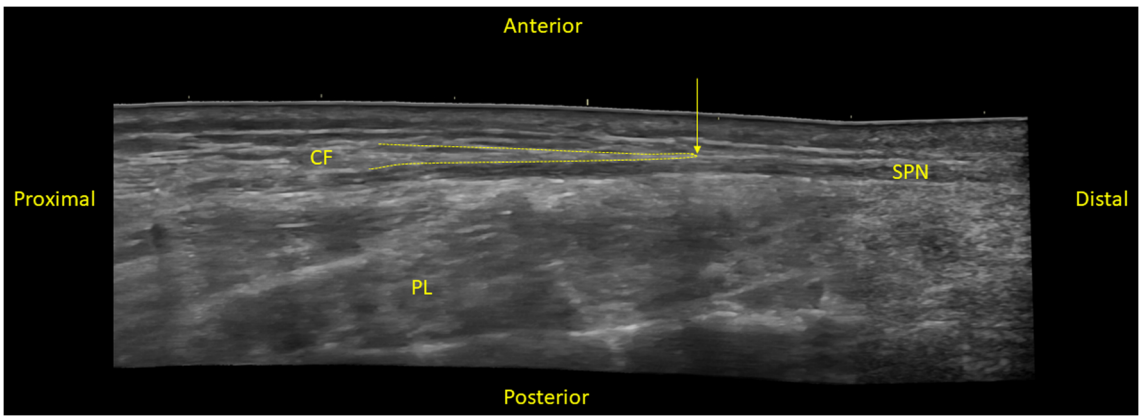

Fig. 2 The crural fascia (CF) is outlined and demonstrates a point at which the superficial peroneal nerve (SPN) pierces the fascia overlying the peroneus longus muscle (PL)

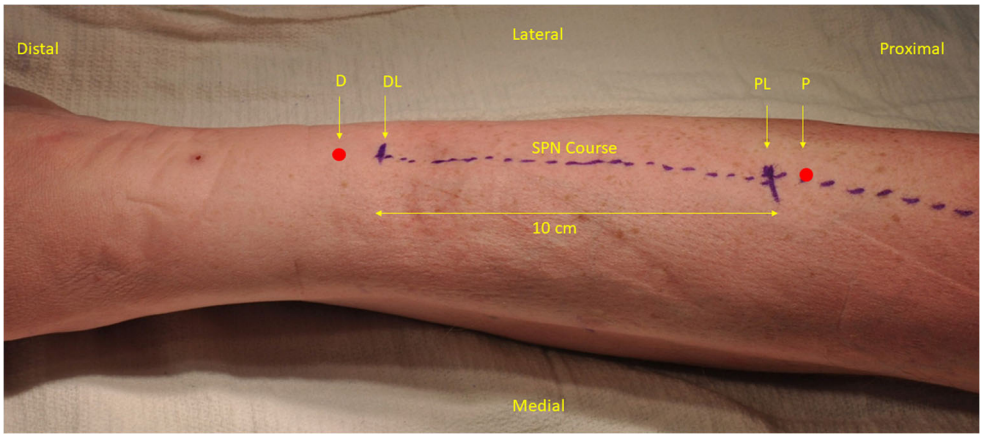

Fig. 3 The gross anatomic image shows the outlines the course of the superficial peroneal nerve, the entry point (P), the proximal margin/limit (PL or PM), the distal limit/margin (DL or DM), and the exit point (D). The length from PL to DL is approximately 10 cm

