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Authors: Ł. Warchol, J. A. Walocha, E. Mizia, M. Bonczar, H. Liszka, M. Koziej

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Ultrasound guided topographic anatomy of the medial calcaneal branches of the tibial nerve

Ł.Warchoł[1], J.A.Walocha[1], E. Mizia[1], M. Bonczar[2], H. Liszka[1], M. Koziej[1]

[1]Department of Anatomy, Jagiellonian University Medical College, Krakow, Poland

[2]Intermed Medical Clinic, Zabierzow, Poland

Address for correspondence: Łukasz Warchoł, Department of Anatomy, Jagiellonian University Medical College, ul. Kopernika 12, 31-034 Kraków, Poland, tel: +48 601 865 239, e-mail: l.warchol@uj.edu.pl

Abstract

Background: The purpose of this study was to evaluate the topographic anatomy of the tibial nerve and its medial calcaneal branches in relation to the tip of the medial malleolus and to the posterior superior tip of the calcaneal tuberosity using the ultrasound examination and to verify its preoperative usefulness in surgical treatment.

Materials and methods: Bilateral ultrasound examination was performed on 30 volunteers and the location of the tibial nerve bifurcation and medial calcaneal branches origin were measured. Medial calcaneal branches were analyzed in reference to the amount and their respective nerves of origin.

Results: In 77% cases tibial nerve bifurcation occurred below the tip of the medial malleolus with the average distance of 5.9 mm and in 48% cases above the attachment of the posterior superior tip of the calcaneal tuberosity with the average distance of 2.7 mm. In 73% cases medial calcaneal branches occurred as a single branch originating from the tibial nerve (60%). The average distance of the first, second and third medial calcaneal branch was accordingly 9.3 mm above, 9.5 mm below and 11.6 mm below the tip of the medial malleolus and 17.7 mm above, 1.6 mm below and 4 mm below the posterior superior tip of the calcaneal tuberosity.

Conclusions: As the tibial nerve and its branches presents a huge variability in the medial ankle area in order to prevent the iatrogenic injuries the preoperative or intraoperative ultrasound assessment (sonosurgery) of its localization should be introduced into the clinic.

Key words: medial calcaneal nerve, ultrasound-guided nerve examination, tarsal tunnel syndrome, medial plantar nerve, lateral plantar nerve, sonosurgery

INTRODUCTION

The tibial nerve arises as a branch of sciatic nerves bifurcation in the popliteal fossa. It runs distally on the tibialis posterior muscle together with the posterior tibial vessels. Usually at the level of flexor retinaculum it terminally divides into lateral and medial plantar nerve. During distal course the tibial nerve emits medial calcaneal branch(es) which is variable in number and origin. Tibial nerve and its branches provides innervation to the posterior lower leg, foot and sole muscles and the skin of medial foot and sole[28].

The knowledge of topographic anatomy of peripheral neurovascular bundles is important in surgical procedures, especially in the medial ankle surgery. It helps to understand the pathophysiology of the tarsal tunnel syndrome and its symptoms such as heel and sole burning pain, paresthesia and numbness radiating to the toes and proximally on the medial side of the calf with often nocturnal presentation [2, 5, 22, 24, 25, 39]. Tibial nerve and its branches may be entrapped in the tarsal tunnel by various internal and external mechanisms [8]. Additionally other medical conditions with body fluid retention and chronic inflammatory processes may lead to nerve compression [13]. Rising prevalence of diabetes mellitus contributes to a large number of compression syndromes [36]. Recently popular outdoor activities (e.g. jogging) also brings new cases of foot pain [23].

One of the utmost treatment options for the foot pain syndromes is a surgery [1, 20]. It must be performed with the highest awareness of tibial nerve anatomy without inflicting iatrogenic damage. According to anatomy books, atlases and cadaveric dissection studies tibial nerve presents a various pattern of its bifurcation as well as origin and number of medial calcaneal branches [6-7, 9-11, 14-17, 21, 27, 30-31, 33]. In relation to the anatomical landmarks we tried to establish the most common topographic localization of the tibial nerve and its final branches and to encourage to the preoperative ultrasound examination prior to medial ankle surgeries.

MATERIALS AND METHODS

Patients: The study was conducted on the 30 volunteers (n=60 lower limbs). There were 16 females and 14 males. The average age of the volunteers was 25.7 years (range 19-50 years). The inclusion criteria were as follows: age 18 years or older, written informed consent for the examination. The exclusion criteria's were any lower limb trauma, surgical or radiotherapeutic procedures of the lower limb, deformation of the lower limb, chronic disease of the lower limb.

The ultrasound examination was performed on the Mylab Gold 25 ultrasound scanner with a 18MHz linear probe (penetration depth 3.0 cm) in the Department of Anatomy between December 2016 and April 2017. The examination and measurements were performed by an orthopedic surgeon with more than 20 years of experience in ultrasound examination.

