Deep Peroneal Nerve: Orientation and Branching at the Ankle and Proximal Part of the Foot

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ABSTRACT

Objective: This study investigated the frequency and types of 1) orientation of the deep peroneal nerve (DPN) and its branches relative to the dorsalis pedis artery (DPA) and the extensor hallucis longus tendon (EHLT) and 2) branching site and pattern of DPN at the distal area of leg and the proximal zone of the foot.

Materials and Methods: One-hundred and sixty specimens from the lower extremities of 80 formalin-embalmed cadavers were investigated for anatomical position, orientation and the branching pattern of DPN by manual dissection, starting from the anterior side of lower extremity just proximal to ankle joint down to the area distal to inferior extensor retinaculum.

Results: The most prevalent medial-to-lateral orientation of structures in the area anterior to ankle joints was the EHLT/DPA/DPN. Comparing DPA with the branching of DPN in the areas inside anterior tarsal tunnel (ATT) and distal to ATT, the most common type was an orientation of DPA that was lateral to both the DPN main trunk and its medial terminal branch. Regarding branching sites and patterns of DPN in the intermalleolar and ATT areas, nearly half of the studied specimens had DPN bifurcation at the intermalleolar level and more than half of the bifurcations were inside the ATT.

Conclusion: This study establishes novel data regarding type variation and prevalence of DPN in areas of ankle and proximal part of foot in the Thai population which could be helpful in clinical practice.

Keywords: Deep peroneal nerve; inferior extensor retinaculum; anterior tarsal tunnel; dorsalis pedis artery; extensor hallucis longus tendon (Siriraj Med J 2022; 74: 440-447)

INTRODUCTION

The deep peroneal nerve (DPN) is composed of both sensory and motor components that innervate certain regions of the lower extremity.[1] At the neck of fibula, DPN branches from the common peroneal nerve, which is one division of the sciatic nerve, and distally terminates as dorsal digital nerves (cutaneous nerves) at the first interdigital cleft of the dorsum of foot. While passing through the anterior compartment of the leg, DPN provides muscular branches and runs downward along the anterior tibial vessels laterally. At the distal part of the leg, DPN runs superficially in companion with the dorsalis pedis artery (DPA, the artery continuing from the anterior tibial artery) and the extensor hallucis

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longus tendon (EHLT). Before passing the dorsum of the foot, the course of DPN is beneath both the superior and inferior extensor retinacula (IER) and is part of the anterior tarsal tunnel (ATT, the roof of which is the IER). After running over the talus bone, DPN bifurcates into the medial terminal branch (MTB) and lateral terminal branch (LTB). The MTB and LTB then accompany the DPA and the lateral tarsal artery, respectively.[2]

Typically, DPN and MTB are located laterally to the DPA. However, variations in DPN orientation and branching have been reported and this reveals their inconsistency.[3,4] These variations mostly concern certain surgical approaches in the leg and foot areas involved with the courses of DPN and also structures supplied by DPN, e.g. ankle arthroscopy, ultrasound-guided DPN block and neurovascular flap surgery. The aim of this study was to investigate 1) the types and frequencies of orientation of DPN and its branches (MTB and LTB) relative to its neighboring structures (DPA and EHLT) and 2) the types and frequencies of the branching site and pattern of DPN at the distal area of the leg and the proximal zone of foot. These findings play a crucial role in providing safety information for surgeons and anesthetists to ensure high accuracy and effectiveness of clinical practice with DPN and to reduce the risk of nearby structures.

MATERIALS AND METHODS

This study was conducted in 80 formalin-embalmed cadavers donated to the Department of Anatomy, Faculty of Medicine Siriraj Hospital, Mahidol University, Thailand for academic and research purposes. This research project was approved by the Siriraj Institutional Review Board (Si 186/2020). One-hundred and sixty specimens of lower extremities were investigated for anatomical position, orientation and branching pattern of DPN by manual dissection starting from the area of anterior side of lower extremity just proximal to ankle joint down to the area distal to IER. The dissected zone was horizontally enlarged to adequately visualize the related anatomical information. Results from the right-sided and left-sided specimens were compared for correlation.

