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ORIGINAL ARTICLE

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Medial plantar nerve: study of its anatomical variations

Nervo plantar medial: estudo de suas variações anatômicas

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ABSTRACT

Objective: To measure and evaluate the distance from the medial plantar nerve (MPN) to six predetermined anatomical landmarks, identifying 12 distances, and establish a correlation with the trajectory of the flexor hallucis longus (FHL) tendon, especially the knot of Henry, and the location of the bifurcation of the posterior tibial nerve (PTN) relative to the tarsal tunnel.

Methods: A descriptive and quantitative study was conducted in which 15 adult feet (six right and nine left) from cadavers were dissected, and the anatomical relationship between the MPN and predetermined structures was evaluated. The distance from the medial border of the medial malleolus to the inferior calcaneal tuberosity [defined as a fixed reference (FR)] was measured to compensate for variability in foot size.

Results: The results indicated that the bifurcation of the PTN was proximal to the tarsal tunnel in 11 feet (73.3%), within the tunnel in three feet (20%), and distal to the tunnel in one foot (6.66%). A statistically significant (p=0.035) association was found between the FR and the distance from the superior calcaneal tuberosity to the MPN, a strong correlation (p=0.004) was found between the FR and the distance from the inferior calcaneal tuberosity to the MPN, and a significant association (p=0.013) was found between the FR and the distance from the medial calcaneal tuberosity to the knot of Henry.

Conclusion: Some anatomical structures, especially the knot of Henry, have a strong correlation with the MPN and should be considered by surgeons who intend to approach the FHL in the plantar region. Bifurcation of the PTN proximal to the tarsal tunnel was the most common presentation.

Level of Evidence V; Expert Opinion.

Keywords: Tibial Nerve; Dissection; Anatomy; Hallux.

RESUMO

Objetivo: Avaliar e mensurar a distância entre o nervo plantar medial (NPM) e seis pontos anatômicos pré-estabelecidos e 12 medidas, estabelecendo uma interrelação com o trajeto do tendão do músculo flexor longo do hálux (FLH), especialmente em relação ao nó de Henry, e também a localização do nervo tibial em relação ao túnel do tarso.

Métodos: Estudo descritivo e quantitativo no qual foram dissecados 15 pés adultos (de cadáver), seis direitos e nove esquerdos, e avaliadas as relações anatômicas do NPM com outras estruturas pré-determinadas. Foi obtida uma medida (definida como "referência fixa"), como forma de evitar variações decorrentes do tamanho do pé, determinada por uma distância entre o colículo do maléolo medial e a tuberosidade inferior do calcâneo.

Resultados: O estudo mostrou que a bifurcação do nervo foi encontrada em 11 pés (73,3%) proximal ao túnel do tarso, em 3 pés (20%) situava-se no túnel e em 1 pé (6,66 7%) encontrava-se distal. Houve relevância estatística (p=0,035) na relação entre a medida fixa e a distância da tuberosidade superior do calcâneo com o NPM, forte relação (p=0,004) entre a medida fixa e a distância da tuberosidade inferior do calcâneo com o NPM, e significância estatística (p=0,013) entre a distância fixa e a distância da tuberosidade medial do calcâneo e o nó de Henry.

Work performed at the Hospital de Base de São José do Rio Preto, São José do Rio Preto, SP, Brazil.

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Conclusão: Avaliamos que certas estruturas anatômicas, principalmente o nó de Henry, mantém relação muito próxima com o NPM, devendo ser lembrado quando abordado cirurgicamente o FLH. A divisão do nervo tibial, proximal ao túnel do tarso foi a apresentação mais frequente.
Nível de Evidência V; Opinião do Especialista.

Descritores: Nervo plantar medial; Dissecção; Anatomia; Hálux.

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INTRODUCTION

The sciatic nerve is formed by the roots of the L4 to S1 vertebrae and, in the region of the popliteal fossa, bifurcates into the tibial nerve and common peroneal nerve at the level of the tarsal tunnel. The tarsal tunnel is a fibro-osseous tunnel that extends from the deep posterior compartment of the leg. The floor of the tunnel is formed by the medial surface of the talus and calcaneus, and the roof of the tunnel is formed by the flexor retinaculum[1], where the posterior tibial tendon, flexor digitorum longus tendon, posterior tibial artery and vein, posterior tibial nerve (PTN), and flexor hallucis longus (FHL) tendon run[2-4]. Although several studies have provided anatomical descriptions of the tarsal tunnel, variations in the bifurcation of the PTN have not been fully established. The neurovascular bundle consists of one artery, two veins, and the PTN, which branches into medial calcaneal, medial plantar, and lateral plantar nerves[1].