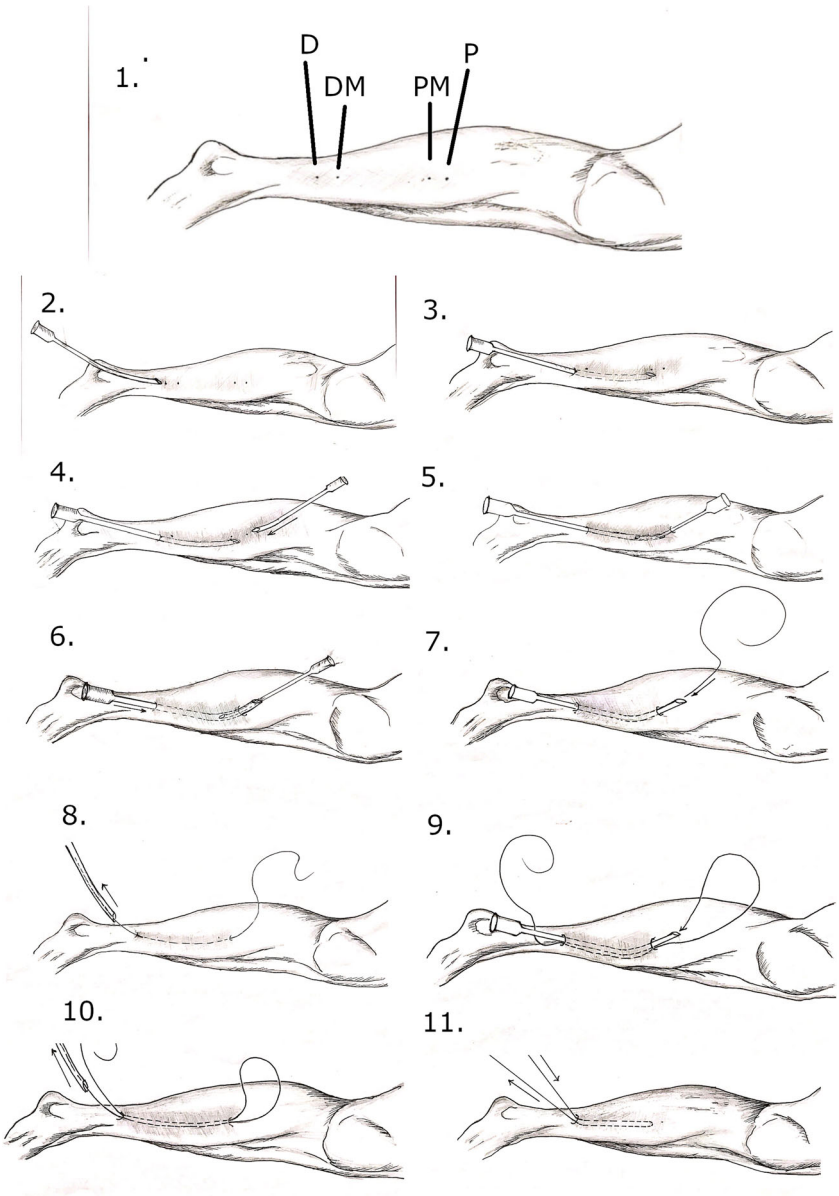

Fig. 4 The 11 steps involved in performing the thread superficial peroneal nerve release is demonstrated along with the entry point (P), exit point (D), proximal margin (PM), and distal margin (DM)

