Anatomic Delineation of Tarsal Tunnel Innervation via Ultrasonography

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Objectives—High-resolution ultrasonography (US) can play an important role in studying nerves, as it has several advantages. Entrapments of distal tibial nerve branches can be mapped out or diagnosed with selective anesthetic blocks, and US can guide therapeutic procedures, such as radiofrequency ablation and selective infiltrations of specific nerve branches. The aim of this study was to verify that US is an effective method for accurately locating the posterior tibial nerve and its terminal branches, such as the medial calcaneal branch, the first calcaneal branch, and the medial and lateral plantar nerves.

Methods—In this study, we analyzed the correlation between US mapping and real anatomy after cadaveric dissection, assessing the distribution and variability of the tibial nerve and its terminal branches. We used 12 fresh anatomic specimens of the foot and ankle, including the calf. A high-resolution US study of the tibial nerve and its branches was performed.

Results—The results of the US studies of the anatomic specimens were drawn as paper diagrams and in data collection tables. Both were completed twice per anatomic specimen, first using the results of the US study and second using the results from dissection of the anatomic specimens; this approach enabled us to compare the results and verify whether the US study and the dissection correlated on the topography of the tibial nerve and its terminal branches. We found almost total agreement between the US and dissection results, with no significant differences between the evaluations.

Conclusions—On the basis of this work, we can conclude that high-resolution US is almost 100% effective as a tool for identifying the tibial nerve and its branches, enabling the specialist to make diagnoses or perform selective treatments on each nerve branch and even to design surgical interventions by observing the patient's anatomy before performing the dissection

Key Words—lateral plantar nerve; lower calcaneal branch; medial calcaneal branch; medial plantar nerve; musculoskeletal; peripheral nerve; sports medicine/orthopedics; tarsal tunnel; tibial nerve; ultrasonography

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Abbreviations
MRI, magnetic resonance imaging; US, ultrasonography

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Tarsal tunnel syndrome is a disorder that affects the tibial nerve or its branches: the medial plantar nerve, the lateral plantar nerve, the medial calcaneal nerve, the motor branch of the abductor muscle to the fifth toe, and the first calcaneal branch. This peripheral neuropathy is considered less common than carpal tunnel syndrome but is much more complicated to diagnose, so its true incidence may be underestimated.

Its diagnosis is established by physical examination and can be confirmed by electrophysiologic tests, although those tests frequently give normal results. However, diagnostic imaging can help identify the site of compression. Magnetic resonance imaging (MRI) is a valid technique for evaluating the peripheral nerves, including those inside the tarsal tunnel,[1,2] but it cannot be used to perform infiltrations in a clinic-based setting or to determine the topography of nerve branches in the operating theater.

High-resolution ultrasonography (US) is playing an increasingly important role in studying nerves, as it has several advantages in comparison to magnetic resonance imaging, such as its low cost, ease of access, rapid examinations,[3] and comparative and dynamic studies, as well as the ability to perform US studies with the patient in a standing position.[4] Additional advantages include the ability to perform selective treatments such as radiofrequency procedures, infiltrations, and even US-guided tarsal tunnel release, which requires precision and verification of the correlation between US and dissection, as shown in previous cadaver studies.

Several authors have described the role of US in this disorder,[2,3,5,6] including evaluation of peripheral nerve entrapment in osseous-fascial tunnels, comparison of the healthy side with the affected side, assessing anatomic alterations such as veins, accessory muscles, and cysts, and others.[4] In 2005, Nagaoka and Matsuzaki[7] reported a series of 17 patients with a space-occupying lesion identified in the tarsal tunnel, which is not always the case.

In this study, we analyzed the anatomic correlation in nerves between US studies (Figure 1) and dissection of fresh anatomic specimens, thus enabling us to validate the use of US for this syndrome, as well as its use in treatments that require maximal accuracy, such as treatment of radiofrequency nerve ablation, which is used often for chronic throat pain, but the reported efficacy of radiofrequency nerve ablation is variable and dependent on the operator's experience and method of localization.