RESULTS

Each Thai cadaver was studied for orientation of DPN, DPA and EHLT in the areas anterior to both ankles. Branching of DPN to MTB and LTB and their courses were also compared with orientation of DPA. The DPN branching site was identified to determine its location in relation to an imaginary line, connecting medial and lateral malleoli, and ATT. The demographic data of 80 cadavers were as follows: age range = 36-104 (mean = 73.6; SD = 14.4) and gender (male/female = 44/36).

Numbers and percentages of the medial-to-lateral orientation of DPN, DPA and EHLT in the area anterior to the ankle joint are summarized in Table 1. All six possible types of orientations were identified in this study. Type O1 (EHLT/DPA/DPN) was the most common and type O4 (DPA/EHLT/DPN) was the least prevalent. Examples of the common types are shown in Fig 1. The course of the DPA was investigated by comparing the branching of DPN to MTB and LTB in areas inside the ATT and distal to ATT (Table 2). The most common type was the orientation of DPA lateral to both DPN main trunk and MTB (type A4). This type was identified in nearly 40% of the studied specimens. Moreover, complex orientation of DPA and DPN as multiple crossings over each other (type A5) was low in prevalence at about 3.1%. However, one specimen was identified as having no MTB and thus, DPA was found to be medial to LTB below ATT (type A6). Three most-common types of orientation are shown in Fig 2.

Branching sites and patterns of DPN were studied in the intermalleolar and ATT areas (Table 3). Almost half of the studied specimens had bifurcation of DPN at the same vertical level as the intermalleolar line (type L2), while the majority of the remaining specimens had bifurcation distal to this line (type L3). Being relative to IER, more than half of DPN bifurcations were localized inside the ATT (type R2) whereas the bifurcations distal to the ATT (type R3) were the least identified. However, 1.3% of the studied specimens had multiple DPN branching (type M) and 0.6% of the studied specimens had no DPN branching (type N). The most and the least prevalent types of DPN bifurcation sites are demonstrated in Figs 3A-3D and multiple branching of DPN visualized in Fig 3E.

Correlations between results from right-sided and the left-sided specimens in this study were similar among different investigated parameters. The percentages of side correlation in the DPN, DPA and EHLT orientations were slightly higher than the orientation between DPA and DPN trunks and branches.

DISCUSSION

As this study focused on the DPN at the lower area of the leg, near the proximal part of the foot, the orientation of the DPN main trunk together with its companions anterior to the ankle was examined first (Table 1). The classic medial-to-lateral orientation of EHLT/DPA/DPN (type O1) was found in about half of all observations. The second-most prevalent type was the EHLT/DPN/

TABLE 1. Numbers and percentages of types of medial-to-lateral orientation of DPN (*N*), DPA (*A*) and EHLT (*T*) at the area anterior to ankle joint.

	Type O1: *T-A-N*	Type O2: *T-N-A*	Type O3: *A-N-T*	Type O4: *A-T-N*	Type O5: *N-A-T*	Type O6: *N-T-A*	Side correlation
No. of specimens detected (percentage)	81 (50.6)	61 (38.1)	6 (3.8)	2 (1.3)	5 (3.1)	5 (3.1)	48 cadavers (60)

