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Topographic anatomy of the neurovascular bundle at the tarsal tunnel and its applied significance

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Abstract:

BACKGROUND: There are different surgical procedures and treatment modalities dealing with medial ankle region such as placement of percutaneous pins in the calcaneus, decompression in tarsal tunnel syndrome, and nerve block. This requires detailed anatomical knowledge about the neurovascular bundle to avoid iatrogenic injury.

AIM OF THE WORK: To study the topography of nerves and vessels at the tarsal tunnel in relation to surface anatomical landmarks.

MATERIALS AND METHODS: The medial calcaneal region of 20 lower limbs of formalin preserved specimens was dissected. The neurovascular structures were identified within a quadrangle named ABCD, formed by four palpable bony landmarks, respectively: inferior tip of medial malleolus, posterior superior tip of calcaneal tuberosity, posteroinferior aspect of medial calcaneus, and tuberosity of navicular bone. A regression analysis was done to correlate the lengths of the four imaginary lines connecting the four bony landmarks with the location of the neurovascular structures.

RESULTS: The posterior tibial artery was located medial to the tibial nerve in 50% of cases. The bifurcation of the artery was found to be proximal to that of the nerve in only one case. The number of the medial calcaneal nerves (MCNs) varied from 1 to 3 branches; the most common was one branch (50%). In two cases, there was high origin of the MCN at a distance of 15.4 and 23.5 cm proximal to the ankle region.

CONCLUSION: The location of the neurovascular bundle at the tarsal tunnel could be predicted by measuring the distances between the anatomical bony landmarks.

Keywords:

Medial calcaneal branch, posterior tibial artery, tarsal tunnel, tibial nerve

Introduction

Pain in the foot manifested as numbness, burning sensation, or paresthesia is a common complaint which has its impact on the quality of life, especially in people with different outdoor activities and also among athletes (Irving *et al*., 2008; Osman *et al*., 2016). This pain could be due to orthopedic problems leading to entrapment of the tibial nerve (TN) or its branches in the tarsal tunnel and also due to plantar fasciitis (Tu and Bytomski, 2011; Thapa and Ahuja, 2014). There are different surgical procedures and treatment modalities dealing with medial ankle region, such as placement of percutaneous pins in the calcaneus, correction of foot and ankle deformities, medial displacement osteotomies, decompression in tarsal tunnel syndrome, and nerve block (Gould, 2014; Kim *et al*., 2014; Thapa and Ahuja, 2014). All these interventions require precise detailed anatomical knowledge about the neurovascular bundle at the tarsal tunnel to avoid iatrogenic injury of these vulnerable structures at the medial region of the ankle joint.

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There are different branching patterns of the TN and posterior tibial artery (PTA) reported in literature and also different origin and number of the medial calcaneal and inferior calcaneal nerves (Mereau *et al*., 2005; Govsa *et al*., 2006). Studying the relationship between the PTA and the location of its bifurcation relative to the bifurcation of the TN at the medial ankle region is crucial to define the safe zone during surgical intervention and to performe therapeutic nerve block (Gamie *et al*., 2009; Kim D.I., *et al*., 2015). Moreover, it is clinically helpful to determine the location of these neurovascular structures in relation to defined surface anatomical landmarks for the proper diagnosis and treatment of such clinical conditions.

Aim of the work

The aim of this work is to study the topography of the nerves and vessels at the tarsal tunnel and its relation to certain anatomical landmarks and ultimately correlating these to its clinical significance.

Materials and Methods

This descriptive study design has received research approval from the Institutional Ethical Committee. The material of this work includes 20 lower limbs of formalin-preserved specimens. Seven (35%) right and 13 (65%) left medial calcaneal regions were dissected.

Dissection and measurement of structures

A medial approach was used for each specimen with the ankle at right angle to the leg.

The flexor retinaculum was divided to access the deeper tendinous and neurovascular structures. The following structures were identified and carefully dissected: TN, medial plantar nerve (MPN), lateral plantar nerve (LPN), PTA, medial plantar artery, lateral plantar artery, medial calcaneal nerve (MCN), and Baxter nerve (inferior calcaneal nerve).