The ultrasound examination was performed with the volunteer lying prone with the foot in neutral position (ankle fixed in the foot stabilizing device and adjusted to the right angle). Each procedure was initiated 40 cm proximally to the tip of the medial malleolus, continuing distally along the tibial nerve course up to its bifurcation and further looking for medial malleolus branches. Following points were marked on the skin with the fine tip skin marker: the tibial nerve bifurcation point, medial calcaneal branches origin, the tip of the medial malleolus and the posterior superior tip of the calcaneal tuberosity (attachment point of the Achilles tendon to the calcaneal tuberosity). Lines crossing the marked points were drawn parallel to the foot plane (Figure 1). Distances from the reference lines (the tip of the medial malleolus line and the posterior superior tip of the calcaneal tuberosity) to the tibial nerve bifurcation line and to the medial calcaneal branches origin lines were measured with the caliper. If the measured point was below the reference line the value is in negative numbers, if above the reference line the value is in positive number. Medial calcaneal branches were analyzed with regards to the number of branches, nerve of origin and relation to the reference lines. The results were transformed into rates and tabulated.

Statistics: Obtained data was statistically processed using descriptive statistics such as percentage, mean, standard deviation. A p-value of < 0.05 was considered as statistically significant. Two groups were compared using the Mann-Whitney test or t-test depending normal distribution. All analyses were performed using MedCalc version 16.8.

The research protocol was approved by the local Ethics Committee (Registry No. 122.6120.315.2016). The study has been performed in accordance with the ethical standards established in the 1964 Declaration of Helsinki and its later amendments. The volunteers were informed about the study protocol and gave both informed and written consent to participate in the study.

RESULTS

There were thirty volunteers (n = 60 lower limbs) with an average age of 25.7 ± 7 amongst which 32 were female (53.3%) and 28 male (46.7%) feet.

The bifurcation of the tibial nerve into to medial and lateral plantar nerve most frequently occurred below the tip of the medial malleolus (76.7%) with the mean distance of -5.93 ± 19.59 mm and above the posterior superior tip of the calcaneal tuberosity (48.3%) with the mean distance of 2.67 ± 19.79 mm (Tables I, II). There were no significant difference between the sexes ($p > 0.05$). The correlation between the reference lines of the tip of the medial malleolus and the posterior superior tip of the calcaneal tuberosity has been proven to be statistically significant ($r = 0.9874$, $p < 0.05$) (Figure 2).

The medial calcaneal branches were identified in the range from one to three ramifications. A total of 80 medial calcaneal branches were visualized. In 44 patients (73.3%) only one medial calcaneal branch was identified with no significant differences between the sexes ($p > 0.05$). Two medial calcaneal branches were presented in 12 patients, and three branches in 4 patients (Table III). Most commonly medial calcaneal branch originated from the tibial nerve as a single branch (60%). As there were two medial calcaneal branches it emerged from the tibial and lateral plantar nerve most frequently (Table IV). Most of the medial calcaneal branches were located below the tip of the medial malleolus with the mean distance of 3.97 mm and above the posterior superior tip of the calcaneal tuberosity with the mean distance of 4.36 mm. It may be assumed that majority of branches is located were between the tip of the medial malleolus and the posterior superior tip of the calcaneal tuberosity.

First medial calcaneal branch (n = 60) originated 9.27 ± 61.73 mm above the tip of the medial malleolus and 17.67 ± 61.18 mm above the posterior superior tip of the calcaneal tuberosity with no statistically significant differences between the sexes ($p > 0.05$) (Table VI). Second medial calcaneal branch (n = 16) originated 9.50 ± 10.09 mm below the tip of the

medial malleolus and 1.63 ± 11.28 mm below the posterior superior tip of the calcaneal tuberosity. Third medial calcaneal branch (n = 4) originated 11.75 ± 9.03 mm below the tip of the medial malleolus and 4.00 ± 8.45 mm below the posterior superior tip of the calcaneal tuberosity (Table II, Figures 3, 4). In one volunteer (n = 2 feet) an exceptionally long distance of the first medial calcaneal branch was measured: 330 mm on the left lower limb and 337 mm on the right lower limb above the tip of the medial malleolus and respectively 335 mm and 343 mm above the posterior superior tip of the calcaneal tuberosity.

DISCUSSION

Up to 15% of adult population suffers from the plantar heel pain[3]. According to Oztuna et al.[32] nerve entrapment is one of the reasons for this condition. As operative decompression of the tarsal tunnel is one of the most effective treatment options it is essential to perform the surgery in concordance with the anatomical structures in order to avoid its iatrogenic injury [12].

First description of the tibial nerve and its branches variable anatomy was published by Horwitz[17] in 1938. Dissecting 100 lower extremities author states that the tibial nerve bifurcation occurs 1.3cm above the tip of the medial malleolus. As to the medial calcaneal branch(es) underlines its difference in number, location and origin. Dellon et al.[10] in 1984 examined 31 cadaver feet. For the first time the malleolar-calcaneal axis (MCA) was proposed as the reference line for the measurements. In 90% of the cases the tibial nerve bifurcation occurred within 1cm of the MCA. Medial calcaneal branch originating above the flexor retinaculum in 65% cases. The author emphasize variability between left and right feet bifurcation location as well as to the number and location of the medial calcaneal branch(es). For the first time a substantial differences between mentioned studies are pointed out. Only 15% of Dellon cases presented the tibial nerve bifurcation at the level of Horwitz results.