The medial plantar nerve (MPN), the widest branch of the three[1], is located between the abductor hallucis and flexor digitorum brevis, lateral to the medial plantar artery[1,5], and is divided into three digital branches. The MPN is a sensory, motor, and autonomic nerve[6] that innervates the plantar medial region, abductor hallucis muscle, flexor digitorum brevis, FHL (this structure is not described in the cited studies), and first lumbrical muscle[1,7].

The FHL tendon is widely used for tendon transfers and can be used for treating pathologies such as posterior tibial tendon insufficiency and insertional and non-insertional Achilles tendinopathies, among others[8].

The FHL muscle originates in the intermuscular septum, immediately below the fibular head, traverses the deep posterior compartment until it reaches, as a tendon, the posteromedial region of the talus and, in a deep plane, follows the flexor digitorum longus tendon until it is inserted into the distal phalange of the hallux. The function of the FHL muscle is to flex the hallux and, secondarily, help the plantar flexion of the ankle[9].

The MPN runs, in a deep plane, to the abductor hallucis muscle, medial to the FHL tendon in the region of the knot of Henry[10]. Therefore, the MPN should be visualised directly[11] to avoid injuries to this nerve[8].

This study is relevant due to the possibility of injuries to the MPN during foot and ankle surgeries, as the knowledge of the trajectory of the MPN from the tarsal tunnel through predetermined anatomical structures may help avoid injuries to this nerve[8,12]. Greene et al. (2001) evaluated the neurovascular structures of the medial region of the foot and ankle and established relationships between these structures and predetermined anatomical landmarks[13]. Injuries to the MPN cause sensory disturbance in the plantar region of the first to the fourth toes, resulting in complaints of electric shock sensations in the medial plantar arch and causing an antalgic gait in supination, limiting the support of the midfoot at the medial border. These injuries also lead to motor disturbance of the abductor hallucis, flexor digitorum brevis, flexor hallucis brevis, and lumbrical muscles[10].

The objective of this study is to measure and evaluate the distance from the MPN to six predetermined anatomical landmarks, identifying 12 distances, and establish correlations among the trajectory of the FHL tendon, knot of Henry, and location of the bifurcation of the PTN.

METHODS

This study was approved by the Research Ethics Committee with registration in the Brazil Platform under CAAE number: 82526618.1.0000.5415.

This descriptive and quantitative study involved dissecting the feet of adult cadavers and was conducted in the anatomy laboratory according to law nº 8.501/92, which provides for the use of unclaimed corpses for research purposes.

Fifteen feet (six right and nine left) were dissected and preserved in 10% formaldehyde. The anatomical relationships of the MPN with predetermined structures, which are critical anatomical landmarks associated with this nerve, were evaluated in these specimens[12]. The bone structures were chosen because they are easily identified due to the fibrous adhesions between the FHL and flexor digitorum longus (knot of Henry).

The distance from the medial malleolus to the inferior calcaneal tuberosity, defined as a fixed reference (FR) used to compensate for foot size, was calculated, and the location of the bifurcation of the PTN (proximal, within, or distal to the tarsal tunnel) was assessed. This relationship was evaluated using a Brasfort® manual calliper, and all cadavers were dissected by the same surgeon. The reference points used to establish a distance relationship between the MPN and FHL included the medial border of the medial malleolus, superior calcaneal tuberosity, navicular tuberosity, medial calcaneal tuberosity, knot of Henry, and inferior calcaneal tuberosity (Figure 1).

A number 15 scalpel was used for extensive resection of the skin, with a length of 5cm proximal to the medial tibial malleolus until the head of the first metatarsus, width of 6cm anterior to the medial malleolus and 5cm posterior to the medial malleolus, and the area was extended when necessary.

The abductor hallucis muscle was removed from the plantar region, the tarsal tunnel was identified, and a rectilinear incision was made on the latter to expose and identify the tibialis posterior tendon, flexor digitorum longus tendon, neurovascular bundle, and FHL tendon. After dissection and individualisation of these structures, measurements were made in the predetermined structures using a calliper, and coloured pins were used as identifiers (Figure 1).