We marked the location and bifurcation sites of neurovascular structures in the ankle region within a quadrangle named ABCD, using four palpable bony landmarks to map out areas: A – Inferior tip of medial malleolus; B – posterior superior tip of calcaneal tuberosity; C – posteroinferior aspect of medial calcaneus; D – tuberosity of navicular bone [Figure 1].

The lengths of the imaginary lines connecting A, B, C, D landmarks namely AB, CD, AC, and BD were measured. Lines BC and AD were not considered because they will not intersect any of the neurovascular structures at this region. The distances between these four lines and the bifurcation of both PTA and TN and the distal MCN were taken. The distal MCN was considered as it is the

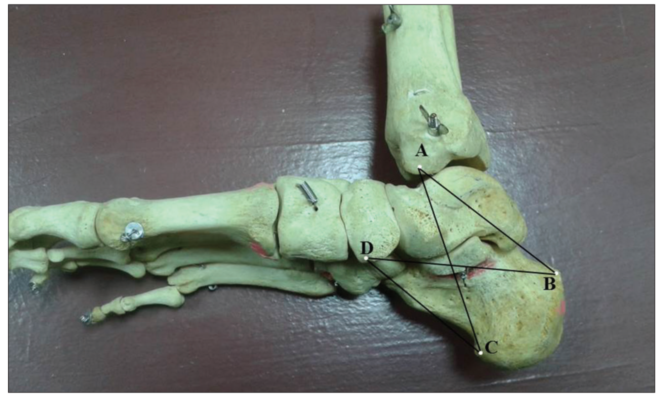

Figure 1: Photograph of skeleton of right ankle region showing four bony anatomical landmarks and the rectangle bounded by them; A - inferior tip of medial malleolus, B - posterior superior tip of calcaneal tuberosity, C - medial process of calcaneal tuberosity, D - navicular tuberosity

one commonly located within this rectangle and could be compromised during surgery.

The number and variant origin of MCN were reported.

The relationship between the TN and the PTA was classified into four types (Kim D.I., *et al*., 2015), as follows: Type I – PTA is medial to TN; Type II – PTA is anterior to TN; Type III – PTA is lateral to TN; Type IV – PTA is located between medial and LPNs.

Measurements were recorded using nondigital vernier caliper accurate up to 0.1 mm [Figure 2].

Values were expressed as means and standard deviations; a level of statistical significance was established at $P < 0.05\%$. Statistical analysis was performed using SPSS version 19 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY).

A regression analysis was done to correlate the lengths of the four imaginary lines connecting the four bony landmarks with the location of the neurovascular structures.

Results

Examination of the 20 dissected medial calcaneal regions showed variations in the relative locations of the neurovascular structures.

Distances between the four bony landmarks

The mean lengths of the four lines in the rectangle ABCD are shown in Table 1.

Topography of the posterior tibial artery and the tibial nerve

The most common type of relationship between the PTA and the TN was Type I (10 feet, 50%), where the PTA was located medial to the TN. The least common type was Type IV (one case, 5%) [Table 2].

The mean distances between the bifurcation of PTA and TN from the four lines are shown in Table 3. Furthermore, the distances between the origin of the most distal MCN and the four lines are shown [Table 3].

The bifurcation of PTA was found to be proximal to that of TN in only one case [Figure 3].

The PTA and the TN bifurcated proximal to the AB line in four and seven cases, respectively.

Medial calcaneal nerves

The number of the MCN varied from 1 to 3 branches; the most common was one branch (50%). Further, its origin was variable, either from TN or its branches [Figure 4a and b]. The most frequent origin was from the LPN in seven cases (35%) [Table 4].

In two cases, there was high origin of one MCN. The most proximal MCN originated from the TN at a distance of 15.4 and 23.5 cm proximal to AB line [Figure 5].

Baxter nerve (inferior calcaneal nerve)

It was present in all cases; it is the first branch of the LPN [Figure 4 b]. After its origin, it passes deep to abductor hallucis muscle. In one case, in which the TN bifurcation was proximal to AB line, the Baxter nerve also originated proximal to AB line.