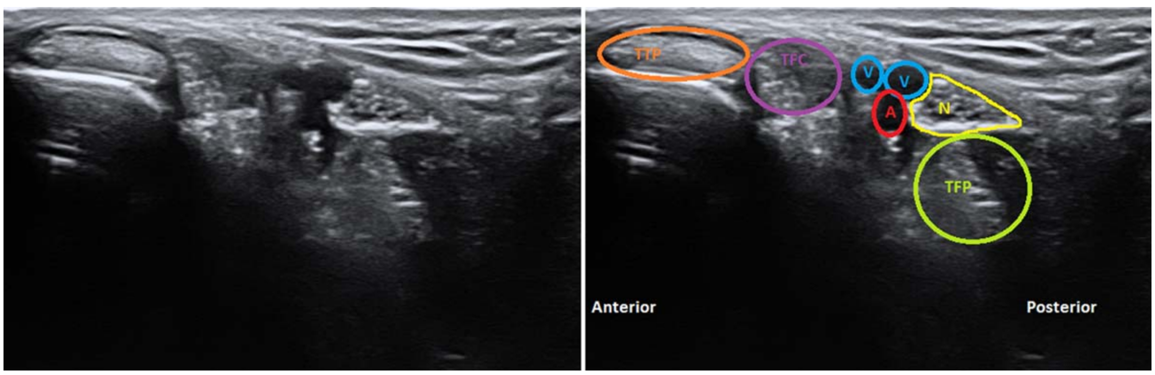
Anatomy and Correlation With US

In cadaver studies of anatomy, various authors have described the variable anatomy of the tibial nerve and its terminal branches in terms of the location of its bifurcation with respect to the flexor retinaculum.[8,9] The main variations are the bifurcation of the tibial nerve into the medial and lateral plantar nerves with respect to the retinaculum, bifurcation of the medial calcaneal branch, and bifurcation of the first calcaneal branch.

The most common pattern described is where the tibial nerve bifurcation occurs below the tunnel (type I); the medial calcaneal branch has variable branches, with 1 or 2 branches, most commonly originating in the tibial nerve inside the tarsal tunnel and crossing the laciniate ligament. The first calcaneal branch is typically a single branch, most commonly originating in the lateral plantar nerve, 1 cm from the tibial medial malleolar-calcaneal line.[10–13]

The general objective of this study was to find out whether there is a precise correlation between US image mapping and real anatomy by follow-up cadaveric dissections assessing the distribution and variability of the tibial nerve and its terminal branches. Identifying patterns of nerve branches is important for performing selective treatments with a high degree of safety, whether

Figure 1. Ultrasonographic depiction of the anatomy of the posterior tarsal tunnel: cross section, transverse or short view. A indicates posterior tibial artery; N, tibial nerve; TFC, common flexor tendon of the toes; TFP, flexor hallucis tendon; TTP posterior tibial tendon; and V, posterior tibial veins.



infiltrations, radiofrequency ablations, and even US-guided surgery of the tarsal tunnel, as in carpal tunnel syndrome.[14,15]

Materials and Methods

Our prospective study was performed in accordance with the principles of the 1964 Declaration of Helsinki (2013 revision). The Anatomy Department of Francisco de Vitoria University provided the specimens used in this study. Surgical studies using specimens from body donors do not require Ethics Committee approval.

To conduct this study, the level of experience of the sonographer was 10 years, with full dedication to the ankle and foot, and we used 12 fresh anatomic specimens of the foot and ankle, including the calf, and an E-CUBE 15 US machine with an L8-17X multifrequency linear transducer (Alpinion Medical Systems, Bothell, WA). Of the 12 specimens, 4 were right and 8 left. Because the anatomic pieces were sectioned below the knee, we could not determine the sex. We did not take these 2 variables into account, considering that they would not affect the results of the study.

We used the anatomic reference line that various authors have used in their studies. This anatomic reference runs from the center of the medial malleolus to the center of the calcaneus and has been called the "the malleolar-calcaneal axis" (Figure 2).[10,16]

Each anatomic specimen was subjected to the following work sequence: First, a US sweep was performed from the proximal end to the distal end of the tibial nerve and its terminal branches, determining the topography of each nerve and describing its origin, its bifurcation, the location of the bifurcation in relation to the retinaculum, and whether it was inside or outside it, and the direction and number of nerve branches. This evaluation was conducted by the same operator in all cases to prevent biases. This topography was drawn onto the cadaveric specimen and on a paper diagram (Figure 3), and the data observed in the US sweep were recorded in a table (Table 1).