For the measurements, a line was drawn from the medial border of the medial malleolus to the inferior calcaneal tuberosity, and this distance served as the FR. Eleven distances were measured from the six reference points as follows: 1. medial border of the medial malleolus to the knot of Henry, 2. medial border of the medial malleolus to the MPN (along the line previously drawn), 3. superior calcaneal tuberosity to the MPN (at 90º to the tuberosity), 4. navicular tuberosity to the MPN (relative to the bifurcation), 5. navicular tuberosity to the MPN (at 90º to the tuberosity), 6. navicular tuberosity to the knot of Henry, 7. medial calcaneal tuberosity to the MPN (along the line previously drawn), 8. medial calcaneal tuberosity to the knot of Henry (along the line previously drawn), 9. MPN to the knot of Henry, 10. inferior calcaneal tuberosity to the knot of Henry (along the line previously drawn), and 11. inferior calcaneal tuberosity to the MPN (along the line previously drawn) (Figures 2 to 4).

These measurements were entered into a database using an MS-Excel spreadsheet from Microsoft Office version 2013. All statistical analyses were conducted using the Statistical Package for the Social Sciences package version 23.0 at a level of significance of 5%.

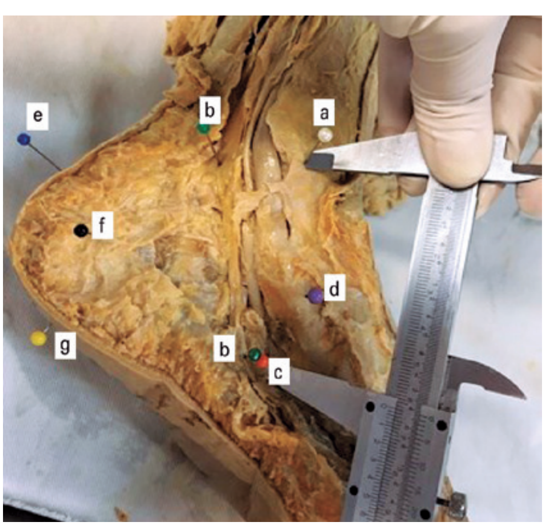

Figure 1. Relationship between the medial plantar nerve and the reference points. (a) Medial border of the medial malleolus, (b) medial plantar nerve, (c) knot of Henry, (d) navicular tuberosity, (e) superior calcaneal tuberosity, (f) medial calcaneal tuberosity, (g) inferior calcaneal tuberosity.
Source: Author's personal archive.

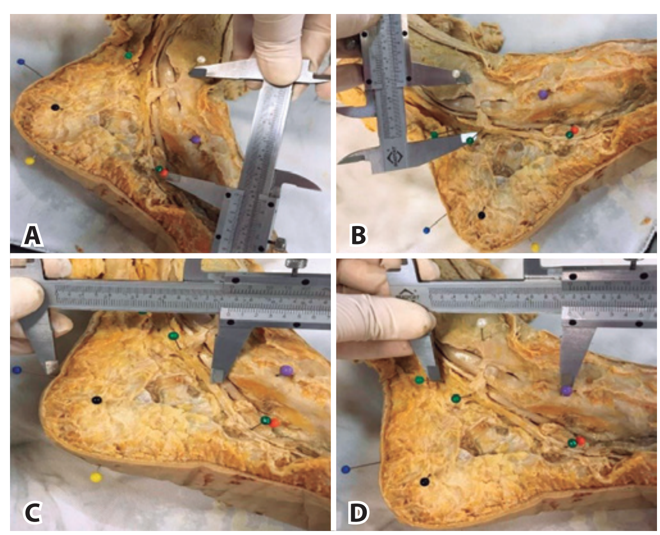

Figure 2. Measurement of the distances from the (a) medial border of the medial malleolus to the knot of Henry, (b) medial border of the medial malleolus to the medial plantar nerve (along the line drawn previously), (c) superior calcaneal tuberosity to the MPN (at 90º to the tuberosity), (d) navicular tuberosity to the medial plantar nerve relative to the bifurcation and at 90º to the tuberosity.
Source: Author's personal archive.

RESULTS

The bifurcation of the PTN was proximal to the tarsal tunnel in 11 feet (73.3%), within the tunnel in three feet (20%), and distal to the tunnel in one foot (6.66%). The mean distance from the medial malleolus to the knot of Henry was 6.07±0.50cm, and the mean distance from the medial malleolus to the MPN was 2.29±0.47cm (Table 1).