The relation between the lengths of the four lines and the location of the neurovascular bundle

A regression analysis was done to correlate the location of the distal MCN and the bifurcation site of PTA and TN, with the lengths of the four lines AB, CD, AC, and BD forming the rectangle on the medial ankle region [Table 5].

Using this equation Y = a+ (b × X), where Y = the distance of the variable from the line and X = the length of the line, we can predict the location of these variables by measuring the distances between the four bony landmarks.

Discussion

Poor understanding of the detailed anatomy of the "tarsal tunnel" could lead to unsatisfactory results of surgical treatment in this area (Singh and Kumar, 2012).

Placement of percutaneous pins in the calcaneus is a procedure which is commonly used for external fixation, traction, and correction of deformities (Bonar and Marsh, 1993; Mekhail *et al*., 1996; Casey *et al*., 2004; Gamie *et al*., 2009). Many anatomical structures at this region, including the medial neurovascular bundle, could be injured during these procedures.

Previous studies used different bony anatomical landmarks to define a safe zone for pin placement at the calcaneus (Mekhail *et al*., 1996; Santi and

Table 1: The mean lengths of the four lines in the rectangle ABCD

Variable	Mean±SD (cm)	Minimum (cm)	Maximum (cm)
Length of AB	5.85±0.56	5.13	7.10
Length of CD	7.51±0.66	6.46	8.70
Length of AC	7.11±0.81	6.27	8.80
Length of BD	8.04±0.59	7.44	9.10

SD - Standard deviation

Table 2: Classification of relationship between posterior tibial artery and tibial nerve

Type	Number of cases (%)
I	10 (50)
II	3 (15)
III	6 (30)
IV	1 (5)

Figure 2: Right medial tarsal region; pins placed into points A (inferior tip of medial malleolus) and B (posterior superior tip of calcaneal tuberosity). Vernier caliper used to measure the distance of bifurcation of tibial nerve from AB line. TN - Tibial nerve

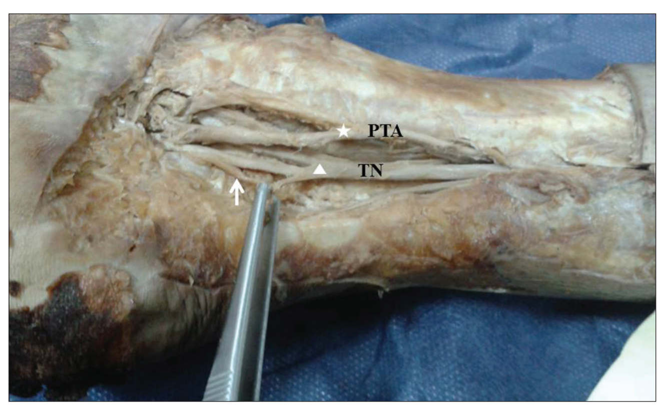

Figure 3: Right medial tarsal region showing the posterior tibial artery bifurcation (*) is proximal to tibial nerve bifurcation (arrowhead). The origin of the medial calcaneal nerve (arrow) is from the site of bifurcation of the tibial nerve. TN - Tibial nerve, PTA - Posterior tibial artery

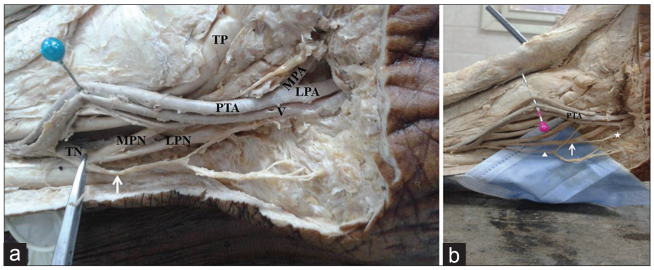

Figure 4: (a) Left medial calcaneal region showing posterior tibial artery; medial plantar artery; lateral plantar artery; venae commitants; tibial nerve; medial plantar nerve; lateral plantar nerve; tibialis posterior tendon. Medial calcaneal nerve (arrow). (b) The previous specimen after retraction of posterior tibial artery showing Baxter nerve (*) originating from lateral planter nerve (arrow). Medial calcaneal nerve (arrowhead) emerges proximal to the site of bifurcation of tibial nerve. TN - Tibial nerve, PTA - Posterior tibial artery, LPN - Lateral plantar nerve, MPN - Medial plantar nerve, MPA - Medial plantar artery, LPA - Lateral plantar artery, V - Venae commitants