The topography has been established in relation to the malleolar-calcaneal axis,[10,16] and 4 divider lines were specified in both proximal and distal directions, 2 proximal and 2 distal, parallel to the medial malleolar-

Figure 2. Malleolar-calcaneal axis.[8,13]

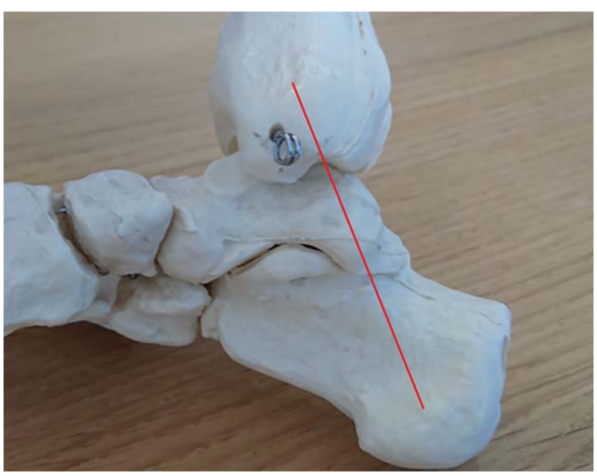


Figure 3. Topography on the cadaver specimen and paper diagram.

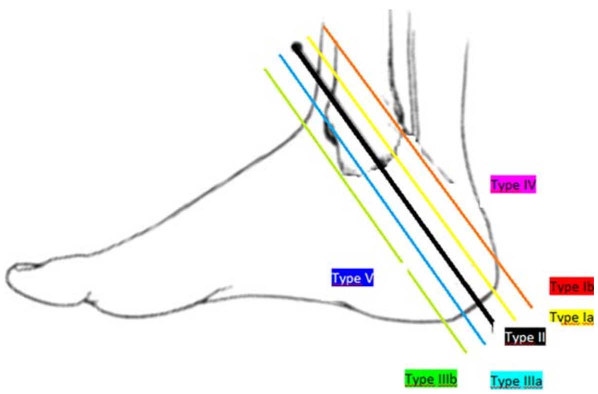
Table 1. Data Collection

Anatomic Specimen No.
Tibial nerve bifurcation classification by type
No. of medial calcaneal branches (different bifurcation points)
Medial calcaneal branch origin (proximal)
Medial calcaneal branch origin (distal)
No. of terminal branches of medial calcaneal branch
Bifurcation in relation to retinaculum (proximal medial calcaneal branch)
Bifurcation in relation to retinaculum (distal medial calcaneal branch)
Distance from bifurcation to malleolar-calcaneal line (medial calcaneal branch inside retinaculum)
Crosses retinaculum (proximal medial calcaneal branch)
Crosses retinaculum (distal medial calcaneal branch)
Bifurcation in relation to retinaculum (1st calcaneal branch)
Distance to malleolar-calcaneal line (1st calcaneal branch)
Origin (1st calcaneal branch)

calcaneal line and with a 1-cm gap between each pair of lines, according to the subclassifications of Torres and Ferreira.[11] These lines describe and delimit the full thickness of the flexor retinaculum, which has a total width of 4 cm. This outline allows 7 anatomic regions to be distinguished, depending on the location of the tibial nerve bifurcation on the medial surface of the ankle and the exact locations of the other nerve branches (Figure 4).

Figure 4 shows 5 lines; depending on where the tibial nerve bifurcation is located, it was classified as one of the following types: type IA corresponds to the space between the black and yellow lines; type IB, between the yellow and red lines; type II, on the black line corresponding to the malleolar-calcaneal axis[10,16]; type IIIA, between the black and blue lines; type IIIB, between the blue and green lines; type IV, proximal to the red line (outside the retinaculum); and type V, distal to the green line (outside the retinaculum). The red and green lines describe the proximal and distal limits of the flexor retinaculum, respectively.

Figure 4. Outline with 7 differentiated regions. The black line represents the medial malleolar-calcaneal axis.



We also used Figure 3 to draw the tibial nerve and its branches for subsequent verification of the correlation between the US image and the anatomic dissection (Figures 5–7), which was performed without knowledge of the anatomic specimen number and using head-mounted magnifiers with a ×4 magnification, again collecting data in the table (Table 1) for subsequent comparison of the correlation between the US and the dissection. These data were statistically analyzed to quantify the level of accuracy of US for locating nerves.

The statistical analysis was conducted with SPSS version 22 software for Windows (IBM Corporation, Armonk, NY). The tests performed were the McNemar test, to decide whether there was any change in response between the 2 time points analyzed, and a κ analysis, to measure the agreement between the evaluations at the 2 time points.[17,18] A value of 1 indicates perfect agreement; a value of 0 indicates that the correlation is no better than would be obtained at random; values of 0 to 0.2 are considered very low; 0.2 to 0.4, low; 0.4 to 0.6, moderate; 0.6 to 0.8, high; and 0.8 to 1, very high.

