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Anatomical variations of the tibial nerve and their clinical correlation

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Abstract: The tibial nerve is a branch of the sciatic nerve, which innervates the legs and feet. Anatomical variations of this nerve at the ankle are commonly found. The variation of the tibial nerve in its branching point and cross-sectional area (CSA) at the ankle is commonly related to clinical condition such as foot neuropathy. Knowledge of these variations can support the clinician in making appropriate clinical decisions. This review aims at providing knowledge on the anatomical variations of tibial nerve at ankle, as well as its clinical correlation. This review outlined the variation of the terminal branching point and CSA of the tibial nerve at the ankle in cadaveric and clinical studies.

Key words: Tibial nerve, Anatomy, Polyneuropathies

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Introduction

The tibial nerve is one of the major branches of the sciatic nerve, which is formed from the ventral roots of segments L4, L5, S1, S2, and S3 of the spinal nerves [1-4]. This nerve contains sensory and motor nerve fibers that travel on the posterior leg and terminal in the foot area [4, 5]. At the posteromedial of the medial malleolus, the tibial nerve has many anatomical variations that correlate to clinical conditions. One of those common clinical conditions is foot neuropathy.

Foot neuropathy is one of the symptoms of foot pain resulting from tibial nerve injuries, presenting as burning, heat, impaired temperature perception, and tingling in the heels and sole [6-8]. Diabetics also tend to experience foot neuropathy due to alterations in the microcirculation of the feet [9]. This condition is known as diabetic polyneuropathy (DPN). Previous studies confirmed the presence of tibial nerve swelling in the tarsal tunnel and chronic compression of the tibial nerve in DPN patients [10].

Ultrasonography (US) is a widely used diagnostic tool to help visualize peripheral nerve conditions, including cross-sectional area (CSA) [11]. There are various reports of anatomical variations in the size of the tibial nerve CSA and their terminal branching point. Understanding the anatomical variations of this nerve is essential for clinical practice. In this review, we describe anatomical variations of the tibial nerve in clinical and cadaveric studies, focusing on variations in the terminal branching point and CSA of the tibial nerve at the level of the proximal tarsal tunnel of ankle area using the medial malleolus as an anatomical landmark.

Methods

Sources of research data were obtained from PubMed and Google Scholar databases. The article search was limited to the English language. We did not attempt to limit the time of publication of the articles. The keywords used in the search were tibial nerve, posterior tibial nerve, cross-sectional area, tarsal tunnel syndrome, neuropathy, and diabetic polyneuropathy.

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Review

Type of anatomical variation of the tibial nerve terminal bifurcation point

In the ankle area, the tibial nerve, located on the posteromedial side of the medial malleolus, runs in the tarsal tunnel [12]. The tarsal tunnel is a narrow fibro-osseous space covered by the flexor retinaculum (laciniate ligament) [7, 13]. This tunnel includes multiple structures such as the tibialis posterior tendon, flexor digitorum longus tendon, posterior tibial artery, posterior tibial vein, tibial nerve, and flexor hallucis longus tendons [14]. Due to its narrow space and structures, this tunnel has been reported to be the most common site for entrapment of the tibial nerve [15].

The tibial nerve is divided into two terminal branches, the medial plantar nerve (MPN) and the lateral plantar nerve (LPN), which innervate the sole of the foot [13, 16]. While the MPN innervate the medial aspect of the sole, the LPN innervate the lateral aspect [4]. Studies have reported several different branching points of the tibial nerve in the ankle. Some researchers use the malleolar-calcaneal axis (MCA), extending from the medial malleolus to the medial calcaneal tuberosity, as a reference line to classify the branching points. Based on that axis, there are five types of tibial nerve branching points: type I (above the axis and within the tarsal tunnel); type II (as high as the axis); type III (distal end of the axis and within the tarsal tunnel); type IV (proximal axis and outside the tarsal tunnel); type V (distal axis and outside the tarsal tunnel) [17].

The difficulty of identifying the flexor retinaculum in cadaver specimens has led some researchers to use the 2 cm proximal and distal axis as a determinant of the area of the tarsal tunnel. Most researchers reported that the branching point of the tibial nerve at the ankle is found in the tarsal tunnel area and proximally of the MCA (Table 1) [13, 16-22]. Tibial nerve branches include not only the MPN and LPN but also the medial calcaneus nerve (MCN) and the inferior calcaneus nerve (ICN). MCN and ICN provide sensory innervation to the heel and the anterior aspect of the calcaneus area, respectively [16, 17]. Thus, Compression on the two nerves can result in pain in the two difference areas; while compression of MCN result in heel pain and compression of the ICN result in Baxter neuropathy [23]. The two nerves vary in origin and number (Table 2) [13, 16, 20].