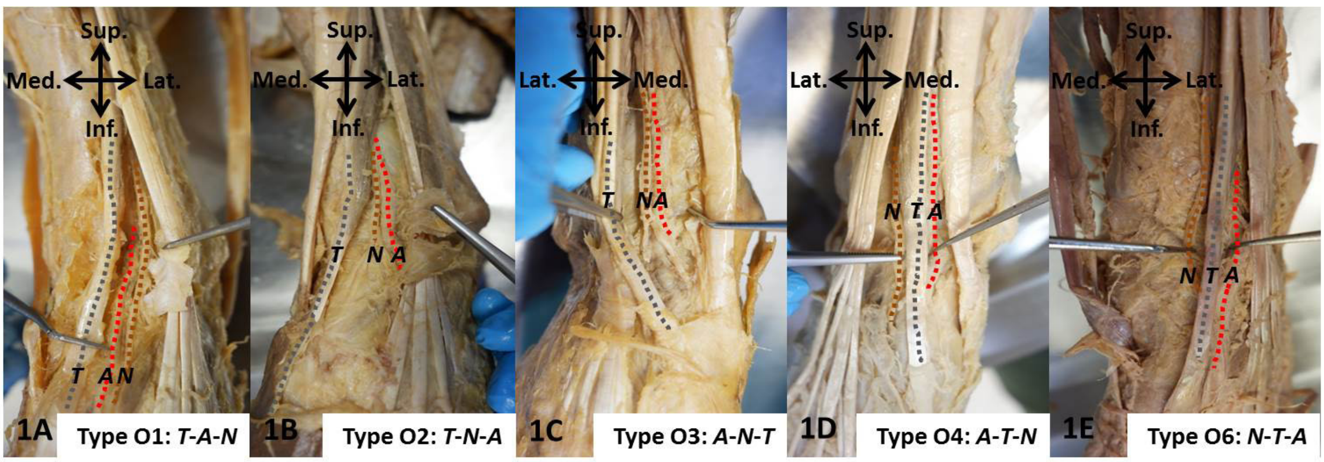

Fig 1. Examples of common types of medial-to-lateral orientation of DPN (*N*, brown dashed line), DPA (*A*, red dashed line) and EHLT (*T*, gray dashed line) at the area anterior to ankle joint.

TABLE 2. Course of DPA compared with the branching of DPN to MTB and LTB in the areas of ATT and distal to ATT.

	Type A1: DPA was medial to DPN in ATT and medial to MTB of DPN below ATT	Type A2: DPA was medial to DPN in ATT and lateral to MTB of DPN below ATT	Type A3: DPA was lateral to DPN in ATT and medial to MTB of DPN below ATT	Type A4: DPA was lateral to DPN in ATT and lateral to MTB of DPN below ATT	Type A5: DPN and DPA crossed over each other at multiple levels	Type A6: No MTB of DPN, DPA was medial to LTB of DPN below ATT	Side correlation
No. of specimens detected (percentage)	38 (23.8)	40 (25)	16 (10)	60 (37.5)	5 (3.1)	1 (0.6)	46 cadavers (57.5)