Results

For the tibial nerve bifurcation, total agreement ($\kappa = 1$) between the evaluations was observed. There was no significant difference between the evaluations, with types IA (41.7%) and IB (50%) being the most common tibial nerve bifurcation regions (Table 2).

For the number of medial calcaneal nerve branches with different points of origin on the tibial nerve, total agreement ($\kappa = 1$) between the evaluations was

Figure 5. Dissection to verify the anatomic correlation.

observed. There was no significant difference between the evaluations, finding 1 branch in 50% of cases and 2 branches in the other 50% of cases (Table 3).

We found the origin of the proximal medial calcaneal branch to be in the tibial nerve in 100% of the sample. Total agreement (100% of responses) between the evaluations was observed (Table 4).

For the origin of the distal medial calcaneal branch, 6 of the 12 anatomic specimens had a distal medial calcaneal branch. In 16.7% ($n = 1$) of these, this nerve branch originated in the lateral plantar nerve, and in the remaining 83.3% ($n = 5$), it developed from the trifurcation. Total agreement ($\kappa = 1$) between the evaluations was observed (Table 5).

In 33.3% ($n = 4$) of specimens, the medial calcaneal branch bifurcation occurred inside the retinaculum, and in 66.7% ($n = 8$), it was outside. Total agreement ($\kappa = 1$) between the evaluations was observed. There was no significant difference between the evaluations (Table 6).

For the bifurcation of the distal medial calcaneal branch in relation to the retinaculum, total agreement (100% of responses) between the evaluations was observed. There was no significant difference between the evaluations. In 100% of cases, the bifurcation occurred within the retinaculum (Table 7).

Of all medial calcaneal branches, 25% were bifurcated within the area between 0 and −1 cm; another

Figure 6. Dissection to verify the anatomic correlation.

Figure 7. Dissection to verify the anatomic correlation.

25% were bifurcated within the area between 0 and 1 cm; 33.3% were bifurcated within the area between 1 and 2 cm; and 16.7% were bifurcated outside and proximal to the retinaculum. For medial calcaneal branch bifurcations found inside the retinaculum and according to the distance from the malleolar-calcaneal line, total agreement ($\kappa = 1$) between the evaluations was observed. There was obviously no significant difference between the evaluations (Table 8). For verification of the proximal medial calcaneal branch crossing the retinaculum, total agreement ($\kappa = 1$) between the evaluations was observed. There was no significant difference between the evaluations; 58.3% did not cross the retinaculum, and 41.7% did cross the retinaculum (Table 9).

For verification of the distal medial calcaneal branch crossing the retinaculum, total agreement (100% of responses) between the evaluations was observed. There

Table 2. Tibial Nerve Bifurcation

Tibial Nerve Bifurcation	Tibial Nerve Bifurcation			
	Type 1A	Type 1B	Type IV	Total
Type 1A				
Count	5	0	0	5
% of total	41.7	0.0	0.0	41.7
Type 1B				
Count	0	6	0	6
% of total	0.0	50.0	0.0	50.0
Type IV				
Count	0	0	1	1
% of total	0.0	0.0	8.3	8.3
Total				
Count	5	6	1	12
% of total	41.7	50.0	8.3	100.0

Table 3. Number of Medial Calcaneal Nerve Branches With Different Points of Origin on the Tibial Nerve

Medial Calcaneal Branches	Medial Calcaneal Branches		
	1	2	Total
1			
Count	6	0	6
% of total	50.0	0.0	50.0
2			
Count	0	6	6
% of total	0.0	50.0	50.0
Total			
Count	6	6	12
% of total	50.0	50.0	100.0

Table 4. Origin of the Proximal Medial Calcaneal Branch

Medial Calcaneal Branch Origin	Medial Calcaneal Branch Origin	
	Posterior Tibial Nerve	Total
Posterior tibial nerve		
Count	12	12
% of total	100.0	100.0
Total		
Count	12	12
% of total	100.0	100.0

Table 5. Origin of the Distal Medial Calcaneal Branch

Medial Calcaneal Branch Origin	Medial Calcaneal Branch Origin		
	Lateral Plantar Nerve	Trifurcation	Total
Lateral plantar nerve			
Count	1	0	1
% of total	16.7	0.0	16.7
Trifurcation			
Count	0	5	5
% of total	0.0	83.3	83.3
Total			
Count	1	5	6
% of total	16.7	83.3	100.0