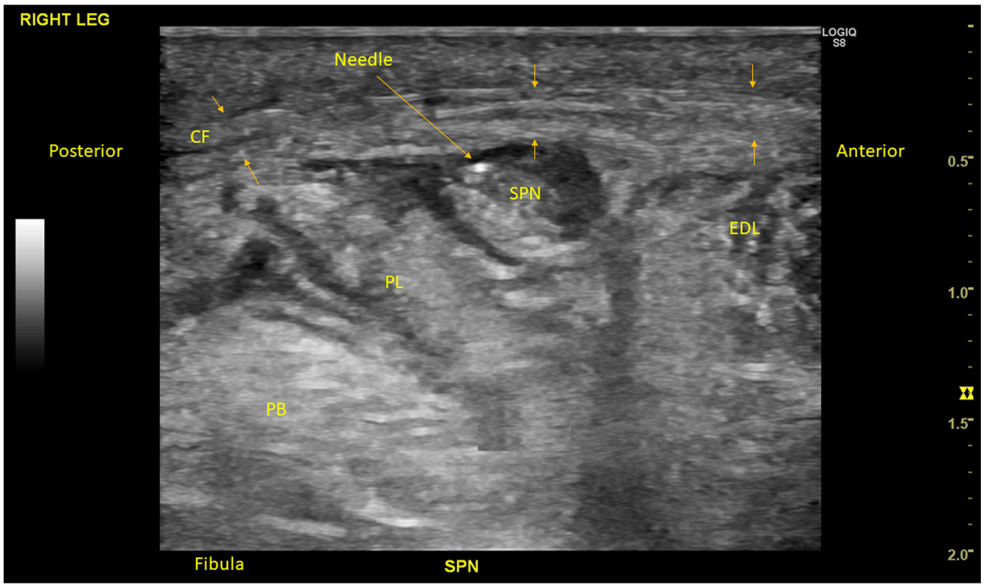

Fig. 5 The short arrows demarcate the crural fascia (CF) while the long arrow identifies the needle which overlies the superficial peroneal nerve (SPN) being hydrodissected. Anterior and medial to the SPN is the extensor digitorum longus (EDL). Posterior and lateral to the SPN is the peroneus longus (PL) and peroneus brevis (PB)

P was used to actually guide the 18-gauge needle directly out of the skin. The proximal end of the thread was then fed directly through the distal tip of the 18-gauge needle and exited at point D. The 18-gauge needle was then withdrawn resulting in a loop of thread around the crural fascia and superficial to the SPN with both ends of the thread now exiting through the distal skin puncture site at D.

Sonographic visualization confirmed the location and course of the looped thread. Using a doppler mode of the ultrasound can confirm that no artery and/or vein is within the inside of the loop. The crural fascia was manually transected by a reciprocating "to and fro" motion of the thread until the thread could be gently pulled out through the skin's D site.

Results

All of the legs were carefully dissected and visually inspected immediately after the thread procedure. The degree and extent of transection of the crural fascia, soft tissue adhesions around the SPN, possible neurovascular injuries, and peroneus longus and peroneus brevis damage were all visualized and evaluated.

All 13 of the fresh frozen lower-extremity specimens demonstrated a complete transection of the crural fascia with full decompression of the SPN (Fig. 7). There were no associated injuries to the neurovascular bundle. There was no obvious damage to the peroneus longus muscle at the PM region.

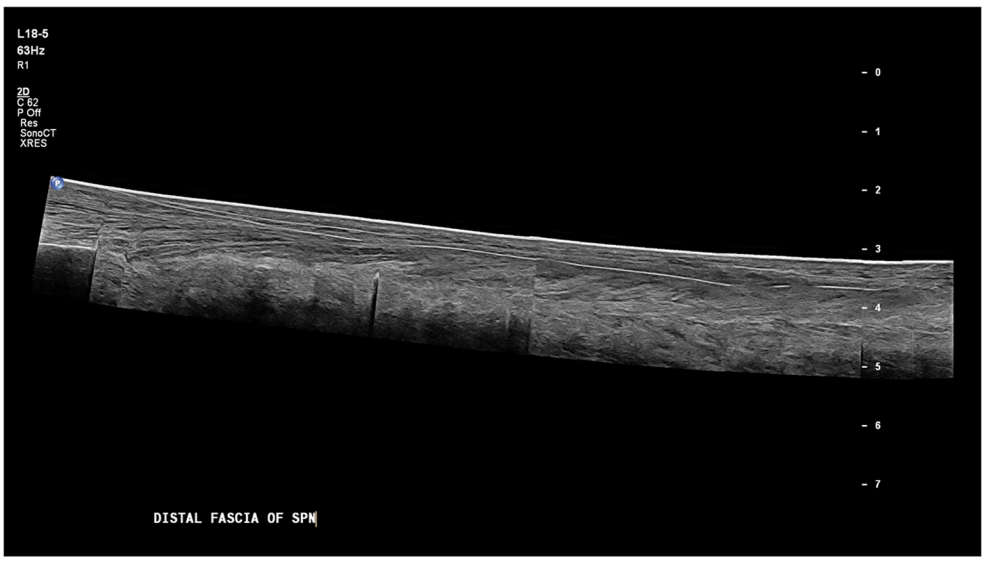

Fig. 6 The panoramic view sonographically demonstrates the entire looping of the crural fascia

