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CASE REPORT

A Split Above: Case Report on High Bifurcation of the Tibial Nerve

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Abstract

The tibial nerve, one of the terminal branches of the sciatic nerve, is a mixed nerve that provides motor innervation to the posterior leg and most intrinsic foot muscles, and cutaneous innervation to the plantar surface of the foot. Here we report a case of an 84-year-old female donor with a tibial nerve bifurcation more proximal to the medial malleolar-calcaneal axis than, to our knowledge, has ever been reported before in the literature. Routine donor dissection conducted at the University of Maryland Eastern Shore Department of Physical Therapy found that the tibial nerve divided into medial and lateral plantar nerves deep to the soleus muscle in the posterior compartment of the leg. The medial malleolar-calcaneal axis was used as a reference line for measurements, spanning from the medial malleolus to the medial calcaneal tubercle. Measurements were taken with a Kynup digital caliper, and the split was found to occur 158.06 mm proximal to the medial malleolar-calcaneal axis. Understanding the extent of neurovascular variation in the medial ankle is critical as this region is commonly targeted in medical interventions such as a nerve block or pin and plate placement for fracture fixation. Here we expand the current knowledge of anatomical variation possible in the lower extremity, highlighting the need for imaging during patient-specific medical interventions.

Key Words: *Cadaveric study; Donor study; Nervous system malformation; Tibial nerve; Tarsal tunnel; Anatomical variation*

Introduction

The tibial nerve (TN) is one of the terminal branches of the sciatic nerve, the other being the common fibular nerve. TN travels between the superficial and deep compartments of the posterior leg, deep to the gastrocnemius and soleus muscles. This nerve is a mixed nerve that provides both sensory innervation to the plantar surface of the heel and motor innervation for both superficial and deep compartments of the leg. The terminal branches of TN, medial plantar nerve (MPN) and lateral plantar nerve (LPN), provide motor and sensory innervation to the foot and ankle. Typically, the TN bifurcates within the tarsal tunnel deep to the flexor retinaculum, located posteroinferior to the medial malleolus. The tarsal tunnel is also a

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conduit for the tendons of muscles located in the deep compartment of the leg. From the medial malleolus moving posteroinferiorly, the order of structures found deep to the flexor retinaculum are tibialis posterior tendon, flexor digitorum longus tendon, Posterior Tibial Artery (PTA) and/or its terminal branches, TN, and flexor hallucis longus tendon [1].

While bifurcation of the TN into its terminal branches proximal to the tarsal tunnel has been seen during donor dissection, a division beyond 14.3 cm from the Medial Malleolar-Calcaneal Axis (MMCA) has, to our knowledge, never been reported before in the literature. The highest recorded split in the literature was documented by Bareither et al. [2], who described a division at 14.3 cm proximal to the tip of the medial malleolus. The next farthest proximal division recorded in the literature was reported by Davis and Schon [3] at 9 cm proximal to the MMCA. Dellon and Mackinnon [4] described one donor with proximal bifurcations bilaterally, at 3 cm and 5 cm proximal to the MMCA. The present case report describes a TN division farther from the MMCA than the authors have found in previously recorded literature. Documentation of anatomical variations is important to inform surgeons of possible variations that can have a major impact on orthopedic procedures, such as plate and pin placement, nerve blocks, and tarsal tunnel release surgeries. Identifying these variations is vital for the proper diagnosis and management of health disorders. This is because anatomy represents the geography of sound medical and surgical practices [5].

Materials and Methods

Donor specimens, embalmed with a phenol, methanol, and glycerin solution, were dissected as part of a Gross Anatomy Pre-Matriculation Preparation Workshop at the University of Maryland Eastern Shore (UMES). Donors for this program were acquired from the Maryland State Anatomy Board. This study was approved by the UMES Institutional Review Board (UMES Protocol #08-2025-006) and the authors state that every effort was made to follow all state and federal regulations in regard to the use of donor specimens for anatomical research. Procedures for lower limb dissection are described in Grants Dissector 17th edition [6]. Graduate students dissected the variant TN with direct assistance from the anatomy lab supervisor, an expert anatomist and dissector. The TN was found to split abnormally proximal in the leg, deep to the soleus muscle. Later, to assess bilateral occurrence, the right leg was dissected by the lead investigator of this study.