Comparing with the other published studies the tibial nerve bifurcation was located inside the tarsal tunnel in 99.9% (Joshi et al.[21]), 93% (Havel et al.[15]), 88% (Torres et al.[37]) and 73% (Louisa et al.[27]) cases. Heimkes et al.[16] defined the tarsal tunnel as the oval osteofibrous canal between talus, calcaneus and flexor retinaculum which stretches from the medial malleolus to the calcaneus. As so it corresponds with the results of the present study in which 76.7% cases presented the bifurcation below the tip of the medial malleolus with the

mean distance of 5.93 ± 19.59 mm. According to the tarsal tunnel definition it may be assumed that majority of the nerves (tibial nerve, lateral and medial plantar nerve) localized by the authors runs and divides in the tarsal tunnel where it may by compressed.

Location of the tibial nerve bifurcation was the subject of many cadaveric studies [37]. Most of them were conducted according to the malleolar-calcaneal axis (MCA) reference line which was fixed between the center of the medial malleolus and the medial calcaneal tuberosity [21, 27]. Some authors suggest the tip of the lateral malleolus as the reference point which is localized below the tip of the medial malleolus [26, 38]. Nevertheless in the present study the authors introduced different, parallel to the foot plane reference lines: line crossing the tip of the medial malleolus and line crossing the posterior superior tip of the calcaneal tuberosity. Measurement according to those two reference lines proved to have a high correlation ($r = 0.9874$). The authors believe that those bony, easy palpable through skin orientation points may appear of better use in the clinic environment.

Many authors published various results in relation to the number, location and origin of the medial calcaneal branch(es). Havel et al[15], Louisa et al.[27] reported the occurrence of the range of one to two branches of the medial calcaneal nerves. Other published studies states the occurrence of the range of one to three (Torres et al.[37]) and even four (Joshi et al.[21]) branches of the medial calcaneal nerves. Single medial calcaneal branch is the most often finding in reports from Havel et al.[15] and Torres et al.[37] whilst two branches are most commonly registered by Louisa et al.[27] and Dellon et al.[10]. Joshi et.al[21] finds single medial calcaneal branch in the same number of dissected lower limbs as double. In the present study the authors visualized a range of one to three medial calcaneal branches with the most common single branch (73.3% of the lower limbs) which is similar to Torres et al and Havel et al reports [37, 15].

In the range of differences the authors of all other publications indicated the tibial nerve as the most frequent nerve of origin for the medial calcaneal branch(es) [15, 21, 27, 37]. The present study states that despite there is a single, double or triple branching pattern the tibial nerve is the most often nerve of origin (87% cases). As it goes to the further ramification models the lateral plantar nerve gives off medial calcaneal branch(es) in 25% cases followed by medial plantar nerve present in 8% cases. Some authors finds medial calcaneal branch(es) originating only from the tibial nerve [35], others claim it goes off only form the tibial or lateral plantar

nerve [14, 17, 21, 23], yet another reports it originates only from the tibial or medial plantar nerve [4].

Medial calcaneal branch(es) location also appears to be a matter of variance among published studies. Some authors observes majority of the medial calcaneal ramifications proximally to the tarsal tunnel [7, 27, 37], others locate it distally [9 ,14]. In the present study the authors registered 60% of medial calcaneal branches located below the tip of the medial malleolus at the same time 70% of them is located above posterior superior tip of the calcaneal tuberosity. It allows to assume that most of the ramifications are located between the two reference lines.

As a single case of an exceptionally distant location of the medial calcaneal branch of 330 mm and 337 mm above the tip of the medial malleolus may appear odd or suggest examiners mistake. It finds confirmation with Torres et al.[37] study where the authors also report a maximal ramification occurring 346.6 mm above the malleolar-calcaneal axis.

Iborra et al and Mullick et al. confirms that the ultrasound usage in the tarsal tunnel syndrome operative treatment leads to respectively 90.12 % and 93 % excellent and good results. In the cadaveric study the authors proved that a high-resolution ultrasonography can visualize the entire course of the tibial nerve as well as its tiny branches which may be applied in the decompression surgeries [18, 19, 29]. Also a sonosurgery, which is a "minimally invasive surgical technique performed with the continuous ultrasound imagining and the use of endoscopic tools" seems promising in improving the surgical result by reducing the risk of iatrogenic injuries [34].

Limitations of the study

The fact that tibial nerve and its branches run together with vessels between muscles and other anatomical structures may mean that its localization changes during the lower limb movement. Therefore for the sake of this study a standardized positioning set up was arranged with all patients lying prone with the foot in neutral position (ankle fixed in the foot stabilizing device and adjusted to the right angle). Second limitation is the localization of the of the posterior superior tip of the calcaneal tuberosity which depends on the foot arch. The angle between calcaneal inclination line and the horizontal line (heel pitch angle) varies in cavus, neutral and flat foot. Therefore in cavus foot the measured distance may be longer whilst shorter in the flat foot. Another restriction is a limited ultrasound resolution. Although

authors were able to track the tibial nerve till its final bifurcation the high frequency ultrasound might miss some tiny terminal nerves, such as medial calcaneal branches. To reduce this factor ultrasound examination was conducted by an experienced orthopedic surgeon.