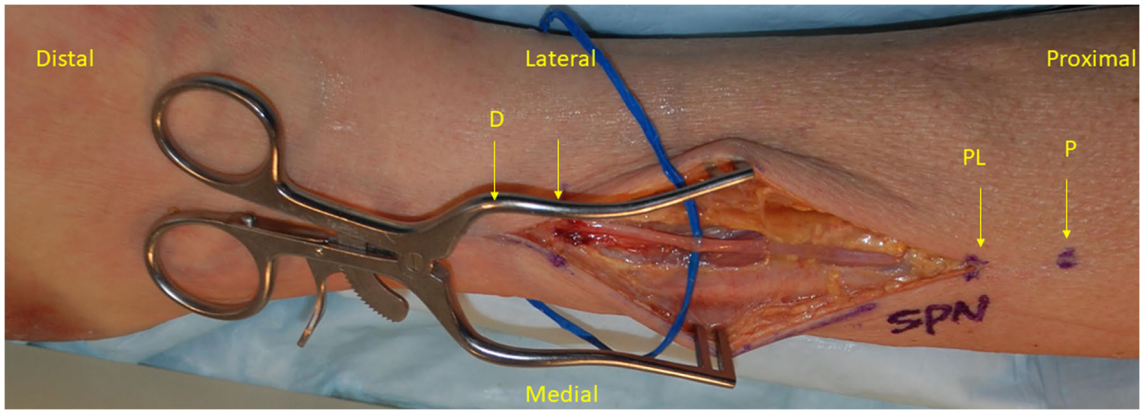

Fig. 7 Gross anatomic inspection of the superficial nerve demonstrates complete transection of the crural fascia from the proximal margin (PM) to distal margin (DPM) using the needle entry (P) and exit points (D). The DM is also the point at which the superficial peroneal nerve pierces the crural fascia and continues superficial to the fascia

Discussion

This surgical cadaveric study demonstrated complete decompression of the SPN. We observed complete transection of the crural fascia around the region of the SPN as it penetrated the crural fascia accompanied by hydrodissection of the SPN separating it from the surrounding soft tissues. There were no significant iatrogenic injuries of the neurovascular bundle. The success of this technique is a result of using high-resolution sonography to visualize important key anatomical structures such as the SPN as the thread is carefully looped around the targeted segment of crural fascia to be cut. Hydrodissection while advancing the needle allows for separation of soft tissue adhesions involving the SPN especially where it penetrates the crural fascia. It is important to note that when performed on patients, bleeding from small vessels is anticipated and post-release compression may be required to tamponade and limit the risk of hematoma formation. This postoperative management has experienced excellent results when performing the thread carpal tunnel release [9].

The control and accuracy of the Guo technique (0.15 to 0.20 mm) was shown in the previous study of thread carpal tunnel release [11]. This level of precision is necessary to avoid iatrogenic injuries to important neurovascular structures when performing TSPNR. Confirming that the SPN has been fully decompressed where it traverses the crural fascia is especially important for producing symptom relief.