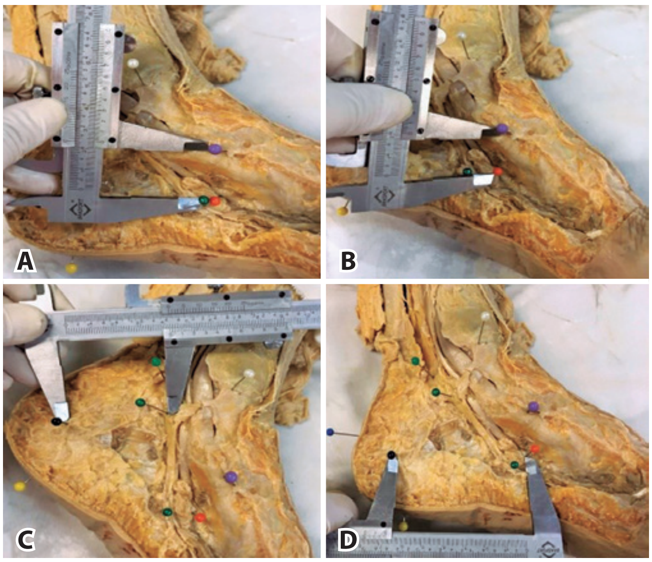

Figure 3. Measurement of the distances from the (a) navicular tuberosity to the medial plantar nerve at 90º to the tuberosity, (b) navicular tuberosity to the knot of Henry, (c) medial calcaneal tuberosity to the medial plantar nerve (along the line drawn previously), (d) medial calcaneal tuberosity to the knot of Henry (along the line drawn previously).
Source: Author's personal archive.

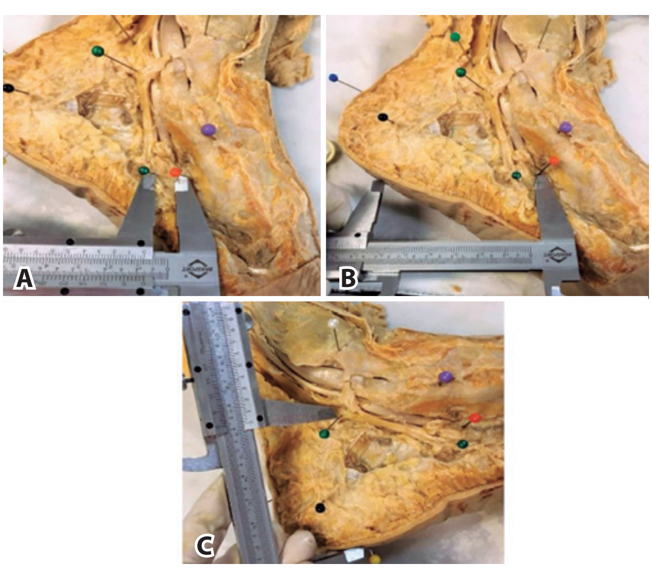

Figure 4. Measurement of the distances from the (a) medial plantar nerve to the knot of Henry, (b) inferior calcaneal tuberosity to the knot of Henry (along the line drawn previously), (c) inferior calcaneal tuberosity to the medial plantar nerve (along the line drawn previously).
Source: Author's personal archive.

The scalar variables for the predetermined distances are shown in Table 2. The mean distance from the MPN to the knot of Henry was 0.33±0.24cm, with a median of 0.2cm.

Correlations between the scalar variable and the bifurcation site and distance from the medial malleolus to the inferior calcaneal tuberosity were determined using Spearman correlation analysis.

There were strong correlations ($p<0.05$) between the FR and the distance from the superior calcaneal tuberosity to the MPN and between the FR and the distance from the inferior calcaneal tuberosity to the MPN. Moreover, a strong association was observed between the bifurcation site and the distance from the medial calcaneal tuberosity to the knot of Henry, but a weak correlation with the other measurements was observed.

The correlation analysis indicated that the FR exhibited a positive correlation coefficient with the following distances: 1. medial malleolus to the MPN, 2. superior calcaneal tuberosity to the MPN, 3. navicular tuberosity to the MPN (relative to the bifurcation), 4. navicular tuberosity to the MPN at 90º to the tuberosity, 5. medial calcaneal tuberosity to the knot of Henry, and 6. inferior calcaneal tuberosity to the MPN, demonstrating that a larger FR resulted in an increase in these measures, and vice-versa.