Table 3: The distances between the bifurcation of posterior tibial artery and tibial nerve and the origin of the distal medial calcaneal nerve from the four lines AB, CD, AC, BD

Variable	Mean±SD (cm)	Minimum (cm)	Maximum (cm)
Dist. PTA-AB	1.40±0.91	0.00	2.71
Dist. PTA-CD	3.77±1.73	0.74	6.60
Dist. PTA-AC	1.83±1.49	0.30	4.40
Dist. PTA-BD	2.15±1.35	0.46	4.20
Dist.TN-AB	1.86±1.04	0.76	4.13
Dist.TN-CD	5.07±1.67	1.27	8.17
Dist.TN-AC	3.01±1.70	0.00	6.62
Dist.TN-BD	3.44±1.42	0.58	5.82
Dist. MCN-AB	1.88±0.75	1.08	3.60
Dist. MCN-CD	3.85±1.79	1.37	6.70
Dist. MCN-AC	2.15±1.69	0.26	4.94
Dist. MCN-BD	2.16±1.75	0.00	4.96

Dist. PTA-AB - Distance between bifurcation of PTA and AB line, Dist. PTA-CD - Distance between bifurcation of PTA and CD line, Dist. PTA-AC - Distance between bifurcation of PTA and AC line, Dist. PTA-BD - Distance between bifurcation of PTA and BD line, Dist.TN-AB - Distance between bifurcation of tibial nerve and AB line, Dist.TN-CD - Distance between bifurcation of tibial nerve and CD line, Dist.TN-AC - Distance between bifurcation of tibial nerve and AC line, Dist.TN-BD - Distance between bifurcation of tibial nerve and BD line, Dist. MCN-AB - Distance between medial calcaneal nerve and AB line, Dist. MCN-CD - Distance between medial calcaneal nerve and CD line, Dist. MCN-AC - Distance between medial calcaneal nerve and AC line, Dist. MCN-BD - Distance between medial calcaneal nerve and BD line, SD - Standard deviation

Botte, 1996). Most of these studies identified one, two, or three bony landmarks to describe the topography of the neurovascular bundle at the tarsal tunnel. For example, Kim BS *et al*. (2015) used only the medial malleolus as a reference point. Joshi *et al*. (2006) used the medio-malleolar-calcaneal axis extending from the tip of medial malleolus to the medial tubercle of calcaneus. Casey *et al*. (2004) identified three bony points, posteroinferior medial calcaneus, inferior medial malleolus, and navicular tuberosity. In the present study, four bony anatomical landmarks were defined, by adding a bony point which is the posterior superior tip of calcaneal tuberosity which has significance in the course of the MCN, in an attempt to locate precisely the neurovascular bundle to minimize damage.

Figure 5: A photograph for a right lower limb showing the origin of the medial calcaneal nerve (arrow) from the tibial nerve in the upper third of the leg. TN - Tibial nerve

Table 4: The number and origin of medial calcaneal nerve

	Number of cases (%)
Number of MCN	
1	10 (50)
2	9 (45)
3	1 (5)
Origin of MCN	
1 TN, 2 MPN	1 (5)
LPN	7 (35)
MPN	1 (5)
Tib. N bif.	4 (20)
TN	3 (15)
TN, LPN	4 (20)

MCN - Medial calcaneal nerve, TN - Tibial nerve, LPN - Lateral plantar nerve, MPN - Medial plantar nerve, Tib. N bif. - Tibial nerve bifurcation

The bifurcation of PTA was distal to that of posterior TN; this was also reported by Joshi *et al*. (2006), Tamang *et al*. (2016), and Yang *et al*. (2017). However, in the present study the opposite was detected in only one case.