CONCLUSIONS

To conclude the authors of the present study together with the other analyzed publications proved that the anatomy of the tibial nerve and its distal branches observed in the medial ankle area is different between left and right limbs, gender and amongst individuals. As is the origin, location and division pattern on the medial calcaneal branch(es). Because of this anatomical variations it is difficult to suggest any safe zone area for the medial ankle surgical treatment, as so the preoperative or intraoperative ultrasound examination is highly recommended.

REFERENCES

1. Ahmad M, Tsang K, Mackenney PJ, Adedapo AO. Tarsal tunnel syndrome: A literature review. Foot Ankle Surg. 2012 Sep;18(3):149-52.
2. Aldridge T. Diagnosing heel pain in adults. Am Fam Physician. 2004 Jul 15;70(2):332-8.
3. Alshami AM, Souvlis T, Coppieters MW. A review of plantar heel pain of neural origin: differential diagnosis and management. Man Ther. 2008 May;13(2):103-11.
4. Andreasen Struijk LN, Birn H, Teglbjaerg PS, Haase J, Struijk JJ. Size and separability of the calcaneal and the medial and lateral plantar nerves in the distal tibial nerve. Anat Sci Int. 2010 Mar;85(1):13-22.
5. Bailie DS, Kelikian AS. Tarsal tunnel syndrome: diagnosis, surgical technique, and functional outcome. Foot Ankle Int. 1998 Feb;19(2):65-72.
6. Bilge O, Ozer MA, Govsa F. Neurovascular branching in the tarsal tunnel. Neuroanatomy. 2003;2:39-41
7. Davis TJ, Schon LC. Branches of the tibial nerve: anatomic variations. Foot Ankle Int. 1995;16(1):21-9.
8. De Maeseneer M. Normal Anatomy and Compression Areas of Nerves of the Foot and Ankle: US and MR Imaging with Anatomic Correlation. Radiographics. 2015 Sep-Oct;35(5):1469-82.
9. Dellon AL, Kim J, Spaulding CM. Variations in the origin of the medial calcaneal nerve. J Am Podiatr Med Assoc. 2002;92(2):97-101.
10. Dellon AL, Mackinnon SE. Tibial nerve branching in the tarsal tunnel. Arch Neurol. 1984 Jun;41(6):645-6.
11. Didia BC, Horsefall AU. Medial calcaneal nerve. An anatomical study. J Am Podiatr Med Assoc. 1990;80(3):115-9.
12. Doneddu PE, Coraci D, Loreti C, Piccinini G, Padua L. Tarsal tunnel syndrome: still more opinions than evidence. Status of the art. Neurol Sci. 2017 Oct;38(10):1735-1739.
13. Flanigan RM. Peripheral nerve entrapments of the lower leg, ankle, and foot. Foot Ankle Clin. 2011 Jun;16(2):255-74.
14. Govsa F, Bilge O, Ozer MA. Variations in the origin of the medial and inferior calcaneal nerves. Arch Orthop Trauma Surg. 2006;126(1):6-14.
15. Havel PE, Ebraheim NA, Clark SE, Jackson WT, DiDio L. Tibial nerve branching in the tarsal tunnel. Foot Ankle. 1988;9(3):117-9.

16. Heimkes B, Posel P, Stotz S, Wolf K. The proximal and distal tarsal tunnel syndromes. An anatomical study. Int Orthop. 1987;11(3):193-6.
17. Horwitz MT. Normal anatomy and variations of the peripheral nerves of the leg and food application in operations for vascular diseases: study of one hundred specimens. Arch Surg. 1938;36(4):626-636.
18. Iborra A, Villanueva M, Sanz-Ruiz P. Results of ultrasound-guided release of tarsal tunnel syndrome: a review of 81 cases with a minimum follow-up of 18 months. J Orthop Surg Res. 2020; 15: 30.
19. Iborra A, Villanueva M, Barrett SL, Rodriguez-Collazo E, Sanz P. Anatomic Delineation of Tarsal Tunnel Innervation via Ultrasonography. J Ultrasound Med. 2018 Jun;37(6):1325-1334.
20. Iborra Á, Villanueva-Martínez M, Barrett SL, Rodríguez-Collazo ER, Sanz-Ruiz P. Ultrasound-Guided Release of the Tibial Nerve and Its Distal Branches: A Cadaveric Study. J Ultrasound Med. 2019 Aug;38(8):2067-2079.
21. Joshi SS, Joshi SD, Athavale AS. Anatomy of tarsal tunnel and its applied Significeance. Journal of the Anat Soc india 2006;55(1):52-6.
22. Keck C. The Tarsal-tunnel syndrome. Bone Joint Surgery 1962;44:180-2
23. Kim DI. Topography of human ankle joint: focused on posterior tibial artery and tibial nerve. Anat Cell Biol. 2015 Jun;48(2):130-7.
24. Kopell HP, Thompson WA. Peripheral entrapment neuropathies of the lower extremity. N Engl J Med. 1960 Aug 14;262:56-60.
25. Lam SJ. A tarsal-tunnel syndrome. Lancet. 1962 Dec 29;2(7270):1354-5.
26. Lijoi F, Lughi M, Baccarani G. Posterior arthroscopic approach to the ankle: an anatomic study. Arthroscopy 2003 Jan;19(1):62-7.
27. Louisia S, Masquelet AC. The medial and inferior calcaneal nerves: an anatomic study. Surg Radiol Anat. 1999;21(3):169-73.
28. Moore KL. Clinically Oriented Anatomy. 8th Edition. LWW 2017
29. Mullick T, Dellon AL. Results of decompression of four medial ankle tunnels in the treatment of tarsal tunnels syndrome. J Reconstr Microsurg. 2008 Feb;24(2):119-26.
30. Ndiaye A, Dia A, Konate I, Diop M, Sow ML. Topographic anatomy of the tibial nerve in the medial malleolus: application to the effect of nerve block anesthesia. Morphologie. 2003;87(277):25-7.
31. Netter FH. Atlas of Human Anatomy. 7th Edition. Elsevier; 2018
32. Oztuna V, Ozge A, Eskandari MM, Colak M, Gölpinar A, Kuyurtar F. Nerve entrapment in painful heel syndrome. Foot Ankle Int. 2002 Mar;23(3):208-11.
33. Paulsen F, Waschke J. Sobotta Atlas of Human Anatomy. 15th Edition. Urban & Fischer; 2012
34. Pilecki Z, Pilecki G, Bubnov R. Introduction to sonosurgery. EPMA J. 2014; 5(Suppl 1): A66.
35. Rondhuis JJ, Huson A. The first branch of the lateral plantar nerve and heel pain. Acta Morphol Neerl Scand. 1986;24(4):269-79.
36. Rowley WR. Diabetes 2030: Insights from Yesterday, Today, and Future Trends. Popul Health Manag. 2017 Feb;20(1):6-12.
37. Torres ALG, Marcus Castro Ferreira MC. Study of the anatomy of the tibial nerve and its branches in the distal medial leg. Acta Ortop Bras. 2012; 20(3): 157–164.
38. Warchoł Ł, Mróz I, Mizia E, Zawiliński J, Depukat P, Kurzydło W, Tomaszewski KA. Vascular density of inferior tibiofibular joint - cadaveric experimental study. Folia Med Cracov. 2017;57(1):47-54.
39. Yates B. Merriman's Assessment of the Lower Limb. 3er Edition. New York: Churchill Livingstone.