To quantify the location of the TN bifurcation, the reference axis and tarsal tunnel definition were adopted from Dellon and Mackinnon [4]. They describe the MMCA as a reference line from the tip of the medial malleolus to the medial calcaneal tubercle. To improve accuracy and reproducibility of measurements, here we used a more specific definition of each bony landmark. A T-pin was placed at the most medial projection of the medial malleolus, and another was placed at the most medial projection on the plantar surface of the medial calcaneal tuberosity. The tarsal tunnel is defined as spanning 2 cm proximal and distal to the MMCA, totaling 4 cm wide, and representing the area under the flexor retinaculum [4]. These landmarks and reference areas are widely accepted in the literature [3,7-9]. Once the T-pins were inserted in the bony landmarks, a cotton string was used to create the reference line. The TN was placed in anatomical position, and the apex of the TN bifurcation was marked with a third T-pin (Figure 1). A Kynup digital caliper was used to take measurements along the path of the nerve, from the axis to the bifurcation. The measurement range of the Kynup digital caliper is 0-6 in / 0-150 mm;

accuracy to ± 0.001 in / 0.02 mm and resolution to 0.0005 in / 0.01 mm. Intraclass correlation coefficient (ICC) data were obtained in a pilot study by measuring 10 limbs from five donors to ensure investigator reliability. Both test-retest and interrater reliability were >0.9 with a standard error of measure (SEM) of 3.3 mm for the lead investigator. Based on the SEM, an acceptable margin of error between the two trials was 3.5 mm. If within this margin of error, the two trials were then averaged to arrive at the final measurement. If the difference was over 3.5 mm, a third trial was recorded, and the two closest measurements were retained and averaged for the final measurement.

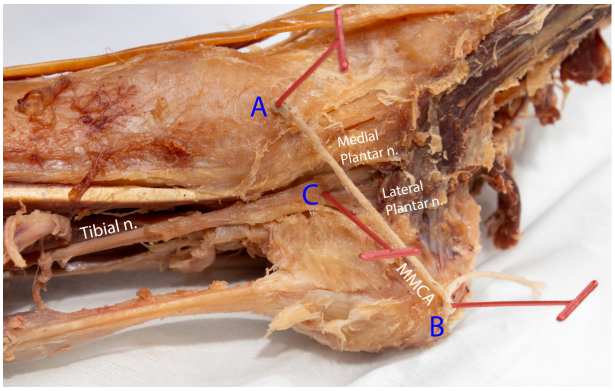

Figure 1) *Medial view of a left ankle, dissected to expose tibial nerve (TN) and bifurcation. T-pins are placed at the most medial projection of the medial malleolus (A), the most medial projection on the plantar surface of the medial calcaneal tuberosity (B), and at the TN bifurcation into medial and lateral plantar nerves (C). A cotton string is used to create the medial malleolar-calcaneal axis (MMCA) reference line between pins A and B. Measurements are taken from the MMCA to T-pin C, in line with the path of the TN.*

Results

Upon measurement of the TN bifurcation of the right leg, the division was found to occur 158.06 mm (15.81 cm) proximal to the MMCA (Figure 2). To assess the presence of bilateral variation, the left leg was dissected and the left TN was found to bifurcate 97.88 mm (9.79 cm) proximal to the MMCA.

Figure 2) *Medial view of the right ankle and lower leg with anomaly, dissected to expose TN and bifurcation. T-pin placement and measurement as described in Figure 1. TN division occurs 158.06 mm (15.81 cm) proximal to the medial malleolar-calcaneal axis (MMCA).*

Discussion

TN branching has been studied in donors since the early 1900s. Thomas Horwitz [10] in 1938, while describing surgical approaches for peripheral nerves, described the ability of the TN to bifurcate into its two terminal branches MPN and LPN, or trifurcate into MPN, LPN, and medial calcaneal nerve (MCN). Analysis of TN variations have been conducted alongside studies into MCN and PTA variability [3,11]. Studies into the variability of structures located in the medial ankle remain a topic for continued research due to the potential for iatrogenic injury to these structures during orthopedic procedures, such as tarsal tunnel release surgeries, pin and plate placements, and nerve blocks. Damage to the TN could result in paresthesia and paresis as its innervation includes muscles responsible for gait and foot mechanics, as well as sensation of the plantar foot.