Tibial nerve cross-sectional area (CSA) variation in the ankle

Ultrasonography (US) is a common imaging technique used to depict the peripheral nerves, including the CSA of nerves [24]. Several studies have measured tibial nerve CSA using US with a frequency range of 5–18 MHz. It was found that the mean tibial nerve CSA in the ankle area ranged from 6.36 to 15.25 mm^2 (Table 3) [11, 24-30]. This broad variation in mean values is likely due to the utilization of diverse research subjects. According to studies, the CSA of the tibial nerve at the level and 1 to 7 cm proximal of medial malleolus in Asian subject was between 11.1 and 12.7 mm^2 [11, 24, 25]. Meanwhile, the mean CSA of tibial nerve in European varied between 6.36 and 13.7 mm^2 [26-29]. Based on a study of 81 cadaveric lower limbs, the average CSA of the tibial nerve at the tip of medial malleolus in fresh and frozen cadaver lower limbs was 15.25±4.65 mm^2 and 13.71±5.66 mm^2, respectively [30].

Several studies have shown that the CSA of nerves in-

Table 1. Types of tibial nerve terminal branching point

Authors	Country	Specimen	Number of feet	Type of branching point (%)				
				Type 1	Type 2	Type 3	Type 4	Type 5
Banik, 2021 [18]	India	Embalmed cadaver and lower limbs	20	45	30	15	10	0
Zhang, 2021 [13]	China	MRI	40	100	0	0	0	0
Inthasan, 2020 [16]	Thailand	Fresh cadaver	40	50	0	0	50	0
Farhan, 2018 [19]	USA	Fresh cadaver	1	100[a)]	0	0	0	0
Iborra, 2018 [20]	Spain	Fresh cadaver	12	91.67	0	0	8.3	0
Kim, 2015 [21]	Korea	Embalmed cadaver	90	7[b)]	1.1[b)]	82.2[b)]	NR	NR
Torres, 2012 [17]	Brazil	Fresh cadaver	50	52	14	22	12	0
Davis, 1995 [22]	USA	Embalmed cadaver	20	90	0	0	10	0
Total mean				66.95	5.63	14.9	11.28	0

MRI, magnetic resonance imagining; NR, not reported. [a)]Not clearly described. [b)]The axis lines: from the medial malleolus to the tuberosity of the Calcanei postero superior.

Table 2. Variation of MCN's origin

Number of branches	Authors	Origin					
		Tibialis nerve	MPN	LPN	Tibialis nerve and MPN	Tibialis nerve and LPN	Tibialis nerve, MPN, and LPN/trifurcation
1	Zhang, 2021 [13]	16/18	-	2/18	-	-	-
	Inthasan, 2020 [16]	5/8	1/8	2/8	-	-	-
	Iborra, 2018 [20]	6/12				-	-
2	Zhang, 2021 [13]	6/21	-	-	-	15/21	-
	Inthasan, 2020 [16]	7/15	-	-	1/15	7/15	-
	Iborra, 2018 [20]	-	-	-	-	1/6	5/6*
3	Zhang, 2021 [13]	-	-	-	-	1/1	
	Inthasan, 2020 [16]	11/17	-	-	4/17	-	2/17

MCN, medial calcaneus nerve; MPN, medial plantar nerve; LPN, lateral plantar nerve.

Table 3. Mean of tibial nerve CSA

Author	Country	Group (n)	Mean (range) age (yr)	Modality	Mean±SD CSA (mm^2)	Reference range of CSA
Singh et al. 2022 [24]	India	200	>18 (18–50)	US 5–18 MHz	11.1±1.1	NR
Warchoł et al. 2021 [30]	Poland	60[a)]	NR	Cadaveric dissection	15.25±4.65	11.77–17.29
		21[b)]	NR		13.71±5.66	9.5–16.15
Bedewi et al. 2018 [25]	Asian	138	38.33 (20–73)	US L18–5 MHz	12.7±4.5	2–30
Seok et al. 2014 [11]	Korea	94	43.9 (20–69)	US 5–12-MHz	12.1±3.1	8.5–22.8[c)]
Boehm et al. 2014 [26]	Caucasian	56	51.8[e)] dan 48.5[f)]	US 15 and 12 MHz	9.6±2.2	NR
Kerasnoudis et al. 2013 [27]	Germany	75	53.46	US-18 MHz	6.36±1.45	3.46–9.26
Tagliafico et al. 2012 [28]	Italy	58	47 (18–81)	US 17–5-MHz	9.6±4[d)]	NR
Cartwright et al. 2008 [29]	Caucasian	60	45.9 (21–80)	US 15-MHz	13.7±4.3	5.1–22.3

CSA, cross-sectional area at the tarsal tunnel; US, ultrasonography; NR, not reported; L, linear transducer. [a)]Lower limb fresh cadaver; [b)]lower limbs fresh frozen cadaver. [c)]7-cm proximal malleolus medial. [d)]Standard error measurement. [e)]Germans, [f)]Hungarians.