Table 6. Bifurcation of the Proximal Medial Calcaneal Branch in Relation to the Retinaculum

Medial Calcaneal Branch Bifurcation	Medial Calcaneal Branch Bifurcation		
	Inside	Outside	Total
Inside			
Count	4	0	4
% of total	33.3	0.0	33.3
Outside			
Count	0	8	8
% of total	0.0	66.7	66.7
Total			
Count	4	8	12
% of total	33.3	66.7	100.0

Table 7. Bifurcation of the Distal Medial Calcaneal Branch in Relation to the Retinaculum

Medial Calcaneal Branch Bifurcation	Medial Calcaneal Branch Bifurcation	
	Inside	Total
Inside	8	8
Count	100.0	100.0
% of total		
Total		
Count	8	8
% of total	100.0	100.0

was no significant difference between the evaluations; 100% of distal medial calcaneal branches crossed the retinaculum (Table 10). For the number of terminal branches of the medial calcaneal branch, moderate agreement ($\kappa = 0.571$) between the evaluations was observed, but there was no significant difference between the evaluations (McNemar $P > .99$; Table 11).

For the bifurcation of the first calcaneal branch in relation to the retinaculum, total agreement (100% of responses) between the evaluations was observed. There was obviously no significant difference between the evaluations. In our sample, 100% of the anatomic specimens were bifurcated inside the retinaculum (Table 12).

Table 8. Bifurcation of the Medial Calcaneal Branch Found Inside the Retinaculum According to the Distance From the Malleolar-Calcaneal Line

Distance From Malleolar-Calcaneal Line, cm	Distance From Malleolar-Calcaneal Line, cm: 0 to –1	0 to 1	1 to 2	None	Total
0 to –1					
Count	3	0	0	0	3
% of total	25.0	0.0	0.0	0.0	25.0
0 to 1					
Count	0	3	0	0	3
% of total	0.0	25.0	0.0	0.0	25.0
1 to 2					
Count	0	0	4	0	4
% of total	0.0	0.0	33.3	0.0	33.3
None					
Count	0	0	0	2	2
% of total	0.0	0.0	0.0	16.7	16.7
Total					
Count	3	3	4	2	12
% of total	25.0	25.0	33.3	16.7	100.0

Table 9. Verification of the Proximal Medial Calcaneal Branch Crossing the Retinaculum

Crosses Retinaculum	Crosses Retinaculum: No	Yes	Total
No			
Count	7	0	7
% of total	58.3	0.0	58.3
Yes			
Count	0	5	5
% of total	0.0	41.7	41.7
Total			
Count	7	5	12
% of total	58.3	41.7	100.0

For the bifurcation of the first calcaneal branch according to the distance from the malleolar-calcaneal line, total agreement ($\kappa = 1$) between the evaluations was observed. There was obviously no significant difference between the evaluations. The bifurcation was in the area between 0 and –1 cm in 83.3% of specimens and between 0 and 1 cm in 16.7% (Table 13).

For the origin of the first medial calcaneal branch, total agreement ($\kappa = 1$) between the evaluations was observed. There was obviously no significant difference between the evaluations. The origin was in the lateral

Table 10. Verification of the Distal Medial Calcaneal Branch Crossing the Retinaculum

Crosses Retinaculum	Crosses Retinaculum: Yes	Total
Yes		
Count	6	6
% of total	100.0	100.0
Total		
Count	6	6
% of total	100.0	100.0

Table 11. Number of Terminal Branches of the Medial Calcaneal Branch

Terminal Branches of Medial Calcaneal Branch	Terminal Branches of Medial Calcaneal Branch: 1	2	Total
1			
Count	1	1	2
% of total	16.7	16.7	33.3
2			
Count	0	4	4
% of total	0.0	66.7	66.7
Total			
Count	1	5	6
% of total	16.7	83.3	100.0

Table 12. Bifurcation of the First Calcaneal Branch in Relation to the Retinaculum

First Calcaneal Branch Bifurcation	First Calcaneal Branch Bifurcation: Inside	Total
Inside		
Count	12	12
% of total	100.0	100.0
Total		
Count	12	12
% of total	100.0	100.0

plantar nerve in 91.7% of the specimens, with the remainder originating in the trifurcation (Table 14).