Previous studies have recorded bifurcations of the TN proximal to the tarsal tunnel, within the tarsal tunnel, and distal to the tarsal tunnel [3,4,8,9,12]. While divisions can be found outside of the tarsal tunnel, these are not common as the majority of divisions occur within this space. A study by Dellon and Mackinnon [4] found the TN divided within the tarsal tunnel in 95% of donors, with 5% splitting proximal to the tunnel. Torres and Ferreira [8] found 88% of TNs in their study split within the tarsal tunnel and 12% divided proximal to the tunnel. A more recent study by D. Malar [13] in 2016

found a 100% occurrence of TN division within the tarsal tunnel. Bifurcation distal to the tarsal tunnel is the most uncommon site reported in the literature with the majority of studies failing to identify any bifurcations distal to the tunnel. Across three separate studies that evaluated a combined 196 limbs, the authors found five occurrences of bifurcation distal to the tarsal tunnel [12,14,15]. Rarer still are proximal divisions recorded beyond 100 mm from the MMCA, with one occurrence reported by Bareither et al. [2] and one in our current study.

The farthest distances recorded from the MMCA have been in a proximal direction. Dellon and Mackinnon [4] observed one individual with MCN splits located 50 mm and 30 mm proximal to the MMCA. Davis and Schon [3] reported the highest bifurcations in their sample as 50 mm and 90 mm proximal to the MMCA, and Torres and Ferreira [8] found several high bifurcations in their sample (at 22.31 mm, 24.71 mm, 27 mm, 53 mm, and 53.3 mm proximal to the MMCA). Previously, the highest reported bifurcation in the literature was found by Bareither et al. [2] at a distance of 143 mm proximal to the tip of the medial malleolus. The current case report recorded the TN division distance from the MMCA as 158.06 mm. After bilateral dissection, the contralateral limb was also found to have a high bifurcation, measured at 97.88 mm above the MMCA. This is a novel variant and the first documented in over 100 years of literature studying TN.

Due to the possibility of variations in the TN and medial ankle neurovasculature, surgeons and anesthesiologists should use extra precautions when planning surgical procedures to ensure proper patient care and to decrease the risk of iatrogenic injury. Historically, techniques for TN blocks have included using surface landmarks like the medial malleolus and calcaneal (Achilles) tendon to guide needle placement [16]. In a study performed by Redborg et al. [17], the historic landmark-based technique was compared against an ultrasound-guided technique for TN nerve blocks. The ultrasound allowed for the TN to be visualized while administering local anesthetic around the nerve. The results showed that while the ultrasound-guided technique required more time, it was more successful and showed significant improvement in efficacy over the landmark-based technique.

Additionally, orthopedic operations requiring fixation of bones in the distal segment of the tibia and in the calcaneus should take into consideration the possibility of TN bifurcation variation. Several sources list safe zones or corridors for pin fixation in the lower extremity to avoid neurological structures, but variation in recommendations are present. Bilge et al. [7] and Ramadoss and Nanjundaiah [18] present recommendations for a safe zone that vary 5-11 mm between studies. In contrast, Ramadoss and Nanjundaiah [18] referenced a 2006 study by Joshi et al., which concluded that there is no anatomically safe zone along the MMCA for blind pin insertion during calcaneal external fixation.

Conclusion

This case report describes a TN bifurcation over 150 mm proximal to the MMCA. Variation in TN bifurcation is important to report as it can have major impacts on orthopedic procedures, such as pin fixations and nerve blocks for surgery or pain relief. This case report demonstrates the need for imaging prior to surgical intervention of this region due to the possibility for significant anatomical variation.

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