Table I. Tibial nerve bifurcation location according to the reference line

location	tip of the medial malleolus		posterior superior tip of the calcaneal tuberosity	
	n	%	n	%
above the reference line	14	23,3%	23	38,3%
at the level of the reference line	0	0,0%	8	13,3%
below the reference line	46	76,7%	29	48,3%

Table II. Results of measurements (mm) and statistics										
Reference line	Measured point		n	Mean±SD	Median	Max.	Min.	Lower quartile (Q1)	Upper quartile (Q3)	Sex differences
tip of the medial malleolus	tibial nerve bifurcation		60	-5,93±19,59	-8,00	60	-33	-19,50	-1,50	p=0,6929
	medial calcaneal branch origin	1 st branch	60	9,27±61,73	-1,00	337	-27	-7,00	6,50	p=0,9409
		2 nd branch	16	-9,50±10,09	-8,50	2	-35	-14,00	-0,50	
		3 rd branch	4	-11,75±9,03	-11,00	-4	-21	-19,50	-4,00	
posterior superior tip of the calcaneal tuberosity	tibial nerve bifurcation		60	2,67±19,79	0,00	72	-26	-10,00	7,50	p=0,6776
	medial calcaneal branch origin	1 st branch	60	17,67±61,18	7,00	343	-17	3,00	13,50	p=0,8939
		2 nd branch	16	-1,63±11,28	-1,00	12	-29	-6,50	8,00	
		3 rd branch	4	-4,00±8,45	-2,50	3	-14	-11,00	3,00	

Table III. Division of the medial calcaneal nerve according to the number of branches				
Number of branches	Male feet (n=28)	Female feet (n=32)	Pooled sexes feet (n=60)	Percentage
One	16 (57,1%)	28 (87,5%)	44	73,3%
Two	10 (35,7%)	2 (6,3%)	12	20%
Three	2 (7,1%)	2 (6,3%)	4	6,7%

Table IV. Pattern of the medial calcaneal branches presentation according to the nerve of origin				
Nerve of origin	Male feet (n=28)	Female feet (n=32)	Pooled sexes feet (n=60)	Percentage
single branch of TN	14 (50,0%)	22 (68,8%)	36	60%
single branch of LPN	2 (7,1%)	5 (15,6%)	7	11,7%
one branch of TN and one of LPN	6 (21,4%)	0 (0,0%)	6	10%
two branches of TN	3 (10,7%)	1 (3,1%)	4	6,7%
two branches of TN and one of MPN	0 (0,0%)	2 (6,3%)	2	3,3%
two branches of TN and one of LPN	2 (7,1%)	0 (0,0%)	2	3,3%
one branch of TN and one of MPN	1 (3,6%)	1 (3,1%)	2	3,3%
single branch of MPN	0 (0,0%)	1 (3,1%)	1	1,7%
TN - tibial nerve; LPN - lateral plantar nerve; MPN - medial plantar nerve				