In 1 anatomic specimen, 2 first calcaneal branches were observed to exist, but 1 of these was not identified by US because of its very small diameter; in the same cadaver, the US study also failed to observe the bifurcation of 1 distal medial calcaneal branch.

McNemar and κ statistical tests were performed,[13,14] and in all of the analyses, we obtained a 100% correlation between the US studies and the dissections, except that we had 83.3% success for the distal medial calcaneal branch and variable numbers of branches, although the result was not significant, since we had 1 error in 6 samples and a variable number of branches to the first calcaneal branch in 92% of cases with variable numbers of branches. Among the errors found, 2 first calcaneal branches were observed in 1 anatomic specimen, but 1 of these was not identified by US because of its very small diameter, and in the same cadaver, the US study also failed to show a bifurcation in 2 terminal branches of a medial calcaneal branch.

Table 13. Bifurcation of the First Calcaneal Branch Found Inside the Retinaculum According to the Distance From the Malleolar-Calcaneal Line

Distance From Malleolar-Calcaneal Line, cm	Distance From Malleolar-Calcaneal Line, cm		
	0 to –1	0 to 1	Total
0 to –1			
Count	10	0	10
% of total	83.3	0.0	83.3
0 to 1			
Count	0	2	2
% of total	0.0	16.7	16.7
Total			
Count	10	2	12
% of total	83.3	16.7	100.0

Table 14. Origin of the First Medial Calcaneal Branch

Medial Calcaneal Branch Origin	Medial Calcaneal Branch Origin		
	Lateral Plantar Nerve	Trifurcation	Total
Lateral plantar nerve			
Count	11	0	11
% of total	91.7	0.0	91.7
Trifurcation			
Count	0	1	1
% of total	0.0	8.3	8.3
Total			
Count	11	1	12
% of total	91.7	8.3	100.0

Discussion

In this study, we intended to verify the anatomic agreement in nerves between US studies and dissection of fresh anatomic specimens, thus allowing us to validate the use of US for tarsal tunnel syndrome and its subsequent use in interventions and US-guided surgery. In cadaver studies, numerous authors have described[10,19–23] the variable anatomy of the tibial nerve and its terminal branches. The main variations are bifurcation of the tibial nerve into the medial and lateral plantar nerves, bifurcation of the medial calcaneal branch and first calcaneal branch, with respect to the retinaculum, the number of branches, and branch origins.

In studies regarding the US correlation of the tibial nerve and its branches, some authors used latex or dye injection.[24,25] In a study by Presley et al,[25] the authors described only the US anatomy of the first branch of the lateral plantar nerve. In our study, we did not use dye because we thought that the contrast might have made dissection of the anatomic complex of the tarsal tunnel, the origin, the bifurcation, and the number of nerve branches more difficult. The main objective of the study was not to describe the anatomic variations but the correlation between US pathways of the tibial branches with precise locations for surgical treatments such as decompressions.

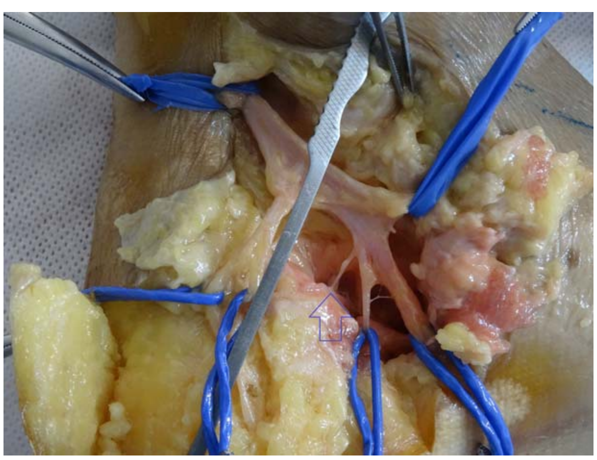
Our results may have differed slightly from those of other authors because our sample size was very small compared to those of other studies, and the main objective of the study was not to describe the anatomic variations but the correlation between US and dissection. In our study, we found that, regarding the location of the bifurcation of the tibial nerve, with US we obtained 100% agreement between US and dissection, and 91% of tibial nerve bifurcations were in the areas corresponding to types IA and IB: 1 cm distal and 1 cm proximal to the malleolar-calcaneal axial line. The US topography and the anatomic dissection were completely correlated. Our results were similar to those of other authors.[10,11,16]

Regarding the medial calcaneal branch, we have drawn the same conclusion as other authors: ie, that it has highly variable anatomy[11,22,23] The variables studied for the medial calcaneus branch, at its origin and bifurcation inside and outside retinaculum and whether it crossed the retinaculum, obtained 100% agreement for US, except for the number of branches, which obtained 83.3% agreement; although because the sample size was small, this result was not significant.