Table 4. Tibial nerve CSA in healthy vs neuropathy subjects

Authors	Country	Modality	Group (n)	Mean age (yr)	CSA (mm^2)
Narayan et al. 2021 [35]	India	US 6–20 MHz and 5–18 MHz	DPN (100)	55.98	13.61±4.99[a)]
			NN (100)	53.66	9.27±1.53
Fantino et al. 2020 [34]	France	US 18 MHz	Susp. TTS (27)	54	20.1±8.8[a)]
			NN (21)	39	10.3±2.3
Kelle et al. 2016 [9]	Turkey	US between 3 and 15 MHz	DPN (53)	53.57	R=33.83±8.98[a)]
					L=31.94±7.19[a)]
			NN (53)	51.87	R=18.67±6.51
					L=18.43±5.79
Kang et al. 2015 [37]	Korea	US 7–12 MHz	DPN (20)	66	12.25±2.88
			NN (20)	65	12.36±2.85
Riazi et al. 2012 [36]	Toronto	US 6–13 MHz	DPN (55)	61.4	22.05±7.40[a)]
			Diabetic non DPN (43)	46.8	17.25±4.68
Lee and Dauphinée, 2005 [10]	Texas	US 10–12 MHz	DPN (24)	57.4	24[a)]
			NN (NR)	NR	12

CSA, cross sectional area of tibial nerve; DPN, diabetic polyneuropathy; NN, nonneuropathy; TTS, tarsal tunnel syndrome; NR, not reported. R, right; L, left. [a)]Significant different.

creases with age [25, 27, 31]. In apart from age, the CSA value is related to body mass index (BMI) and weight. However, a meta-analysis reported no relationship between age, weight and tibial nerve CSA value [32]. Changes in tibial nerve's form and size can be caused by the position of the ankle joint. Previous studies showed that CSA of tibial nerve in the

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plantarflexed was greater than that of dorsiflexed [33].

Variation of the cross-sectional area (CSA) of the tibial nerve in foot neuropathy

The increase of the tibial nerve CSA may indicate abnormality. Tarsal tunnel syndrome (TTS) and diabetic polyneuropathy (DPN) are conditions caused by prolonged tibial nerve compression, which is related to an increase in the CSA of this nerve [10]. DPN has several symptoms, including paranesthesia, loss of sensory sensation, and hyperesthesia [9]. Several previous studies was reported differences in the mean value of the tibial nerve CSA between healthy subjects and patients with symptomatic neuropathy (Table 4) [9, 10, 34-37].

According to a study conducted in France, patients with TTS had higher mean CSA tibial nerve than in healthy subject at the inside of tarsal tunnel. CSA tibial nerve in TTS patients was 20.1 mm^2 and in healthy subjects was 10.3 mm^2 [34]. The difference in the CSA tibial nerve between DPN and healthy subjects was also noted. A study in India reported that the mean value of CSA tibial nerve at 3 cm proximal medial malleolus in patient with DPN was 13.61 mm^2 and in healthy subjects was 9.27 mm^2 [35]. A study in Texas also reported a higher mean value of CSA tibial nerve in patients with DPN than in healthy subject, which was 24 mm^2 and 12 mm^2, respectively [10].

Another study comparing the right and left leg was also found the difference in the CSA tibial nerve value between DPN and healthy subjects. In patients with DPN, the mean tibial nerve CSA value was 33.83 mm^2 on the right and 31.94 mm^2 on the left leg, whereas in healthy subjects, the CSA tibial nerve was 18.67 mm^2 on right leg and 18.43 mm^2 on the left leg [9]. In diabetic subject with DPN and those without DPN, the CSA of tibial nerve had different mean values of 22.05 mm^2 and 17.25 mm^2, respectively [36]. A study conducted in Korea showed there was no significant difference between the mean CSA of the tibial nerve at the level of medial malleolus in DPN patients and healthy subjects (12.25 mm^2 vs 12.36 mm^2, respectively) [37].

The CSA of the tibial nerve seems to be similar on both sides of the leg, so the value of tibial nerve CSA on the contralateral side can act as internal control in predicting abnormality [24, 28].

Conclusion

In this review, the MCA was used as the baseline for determining the tibial nerve branching point and the tarsal tunnel was defined as the area 2 cm proximal and distal to the MCA. According to these baselines, the most common location of the tibial nerve branching point was type I. It was difficult to provide concise data since the studies used various baselines in determining the branching point of the tibial nerve in the ankle. Therefore, in the future, the agreement will be required to determine that baseline.

Another anatomical variation we have review was CSA of tibial nerve at the ankle. In healthy subject there was various size of CSA tibial nerve. Hence there was an increase CSA tibial nerve in neuropathy patient. On both sides of the leg, there was no significant difference in CSA of tibial nerve at the ankle, so that it can be used as an internal control in establishing the diagnosis.

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Author Contributions

Conceptualization: ASS. Data acquisition: ASS, DF. Data analysis or interpretation: ASS, DF. Drafting of the manuscript: ASS. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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