Table V. Location of all medial calcaneal branches according to the reference lines (mm)								
	Reference line	Location	n=78	%	Mean	Median	Max.	Min.
all medial calcaneal branches	tip of the medial malleolus	above the reference line	25	31,25%	-3,97	-3	23	-35
		at the level of the reference line	7	8,75%				
		below the reference line	48	60,0%				
	posterior superior tip of the calcaneal tuberosity	above the reference line	56	70,0%	4,36	5	34	-29
		at the level of the reference line	2	2,5%				
		below the reference line	22	27,5%				

*2 max. distal locations were excluded from the statistics (330/335mm, 337/343mm)

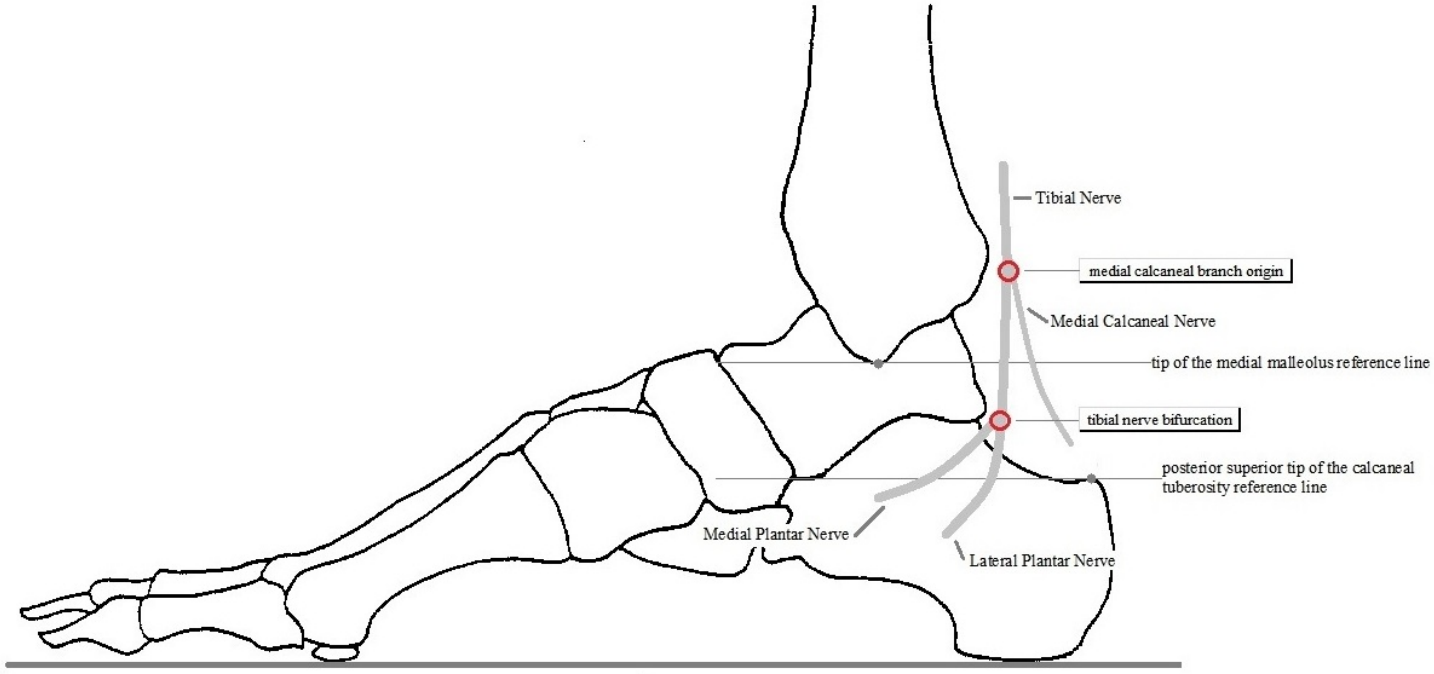
Table VI. First medial calcaneal branch location in relation to reference according to the sex											
	Reference line	Sex	n	Mean±SD	Median	Max.	Min.	Lower quartile (Q1)	Upper quartile (Q3)	p-value	correlation
1 st medial calcaneal branch	tip of the medial malleolus	F	32	-0,91±11,51	-0,5	23,0	-22	-8,5	6,0	0,9409	0,9463
		M	28	20,89±88,95	-1,5	337,0	-27	-6,5	6,5		
	posterior superior tip of the calcaneal tuberosity	F	32	7,56±12,03	6,5	34,0	-16	3,5	14,5	0,8939	
		M	28	29,21±88,05	7,0	343,0	-17	2,0	13,0		