Our study's conclusion on medial calcaneal branches is that this nerve branch has the most varied anatomy in terms of the number, bifurcation area, and origin and whether it passes outside or inside the retinaculum. This variation probably occurs because it innervates the heel, which is the most innervated part of the foot, but that factor was outside the scope of this study. We observed that when there are 2 calcaneal branches, the proximal branch bifurcates from the tibial nerve and most commonly passes outside the retinaculum, and the distal branch originates from the trifurcation and passes inside the retinaculum, perforating the latter to become superficial. With respect to the first calcaneal branch, our evaluation of the origin, place of bifurcation, and number of branches obtained 100% agreement for US, except for the number of branches, which obtained 92% agreement.

Through our study of 12 anatomic specimens, we were able to observe that, despite the anatomic variability, high-resolution US allowed us to determine the topography of the nerve branches, with excellent correlations with the subsequent anatomic dissections in almost 100% of cases. There was only 1 anatomic specimen with errors in the description of the first calcaneal branch, where in the US study we observed 1 branch, whereas dissection showed that there were 2 branches, and in the description of the bifurcation of the medial calcaneal branch into its terminal branches, we only identified 1 branch, and dissection found 2 branches.

Figure 8. First calcaneal branch anatomic variant (blue arrow).



It must be emphasized that the branches we did not observe by US had diameters that were too small (<1 mm), as shown in Figure 8 for the case of the first calcaneal branch. Although the anatomic specimens used were fresh and very well preserved, we think that this error was probably due to hydration of the specimen, which can affect the US image such that the echogenicity of such a small structure may be altered, leading to difficulties in identification by US. It could also be because we were at the limits of the resolution capacity of our equipment and training.

The study may have been limited by the experience and skill of the examiner identifying the nerves by US, the US machine used (which must be of high resolution to be able to identify nerves with very small diameters), and the state of preservation of the cadaveric specimens, which can be a source of confusion in this type of study. In our study, the first 2 authors interpreted the results of the US sweeps together, which could have been a confusing factor. All specimens were free of areas with freezer burn, which could distort the US image.

To the best of our knowledge, there are no previous studies on the correlation between US and the topography of the tibial nerve and its branches. We think that it is important to be able to detect the different patterns to understand a possible affliction of each nerve and even to be able to perform selective blocks of each nerve branch and even treatments such as radiofrequency ablation very selectively. This ability substantiates the efficacy of high-resolution US for improved planning of diagnostic or therapeutic interventions, including US-guided tarsal tunnel release.

We found that high-resolution US is as effective as dissection for showing the anatomic variations of the tibial nerve. The training of the operator and the quality of the equipment may have been the 2 major biases. Nonetheless, this work could be very useful for establishing a working method in the surgical setting, as the surgeon can perform a study and design the surgery with US support, observing the patient's anatomy and anatomic variations before proceeding to surgical dissection, which could prevent intraoperative complications.

In conclusion, the purpose of this research was not to conduct a statistical study of the anatomic variations of the tibial nerve and its branches but, rather, to assess whether an operator with US experience and accurate knowledge of the anatomic region under study could effectively identify the tibial nerve and its branches using a high-resolution US machine, enabling the specialist to make diagnoses or carry out selective treatments on each nerve branch and even to design surgery by observing the patient's anatomy before performing the dissection. Accurate location is also important to avoid iatrogenic damage to the tibial branches in patients with anatomic variations. Ultrasound-guided surgery of the tarsal tunnel can be a procedure with great contributions to decompressive surgery of the tibial nerve and its distal branches, performing small portal incisions of 1 to 2 mm in size under local anesthesia. Using this approach could decrease complications such as perineural fibrosis, infection, and incisional dehiscence.