The PTA was always superficial to the TN at the tarsal tunnel, and this finding was reported before in a previous study (Tamang *et al*., 2016).

MCN origin and number were variable in the present study, which was consistent with results of previous research. Govsa *et al*. (2006) described different variations for the MCN; most commonly, there were two MCN branches, one arising from the LPN and the other from the MPN. In another study, the most common finding was two independent branches, one arising before the bifurcation of the TN and the other arising from the MPN (Gamie *et al*., 2009). Kim DI *et al*. (2015) reported that MCN originated from the TN in most cases.

Table 5: Regression analysis to predict the location of the distal medial calcaneal nerve and the bifurcation site of posterior tibial artery and tibial nerve from the surface measurements (lengths of the four lines)

Variable	Mean±SD length of rectangle's line (cm)	Constant (a)	*b*	Mean±SD distance of the variable from the line (cm)	*r*
PTA bifurcation					
AB	5.85±0.56	−4.198	0.957	1.40±0.91	0.595
CD	7.51±0.66	−7.139	1.453	3.77±1.73	0.553
AC	7.11±0.81	−7.532	1.316	1.83±1.49	0.720
BD	8.04±0.59	−7.779	1.235	2.15±1.35	0.540
TN bifurcation					
AB	5.85±0.56	1.739	0.021	1.86±1.04	0.321
CD	7.51±0.66	−0.807	0.783	5.07±1.67	0.309
AC	7.11±0.81	0.031	0.419	3.01±1.70	0.420
BD	8.04±0.59	3.871	−0.054	3.44±1.42	0.422
MCN					
AB	5.85±0.56	5.082	−0.547	1.88±0.75	0.463
CD	7.51±0.66	−5.072	1.188	3.85±1.79	0.522
AC	7.11±0.81	−3.62	0.812	2.15±1.69	0.390
BD	8.04±0.59	−9.275	1.423	2.16±1.75	0.52

Y=a+ (b×X), Y - Distance of the variable from the line, X - Length of the rectangle's line. MCN - Medial calcaneal nerve, TN - Tibial nerve, PTA - Posterior tibial artery, SD - Standard deviation

A safe zone for percutaneous pin placement in the medial calcaneus was defined in previous studies as being located beyond a midpoint between the inferior tip of the medial malleolus and the posterior-inferior medial calcaneus; however, the MCN branches remain at risk of injury (Mereau *et al*., 2005).

Baxter nerve or the inferior calcaneal nerve was named after Dr. Donald Baxter, who first described the syndrome of Baxter's nerve entrapment in 1984 (Baxter and Thigpen, 1984).

It is a mixed nerve, motor mainly to abductor digiti minimi and sensory to calcaneal periosteum and long plantar ligament. It could be compressed adjacent to the medial calcaneal tuberosity or due to hypertrophied abductor hallucis muscle (Martin-Oliva *et al*., 2013; Kim BS *et al*., 2015; Pomeroy *et al*., 2015).

In the present study, inferior calcaneal nerve consistently originated from the LPN distal to AB line, except in one case in which TN bifurcation was proximal to AB line; the Baxter nerve also originated 0.7 cm proximal to AB line. These anatomical findings could be useful for performing procedures, such as nerve block or electrophysiologic studies.

A regression analysis was conducted to correlate the surface measurements (lengths of the four lines connecting the four bony points) with the location of the different neurovascular structures at the medial ankle region. By applying the equation of this regression analysis, location of these neurovascular structures could be predicted preoperatively; this could be helpful to minimize the risk of injury to these structures.

Conclusion

In fact, it is a bit difficult to predict the likelihood of iatrogenic neurovascular injuries because of the anatomical variations encountered in the tarsal canal; however, nerve entrapment syndromes could be managed more effectively when surgeons are oriented with the detailed anatomy of this region. We believe that full orientation with the anatomy of the tarsal tunnel among neuroradiologists and foot and ankle surgeons will provide better preoperative planning and localization of the site of lesion and/or nerve compression; accordingly, better outcomes for the management are expected.

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Conflicts of interest

There are no conflicts of interest.

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