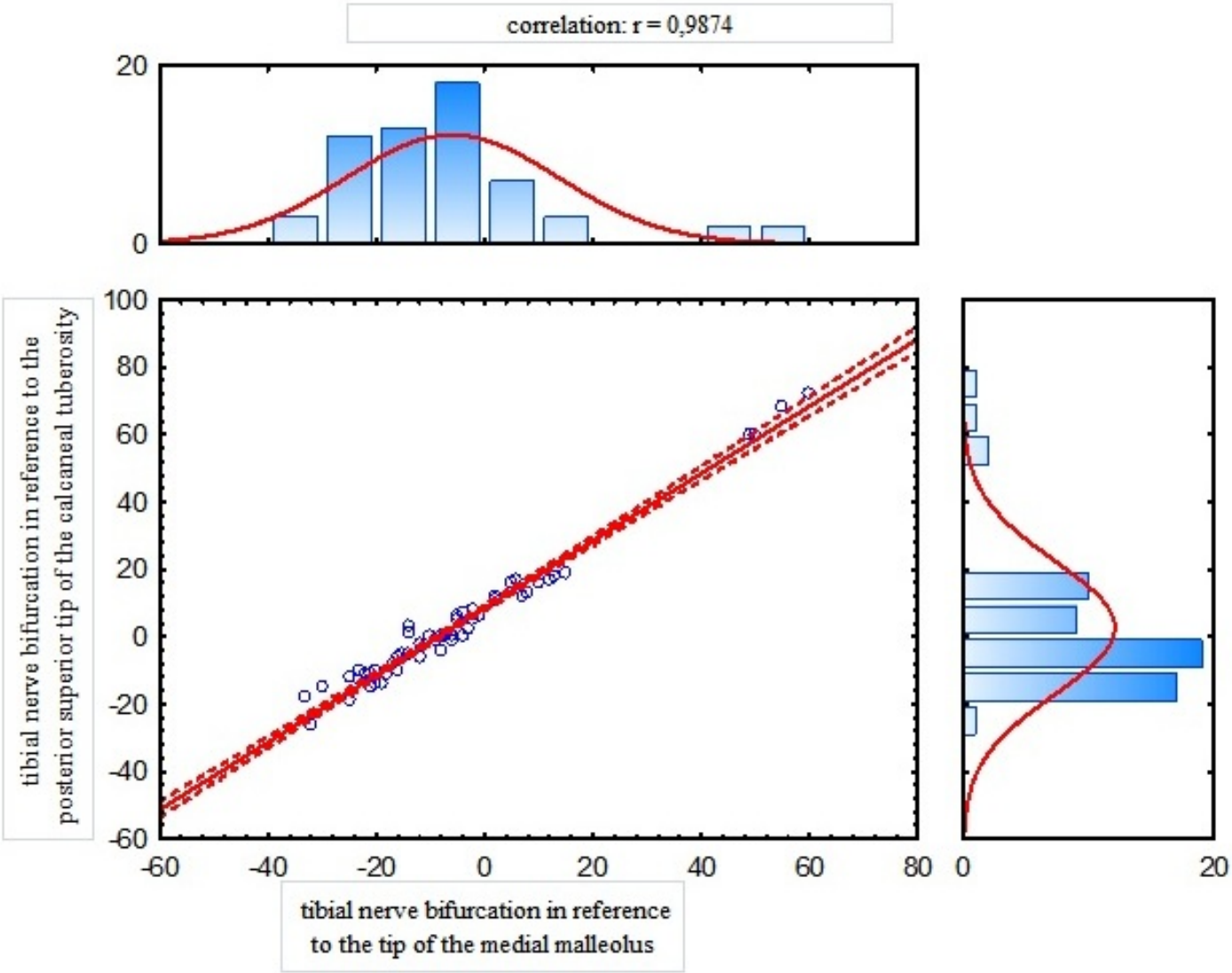
Figure 1. Foot scheme with the measured points and the reference lines.

Figure 2. Correlation of the reference lines according to the tibial nerve bifurcation.

Figure 3. Medial calcaneal branches location in relation to the medial malleolus.

Figure 4. Medial calcaneal branches location in relation to the posterior superior tip of the calcaneal tuberosity.


Tibial Nerve
medial calcaneal branch origin
Medial Calcaneal Nerve
tip of the medial malleolus reference line
tibial nerve bifurcation
posterior superior tip of the calcaneal tuberosity reference line
Medial Plantar Nerve
Lateral Plantar Nerve