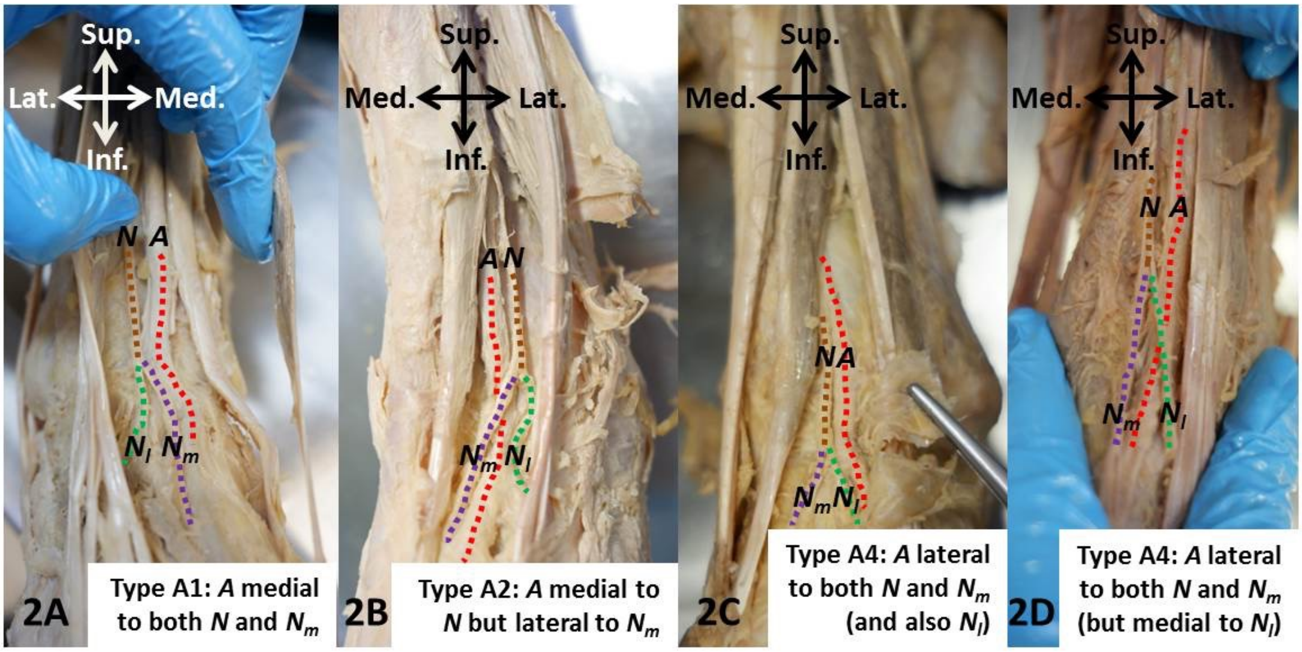

Fig 2. The three most-common types of the course of DPA compared with the branching of DPN to MTB and LTB in ATT and areas distal to ATT. (*N*, brown dashed line = DPN main trunk; *A*, red dashed line = DPA; *Nm*, purple dashed line = MTB; *Nl*, green dashed line = LTB)

TABLE 3. Branching sites and patterns of DPN in the intermalleolar and ATT areas.

	Presence of bifurcation to MTB and LTB						Type M: Presence of multiple branching of DPN	Type N: Absence of branching
	Compared with imaginary line connecting medial and lateral malleoli			Compared with IER (or ATT)				
	Type L1:	Type L2:	Type L3:	Type R1:	Type R2:	Type R3:		
	Proximal to imaginary line	Midway between medial and lateral malleoli	Distal to imaginary line	Proximal to IER (above ATT)	Posterior to IER (in ATT)	Distal to IER (below ATT)		
No. of specimens detected (percentage)	17 (12.4)	65 (47.4)	55 (40.2)	45 (36.6)	69 (56.1)	9 (7.3)	2 (1.3)	1 (0.6)

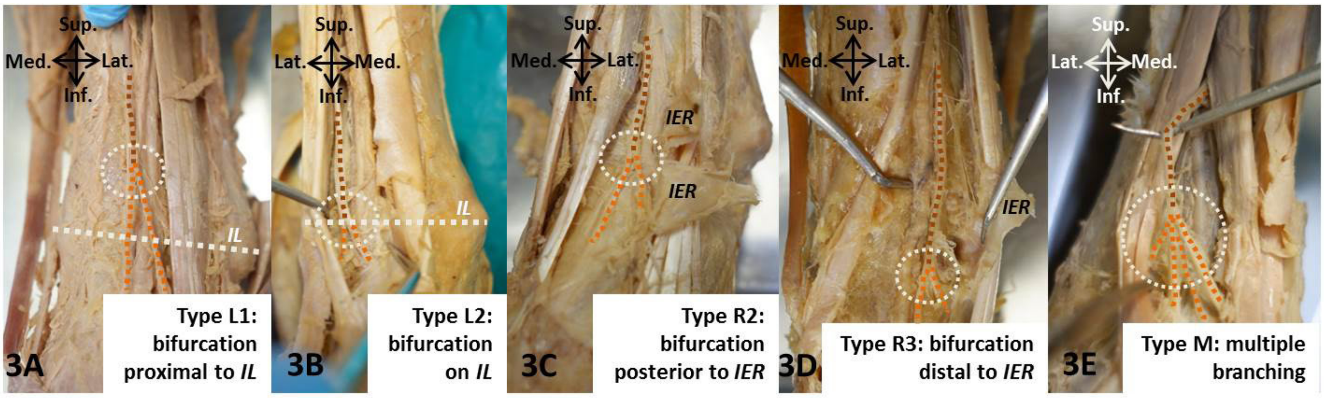

Fig 3. The most and the least prevalent types of DPN bifurcation site (3A-3D) in the intermalleolar and ATT areas, and the multiple branching of DPN (3E). (*IL*, white dashed line = imaginary line connecting medial and lateral malleoli; white dashed circle = area of DPN branching; brown dashed line = DPN main trunk; orange dashed line = branches of DPN)

DPA orientation (type O2) in about 40% of all cases. This means that EHLT was mostly found as the medial-most structure while DPN and DPA could be interchangeable. By using EHLT as a fixed medial landmark, this is useful for clinical procedures involving the area anterior to the ankle joint (e.g. ultrasound-guided DPN block and ankle arthroscopy). Nonetheless, orientation similarity of both sides can be implemented in only about 60% of cases.