There are several challenges and disadvantages in performing conventional open surgery for SPN entrapment. One difficulty is determining the intraoperative location of the SPN [4]. The anatomy of the SPN is quite variable [22]. High-definition sonography can clearly identify the course of the SPN as well as its branching pattern from where it arises proximally from the common peroneal nerve just distal to the fibular head all the way distally to the dorsum of the foot. The anatomical variants of both the SPN and surrounding blood vessels may be recognized before starting the procedure thereby decreasing the risks of iatrogenic injury. Another disadvantage of open surgery is that it involves making a long surgical skin incision over a length of 15 to 20 cm, as well as an extensive anatomical exposure to find the SPN. This additional surgical trauma may lead to excess scar formation that increases the risk of adhesions forming postoperatively around the SPN. Scar formation may not only increase the risk of persistent and/or new pain but also increase the risk of developing recurrent SPN entrapment. It is likely that minimizing surgical trauma and the need for a skin incision may accelerate the process of recovery resulting in earlier resumption of routine daily activities as well as an earlier return to work. It also seems reasonable that by only creating two needle puncture sites in the skin and avoiding a long skin incision, the TSPNR may reduce the risk of infection as well as preserve skin and subcutaneous sensory nerves thereby reducing pain, tenderness, and numbness in addition to reducing the recovery time.

The results in performing open surgical release of the SPN by fasciectomy have been reported [3, 5, 15, 24, 25]. In all of these studies, a tourniquet was used during surgery which potentially may increase the risk of developing a complex regional pain syndrome. In addition, conventional open surgeries were performed under general or regional anesthesia with relatively prolonged operative times and had to be performed in an operative room. TSPNR uses local anesthesia without tourniquet and is performed in an office-based procedure room [7, 9–11, 21]. Future studies should evaluate the economic implications and postoperative complications of the TSPNR compared with the conventional open surgical release procedure.

The differential diagnosis for superficial peroneal nerve entrapment neuropathy includes lumbar radiculopathy, pseudoradicular pain syndrome [24, 25], nerve sheath tumors, anatomical defects resulting from prior trauma, and chronic or exertional lateral compartment syndrome [5, 13, 16]. Ultrasound can help confirm the diagnosis before surgery.

Practitioners of the TSPNR procedure should have a good working knowledge of sonographic anatomy as well as the

ability to manipulate needles under ultrasound guidance. We strongly recommend that providers participate in an educational course on ultrasound if they do not routinely use ultrasound in their practice.

Conclusion

This cadaveric validation study demonstrated that the TSPNR method can completely and safely decompress the SPN by transecting the crural fascia without causing iatrogenic neurovascular injury in cadavers. Additional studies that further confirm the accuracy, reliability, feasibility, and safety of this new ultra-minimally invasive procedure will hopefully allow it to enter clinical practice and improvepatient care.

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Compliance with ethical standards