DISCUSSION

The FHL tendon is a strong flexor and widely used in tendon transfers in foot and ankle surgeries[8]. The MPN, a sensory, motor, and autonomic nerve[6], runs in a plane deep to the abductor hallucis muscle, running medial to the FHL tendon in the region of the knot of Henry[10].

In our study, the mean and median values of the correlation between the MPN and knot of Henry indicated these two anatomical landmarks were strongly associated, and

Table 1. Categorical variables.

Variable	Category	Frequency	Percentage
Side	R	6	40%
	L	9	60%
Location of the bifurcation of the posterior tibial nerve (distal, within, or proximal to the tarsal tunnel)	Within	3	20%
	Distal	1	6.7%
	Proximal	11	73.3%

Source: Prepared by the author based on the results of the research.

Table 2. Scalar variables for predetermined distances.

Measured distances	n	Minimum	Maximum	Mean	Standard deviation	25th percentile	50th percentile (median)	75th percentile
Medial malleolus to the knot of Henry	15	5.10	6.80	6.07	0.50	5.70	6.00	6.50
Medial malleolus to the medial plantar nerve	15	1.50	2.90	2.29	0.47	1.80	2.40	2.70
Superior calcaneal tuberosity to the posterior tibial nerve	15	4.00	7.60	5.41	1.14	4.50	5.50	6.10
Navicular tuberosity to the posterior tibial nerve relative to the bifurcation of this nerve	15	3.10	8.10	6.03	1.39	5.10	6.20	7.30
Navicular tuberosity to the posterior tibial nerve at 90º to the tuberosity	15	1.40	2.30	2.01	0.27	1.90	2.10	2.20
Navicular tuberosity to the knot of Henry	15	1.20	4.10	2.15	0.74	1.60	2.20	2.50
Medial calcaneal tuberosity to the posterior tibial nerve	15	2.30	4.60	3.36	0.62	3.10	3.20	4.00
Medial calcaneal tuberosity to the knot of Henry	15	4.60	7.90	6.19	0.76	6.00	6.20	6.60
Posterior tibial nerve to the knot of Henry	15	0.10	1.00	0.33	0.24	0.20	0.20	0.30
Inferior calcaneal tuberosity to the knot of Henry	15	5.10	7.60	6.89	0.64	6.60	6.80	7.40
Inferior calcaneal tuberosity to the posterior tibial nerve	15	4.40	6.50	5.51	0.66	4.90	5.50	6.00
Medial malleolus to the inferior calcaneal tuberosity	15	6.40	8.70	7.80	0.60	7.40	7.80	8.30

Source: Prepared by the author based on the results of the research.

Table 3. Spearman correlation analysis and degree of correlation between the variables of interest. Correlation coefficient (CC), significance (S), number of feet (n).

Measured distances	Statistics	Bifurcation is located distal, within, or proximal to the tarsal tunnel	Distance from the medial malleolus to the inferior calcaneal tuberosity
Medial malleolus to the knot of Henry	CC (r)	-0.183	+0.050
	p-value	0.513	0.861
	n	15	15
Medial malleolus to the posterior tibial nerve	CC (r)	+0.060	+0.193
	p-value	0.831	0.491
	n	15	15
Superior calcaneal tuberosity to the posterior tibial nerve	CC (r)	-0.125	+0.546
	p-value	0.656	**0-035**
	n	15	15
Navicular tuberosity to the posterior tibial nerve relative to the bifurcation of this nerve	CC (r)	-0.493	+0.095
	p-value	0.062	0.736
	n	15	15
Navicular tuberosity to the posterior tibial nerve at 90º to the tuberosity	CC (r)	-0.277	+0.294
	p-value	0.317	0.288
	n	15	15
Navicular tuberosity to the knot of Henry	CC (r)	+0.311	-0.452
	p-value	0.259	0.091
	n	15	15
Medial calcaneal tuberosity to the posterior tibial nerve	CC (r)	-0.051	+0.346
	p-value	0.856	0.207
	n	15	15
Medial calcaneal tuberosity to the knot of Henry	CC (r)	-0.623	-0.092
	p-value	0.013	0.744
	n	15	15
Posterior tibial nerve to the knot of Henry	CC (r)	-0.201	-0.071
	p-value	0.472	0.803
	n	15	15
Inferior calcaneal tuberosity to the knot of Henry	CC (r)	-0.021	-0.087
	p-value	0.941	0.757
	n	15	15
Inferior calcaneal tuberosity to the posterior tibial nerve	CC (r)	-0.413	+0.694
	p-value	0.126	0.004
	n	15	15

Source: Prepared by the author based on the results of the research.

this characteristic should be considered by surgeons who intend to approach the FHL in the plantar region. However, the association of the MPN with the other structures is weak, and therefore these structures are less susceptible to injuries during surgical procedures.