References

1. Erickson SJ, Quinn SF, Kneeland JB, et al. MR imaging of the tarsal tunnel and related spaces: normal and abnormal findings with anatomic correlation. *AJR Am J Roentgenol* 1990; 155:323–328.
2. Kerr R, Frey C. MR imaging in tarsal tunnel syndrome. *J Comput Assist Tomogr* 1991; 15:280–286.
3. Martinoli C, Bianchi S, Gandolfo N, Valle M, Simonetti S, Derchi LE. US of nerve entrapments in osteofibrous tunnel of the upper and lower limbs. *Radiographics* 2000; 20(special issue):S199–S217.
4. Fantino O, Coillard JY, Borne J, Bordet B. Ultrasound of the tarsal tunnel: normal and pathological imaging features. *J Radiol* 2011; 92: 1072–1080.
5. Demondion X, Boutry N, Bry R, Khalil C, Jaspart M, Cotten A. Tibial nerve entrapment syndromes at the ankle and foot level: imaging assessment. *Rev Rhum* 2007; 74:409–414.
6. Fantino O. Role of ultrasound in posteromedial tarsal tunnel syndrome: 81 cases. *J Ultrasound* 2014; 17:99–112.
7. Nagaoka M, Matsuzaki H. Ultrasonography in tarsal tunnel syndrome. *J Ultrasound Med* 2005; 24:1035–1040.
8. Cozzarelli J, Sollitto RJ, Thapar J, Caponigro J. A 12-year long-term retrospective analysis of the use of radiofrequency nerve ablation for the treatment of neurogenic heel pain. *Foot Ankle Spec* 2010; 3: 338–346.
9. Arslan A, Koca TT, Utkan A, Sevimli R, Akel I. Treatment of chronic plantar heel pain with radiofrequency neural ablation of the first branch of the lateral plantar nerve and medial calcaneal nerve branches. *J Foot Ankle Surg* 2016; 55:767–771.
10. Dellon AL, Mackinnon SE. Tibial nerve branching in the tarsal tunnel. *Arch Neurol* 1984; 41:645–646.
11. Torres ALG, Ferreira MC. Study of the anatomy of the tibial nerve and its branches in the distal medial leg. *Acta Ortop Bras* 2012; 20: 157–164.
12. Sarrafian SK. *Anatomy of the Foot and Ankle: Descriptive, Topographic, Functional*. 2nd ed. Philadelphia, PA: JB Lippincott Co; 1983.
13. Arenson DJ, Cosentino GL, Suran SM. The inferior calcaneal nerve: an anatomical study. *J Am Podiatr Assoc* 1980; 70:552–560.
14. McShane JM, Slaff S, Gold JE, Nazarian LN. Sonographically guided percutaneous needle release of the carpal tunnel for treatment of carpal tunnel syndrome: preliminary report. *J Ultrasound Med* 2012; 31: 1341–1349.
15. Rojo-Manaute JM, Capa-Grasa A, Chana-Rodríguez F, et al. Ultra–minimally invasive ultrasound-guided carpal tunnel release. *J Ultrasound Med* 2016; 35:1149–1157.
16. Havel PE, Ebraheim NA, Clark SE, Jackson WT, DiDio L. Tibial nerve branching in the tarsal tunnel. *Foot Ankle Int* 1988; 9:117–119.
17. Everitt BS. *The Analysis of Contingency Tables*. 2nd ed. London, England: Chapman & Hall; 1992.
18. Ferrán Aranaz, M. *SPSS Para Windows: Programación y Análisis Estadístico*. New York, NY: McGraw Hill; 1996.
19. Heimkes B, Posel P, Stotz S, Wolf K. The proximal and distal tarsal tunnel syndromes: an anatomical study. *Int Orthop* 1987; 11:193–196.
20. Davis TJ, Schon LC. Branches of the tibial nerve: anatomic variations. *Foot Ankle Int* 1995; 16:21–29.
21. Louisia S, Masquelet AC. The medial and inferior calcaneal nerves: an anatomic study. *Surg Radiol Anat* 1999; 21:169–173.
22. Dellon AL, Kim J, Spaulding CM. Variations in the origin of the medial calcaneal nerve. *J Am Podiatr Med Assoc* 2002; 92:97–101.
23. Hamm JT, Sanders M. Anatomic variations of the nerve to the abductor digiti quinti muscle. *Foot Ankle* 1987; 8:123.
24. Peer S, Kovacs P, Harpf C, Bodner G. High-resolution sonography of lower extremity peripheral nerves. *J Ultrasound Med* 2002; 21:315–322.
25. Presley JC, Maida E, Pawlina W, Murthy N, Ryssman DB, Smith J. Sonographic visualization of the first Branch of the lateral plantar nerve (Baxter nerve). *J Ultrasound Med* 2013; 32:1643–1652.