Conflict of interest Two of the authors, Danzhu Guo and Danqing Guo, are brothers to Joseph Guo who is the inventor of the Loop & Sheer thread. All other authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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 and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Balius R, Bong DA, Ardèvol J, Pedret C, Codina D, Dalmau A (2016) Ultrasound-guided fasciotomy for anterior chronic exertional compartment syndrome of the leg. J Ultrasound Med Off J Am Inst Ultrasound Med 35(4):823–829
2. Ducic I, Dellon AL, Graw KS (2006) The clinical importance of variations in the surgical anatomy of the superficial peroneal nerve in the mid-third of the lateral leg. Ann Plast Surg 56(6):635–638
3. de Fijter WM, Scheltinga MR, Luiting MG (2006) Minimally invasive fasciotomy in chronic exertional compartment syndrome and fascial hernias of the anterior lower leg: short- and long-term results. Mil Med 171(5):399–403
4. Franco MJ, Phillips BZ, Lalchandani GR, Mackinnon SE (2017) Decompression of the superficial peroneal nerve: clinical outcomes and anatomical study. J Neurosurg 126(1):330–335
5. Garfin S, Mubarak SJ, Owen CA (1977) Exertional anterolateral-compartment syndrome. Case report with fascial defect, muscle herniation, and superficial peroneal-nerve entrapment. J Bone Joint Surg Am 59(3):404–405
6. Grant TH, Omar IM, Dumanian GA, Pomeranz CB, Lewis VA (2015) Sonographic evaluation of common peroneal neuropathy in patients with foot drop. J Ultrasound Med Off J Am Inst Ultrasound Med 34(4):705–711
7. Guo D, Guo D, Guo J, Malone DG, Wei N, McCool LC (2016) A cadaveric study for the improvement of thread carpal tunnel release. J Hand Surg 41(10):e351–e357
8. Guo D, Guo D, Guo J, McCool LC, Tonkin B (2018) A cadaveric study of the thread trigger finger release: the first annular pulley transection through thread transecting technique. Hand 13(2):170–175
9. Guo D, Guo D, Guo J, Schmidt SC, Lytie RM (2017) A clinical study of the modified thread carpal tunnel release. Hand 12(5):453–460
10. Guo D, McCool L, Senk A, Tonkin B, Guo J, Lytie RM, Guo D (2018) Minimally invasive thread trigger digit release: a preliminary report on 34 digits of the adult hands. J Hand Surg Eur 43(9):942–947
11. Guo D, Tang Y, Ji Y, Sun T, Guo J, Guo D (2015) A non-scalpel technique for minimally invasive surgery: percutaneously looped thread transection of the transverse carpal ligament. Hand (New York, NY) 10(1):40–48
12. Henry AK (1973) Extensile exposure, Second edn. Churchill Livingstone
13. Kopell H, Thompson W (1963) Entrapment neuropathies. Williams & Wilkins, Baltimore, Maryland
14. KOPELL HP, THOMPSON WA (1960) Peripheral entrapment neuropathies of the lower extremity. N Engl J Med 262:56–60
15. Macaré van Maurik JFM, ter Horst B, van Hal M, Kon M, Peters EJG (2015) Effect of surgical decompression of nerves in the lower extremity in patients with painful diabetic polyneuropathy on stability: a randomized controlled trial. Clin Rehabil 29(10):994–1001
16. Mackey D, Colbert DS, Chater EH (1977) Musculo-cutaneous nerve entrapment. Ir J Med Sci 146(4):100–102
17. Mackinnon SE (2018) Superficial peroneal nerve release in the lower leg - extended. In: WUSTL learn surg. https://www.youtube.com/watch?v=OGBWww538oY
18. Malavolta M, Malavolta L (2007) Surgery for superficial peroneal nerve entrapment syndrome. Oper Orthop Traumatol 19(5–6):502–510
19. Marques Mansano A, Trescot A (2016) The role of peripheral nerve injections in the diagnosis and treatment of CRPS. Phys Med Rehabil Res. https://doi.org/10.15761/PMRR.1000121
20. Peer S, Kovacs P, Harpf C, Bodner G (2002) High-resolution sonography of lower extremity peripheral nerves: anatomic correlation and spectrum of disease. J ultrasound Med Off J Am Inst Ultrasound Med 21(3):315–322
21. Ray WZ, Mahan MA, Guo D, Guo D, Kliot M (2017) An update on addressing important peripheral nerve problems: challenges and potential solutions. Acta Neurochir 159(9):1765–1773
22. Rosson GD, Dellon AL (2005) Superficial peroneal nerve anatomic variability changes surgical technique. Clin Orthop (438):248–252
23. Saragaglia D, Farizon F, Drevet JG, Butel J (1986) Peroneal nerve entrapment syndrome of the front of the foot. Treatment by neurolysis. Apropos of a bilateral case. Rev Chir Orthop Reparatrice Appar Mot 72(8):579–581
24. Styf JR, Körner LM (1986) Chronic anterior-compartment syndrome of the leg. Results of treatment by fasciotomy. J Bone Joint Surg Am 68(9):1338–1347
25. Styf J, Morberg P (1997) The superficial peroneal tunnel syndrome: results of treatment by Descompression. J Bone Jt Surg 79-B(5):801–803
26. Yang LJS, Gala VC, McGillicuddy JE (2006) Superficial peroneal nerve syndrome: an unusual nerve entrapment. J Neurosurg 104(5):820–823