In Achilles tendinopathies, if the recommended technique is transfer of the FHL, especially in cases in which a longer graft is required(8,11,12,14), the double-incision technique, in which the second incision is performed in the medial and plantar region of the midfoot (on the knot of Henry), can be used. There is a risk of unintended injury to the MPN during its isolation because of the proximity of this nerve to the knot of Henry(8). Injuries to the MPN can be avoided by making a second incision of appropriate size for direct visualisation of the structures, maintaining the foot pronated, and identifying and separating the MPN during dissection of these structures(6,11). Mulier et al.(12) evaluated the occurrence of MPN injuries in 24 cadavers after performing a double incision and observed that the MPN was injured in six cases(8). Amlag et al.(11) performed a retrospective study with 25 patients undergoing double incision, visualised the MPN, and separated it before dissecting the FHL. These authors found that the MPN was not injured in any of the cases, emphasising the importance of adequate visualisation and separation to avoid injuries to this nerve(11).

The tarsal tunnel is fibro-osseous, with moderate flexibility, and any excessive tension within this tunnel caused by scars, bone deformities, or tumours may lead to symptoms of nerve compression. Compression of the PTN may cause different symptoms depending on the location of the bifurcation, especially in cases in which the bifurcation is proximal to the tarsal tunnel(15). Moreover, this bifurcation determines the direction in which the nerve runs, and this direction is closely correlated with clinical function(15-17). Torres et al. indicated that identifying the bifurcation site was essential because the probability of nerve compression in bifurcations within the tunnel was increased(1).

In our study, the bifurcation of the PTN was proximal to the tarsal tunnel in 11 feet (73.3%), within the tunnel in 3 feet (20%), and distal to the tunnel in 1 foot (6.66%). This result differs from that of other studies(13,18,19), wherein most bifurcation sites were located within the tunnel, and few were located proximal or distal to the tunnel. Moraes Filho et al. examined 38 cadavers and observed that the bifurcation was proximal to the tunnel in 31.75% of the cases and within the tunnel in 65.78% of the cases; these results are different from ours. Evaluation of the bifurcation site during surgery is essential to guarantee precision and attention to the size of the access route. The PTN and its branches should be identified during the incision of the tarsal tunnel, and the incision can be extended as necessary until the nerve trunk and branches are isolated(1,4,20).

The objectives proposed in the present study were partially achieved, allowing the evaluation and measurement of the anatomical relationships of the MPN with 11 reference distances and establishing a correlation between the trajectory of the FHL, especially the knot of Henry, and the location of the bifurcation of the PTN in the 15 studied feet.

CONCLUSION

The anatomical results of the foot dissections indicated that specific anatomical structures, particularly the knot of Henry, maintained a close association with the MPN and that the distances among the FR, superior calcaneal tuberosity, and MPN followed a constant pattern in the anatomical structures evaluated. These parameters, especially the proximity to the knot of Henry, with a mean distance of 0.33cm, should be carefully evaluated by surgeons to avoid injuries to the MPN during surgical procedures. The bifurcation of the PTN was proximal to the tarsal tunnel in most cases (73.3%), and therefore, this nerve was less susceptible to compression in our sample.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MBC *(https://orcid.org/0000-0002-2021-1126) conceived and planned the activities that led to the study, interpreted the results of the study and approved the final version; HI *(https://orcid.org/0000-0002-1179-4809) conceived and planned the activities that led to the study, participated in the review process and approved the final version; MGF *(https://orcid.org/0000-0002-5163-1035) participated in the review process, interpreted the results of the study and approved the final version; RAM *(https://orcid.org/0000-0003-4583-7413) participated in the review and approved the final version; FB *(https://orcid.org/0000-0003-4099-2879) conceived and planned the activities that led to the study and approved the final version. *ORCID (Open Researcher and Contributor ID).

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