A further investigation was performed to observe patterns of orientation of DPN at the branching level (MTB and LTB). A total of six patterns were found in this study (Table 2). Surprisingly, the classic orientation type (type A1: DPA was medial to DPN in ATT and medial to MTB of DPN below ATT) was not the most prevalent but rather type A4 (DPA located laterally). This result contrasts previous studies which show DPA located medially to MTB (types A1 and A3) and medially to DPN (types A1 and A2) being most prevalent (76% and 92.9%, respectively).[2,5] Nevertheless, the prevalence of DPA types located medially to the DPN main trunk in ATT (type A1: 23.8% and type A2: 25%) were not much different than the previous study (type A1: 36.1% and type A2: 25%).[3] The observation of DPN and DPA crossing over each other at multiple levels (type A5: 3.1%) was slightly less than in one previous study (8.4%)[4] and significantly less frequent than in another study (30.6%).[3] The prevalence of instances of no MTB found (type A6: 0.6%) was low, and much rarer than in a previous observation (8.3%).[3] To use these six types in practice, side similarity can be implied with a confidence level of nearly 60%.

Variations of the DPN branching level was also observed in our specimens. There were two stable landmarks used for positional reference. The first was an imaginary line connecting the medial and lateral malleoli as an intermalleolar line, the vertical level of which was approximately assumed as the level of ankle mortise. The other was the IER, which superficially covers the ATT. These two landmarks were independently located, so the IER was equally proximal, anterior, and distal to the ankle mortise.[2] In this study, bifurcation of DPN, either proximal to (type L1) or at the intermalleolar level (type L2), was high in frequency, or about 60%, but a significantly lower frequency was reported in a previous study (23%).[2] When considered in separate categories, DPN bifurcations at the intermalleolar line (type L2) and distal to it (type L3) were twice as high in prevalence than a previous study (47.4% vs 21% and 40.2% vs 27%, respectively).[4] In the case of an IER landmark, specimens with DPN bifurcation in the ATT observed in this study (type R2) gave the highest prevalence similar to a previous report. However, the prevalence was to a much different extent (56.1% vs 86.1%).[6] Interestingly, DPN bifurcation proximal to IER (type R1) has not been previously observed at high frequency as reported in this study (36.6%). Meanwhile, bifurcation below ATT (type R3) was comparable to a prior study (7.3% vs 5.6%).[6] The absence of branching (type N) and multiple branching (type M) was also found in this study at a low frequency like other studies.[4,6]

In addition to the studies aforementioned, there still have been a number of studies regarding the structural variation of both DPN and DPA by presenting significantly diverse data on type and prevalence which depended on either numbers of studied specimen or cadaveric ethnicity. For example, a study on DPA course compared to DPN branching performed in an Asian population revealed the different levels of variation prevalence from our current study.[7] The most- and least-common types found in this study were the types A1 and A6 at 36.7% and 6.7%, respectively, in prevalence while the types A2 and A5 were about 30% and 26.7%, respectively. Interestingly, there was no existence of types A3 and A4 in this study. Not only the courses of DPN and DPA that have been widely investigated but the branching pattern of DPN has also been focused. For instance, it has been found for many decades in other ethnic groups that the termination of DPN can also exist in multiple branching similar to the type M reported in our current study, not only the bifurcation into MTB and LTB.[8] In terms of positional variation for applying in clinical entrapment of DPN, various etiologies has been discovered other than the ATT syndrome caused by IER entrapment.[9] Compression by the extensor hallucis brevis muscle can be a cause that has been reported.[10] Likewise, fascia around the areas of tarsal and metatarsal bones were also considered as the possible structural constraint for DPN.[11] Therefore, further variation study in our population to demonstrate the incidence of each etiology causing the ATT syndrome in the patients is required.