correlation: r = 0,9874
20
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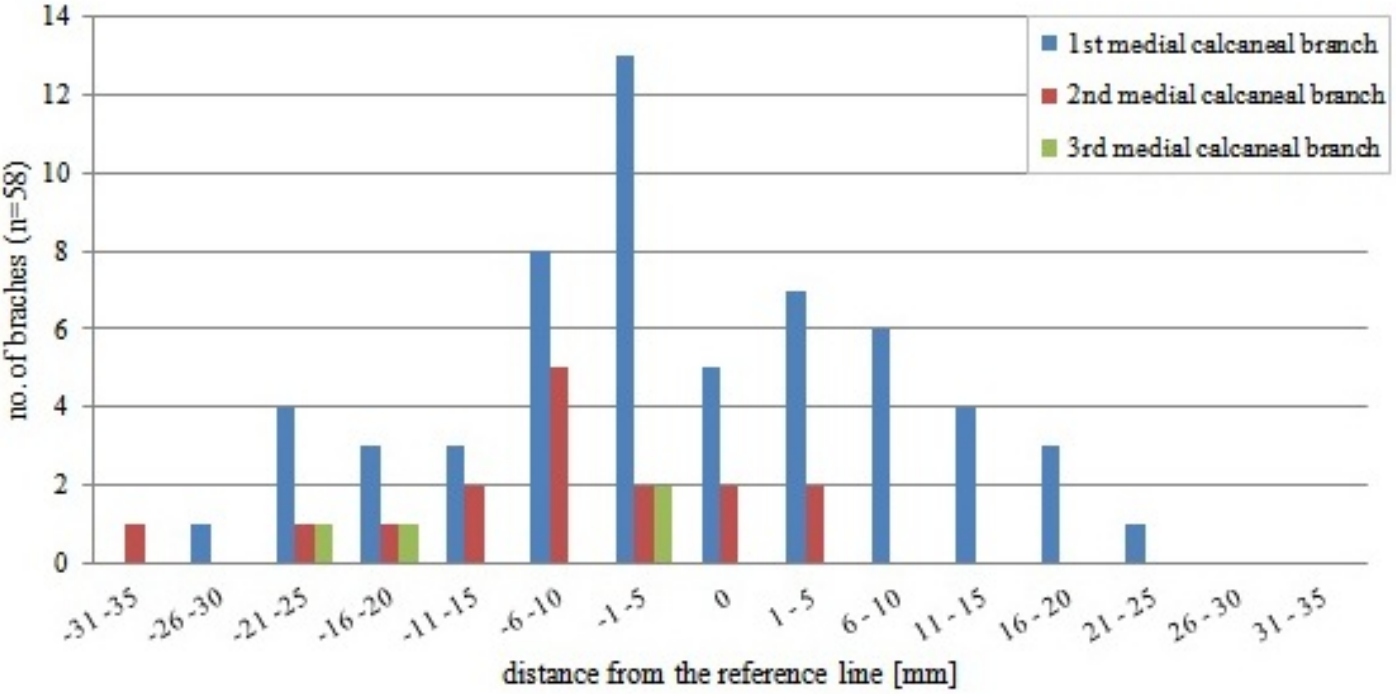
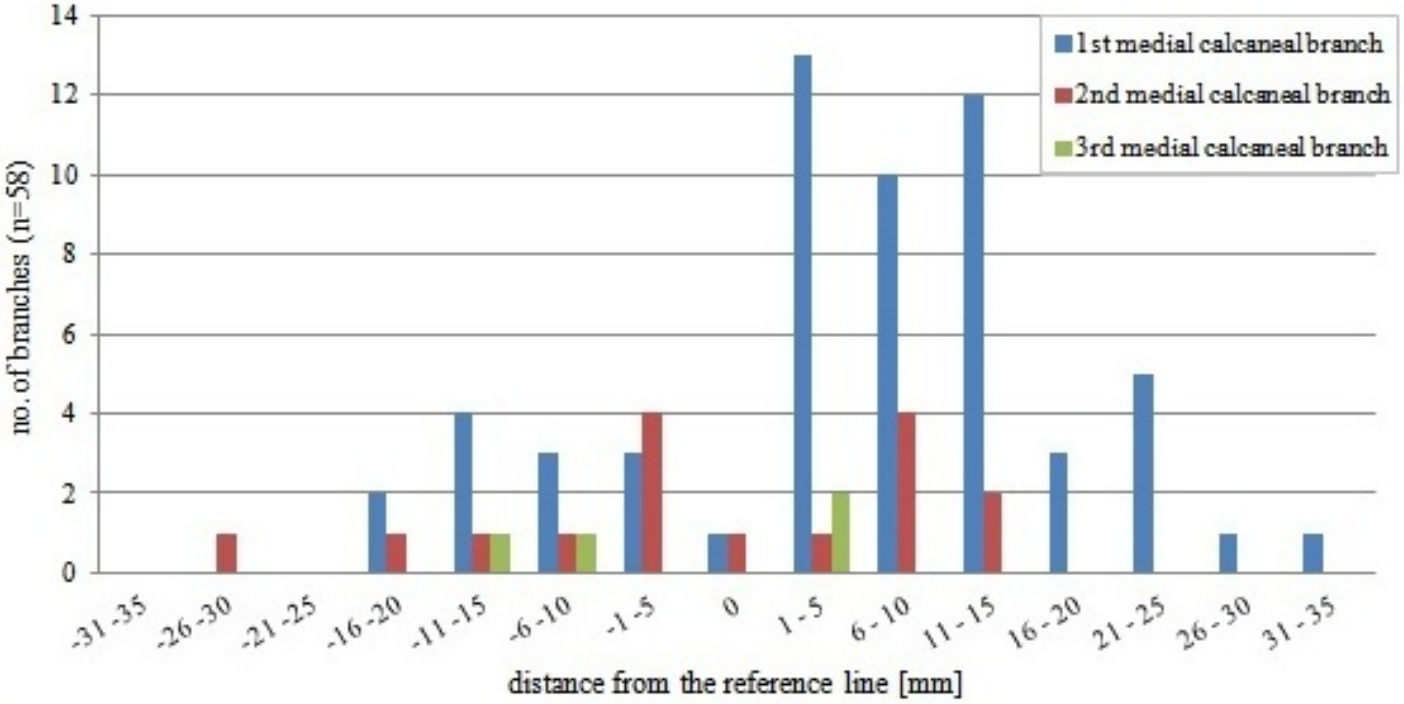
tibial nerve bifurcation in reference to the posterior superior tip of the calcaneal tuberosity
tibial nerve bifurcation in reference to the tip of the medial malleolus



*2 max. distal locations were not included in the table (330mm, 337mm)



*2 max. distal locations were not included in the table (335mm, 343mm)