Another structural variation that has been commonly found in other populations and is worth determining its prevalence in our population is the accessory deep peroneal nerve (ADPN) which branches from the superficial peroneal nerve. It carries the motor component to supply several muscles including certain or total parts of the extensor digitorum brevis (EDB)[12,13] and the sensory innervation for areas of fibula periosteum, lateral zone of ankle and metatarsal area.[14,15] ADPN has been previously investigated by either manual dissection in cadaveric specimens or electrophysiological study in plenty of studies. According to the meta-analysis of these studies[16], the pooled prevalence of ADPN existence and EDB innervation by ADPN once existing were about 18.8% and 79.5%, respectively. No significant difference between the males and females in ADPN prevalence was detected.[17] By investigating the inheritance among the family members of the ADPN presence, the autosomal dominant mode was suggested.[18]

Besides the variations detected in DPN course and branching, the arterial system that runs parallelly with DPN also displays its variation in several patterns as encountered in several cadaveric and angiographic studies. Starting from the constant anterior tibial artery (ATA) that mostly lies medially to the DPN except for the middle-third of this nerve, leading to another name of DPN as nervus hesitans, the distal part (DPA) inconstantly varies in its orientation into several types as described in Table 1. In some studies, 8% of investigated DPA were found to arise from arteries other than the single direct extension from ATA.[19] At the level of ankle joint, only 58% of studied specimens were found to branch medially (36%), laterally (55%) or even bilaterally (9%) in previous study.[20] These findings are useful for being aware of the risk in pseudoaneurysm formation during ankle arthroscopy or anterior hindfoot surgery. Apart from the orientation variation of the distal part of DPA described in Table 2, there have been additional variations in terms of number, location and also its branching pattern.[21-23] For example, distance variation due to DPA location in relation to the tarsal navicular bone was established to provide the practical data for the midfoot surgery.[21] In the sense of number, this artery itself can be found in double or even the increase in distal branching as atypical trifurcation.[23] Furthermore, the branching patterns on the dorsum of foot were surprisingly various as classified up to 9 types with the typical pattern at only 36.4% in prevalence.[22] All of these knowledge play an important role in reducing the risk of complications from intervention dealing with this artery or the structures nearby, eg., nerves, bones and joints.

DPN is a nerve that courses profoundly among the muscular tissue in the leg compartment and superficially beneath the cutaneous tissue as found in 1) the neck of the fibula as the part branching from the common peroneal nerve and 2) the area anterior to the ankle joint before running down to the ATT. Anatomical variations of the former part of DPN in Thais has been studied by Chompoopong *et al.* to avoid an iatrogenic injury caused during fibular biopsy[24] while variations in the latter were examined in this study. However, our findings are in agreement and disagreement with previous studies. This can be elucidated by two explanations: the difference in ethnicities of the investigated cadavers and the numbers of cadavers used in each study. A sufficient number of specimens were included in this study in order to achieve high reliability of the results and to reach

Variability in type and prevalence in the course of DPN and its branching pattern found in this study can be used in clinical practice under various contexts such as population-specific treatment. The main application of this research is the direct procedures on DPN and its branches, eg. nerve block[25,26], nerve stimulation and conduction study[27,28], surgical nerve transfer[29] and flap surgery for lower extremity reconstruction which is commonly operated on in a tertiary-care center.[30] In addition, another useful aspect is to minimize iatrogenic injuries of structures surrounding the DPN during certain procedures such as ankle arthroscopy and surgery in the ankle and foot areas.[31] Likewise, certain natures of the

DPN unveiled in this study can also correlate to clinical imaging information[32,33] and be used to predict clinical neurovascular consequences following a traumatic injury or treatment in the ankle and foot region.[34]

CONCLUSION

Based on the specimens, this study provides novel information on the type of variation and prevalence of DPN in the ankle and proximal part of the foot in the multiracial population inhabiting in Thailand. Therefore, this information can be used to help update population-specific clinical databases in this region. Due to significant differences found in our study when compared with data from other studies in other population groups, our study confirms that population-specific studies on structural variation is required before application in practice.

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