Review paper

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Sonographic assessment of the tarsal tunnel compared to cadaveric findings: a pictorial study

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Abstract

Aim of the study: To present the anatomy of the tarsal tunnel and demonstrate the utility of high-resolution ultrasound for tarsal tunnel examination. **Materials and methods:** Anatomical dissection was performed on a defrosted cadaveric model to demonstrate relevant anatomical structures of the tarsal tunnel, namely tendons, vessels and nerves. The tibial nerve division was demonstrated; the bifurcation of the tibial nerve into the medial and lateral plantar nerve, two medial calcaneal nerve branches were identified originating from the tibial nerve and the Baxter's nerve was identified as the first branch of the lateral plantar nerve. An ultrasound examination of the tarsal tunnel region was performed on a healthy volunteer. A linear probe was used and sonographic images were obtained at different levels of the tarsal tunnel: the proximal tarsal tunnel, the tibial nerve division into the medial and lateral plantar nerves, the distal tarsal tunnel, the Baxter's nerve branching point and the Baxter's nerve crossing between the abductor hallucis and quadratus plantae muscle. **Results:** Sonographic images were correlated with anatomical structures exposed during cadaveric dissection. **Conclusions:** We presented the anatomic-sonographic correlation of the tarsal tunnel and showed that high-resolution ultrasound is a useful imaging modality for tarsal tunnel assessment.

Introduction

Pathology associated with the tarsal tunnel (TT) is not as uncommon as previously believed. Conditions causing heel or plantar pain are commonly under or misdiagnosed[1–4]. The differential diagnosis for foot pain in this region includes tarsal tunnel syndrome (TTS), Baxter's neuropathy, plantar fasciitis, plantar fascia rupture, tendinopathy of the flexor tibialis posterior tendon (PTT), the flexor digitorum longus tendon (FDLT) and the flexor hallucis longus tendon (FHLT), S1 radiculopathy, calcaneal stress fracture, and plantar fat pad disorders[3–6]. A diagnosis may be achieved with a combination of good clinical examination and appropriate diagnostic methods, such as imaging and nerve conduction studies. In TTS, up to 20% to 40% of cases are considered idiopathic, but specific compression causes may be found in 60–80% of cases[1–3,5,7].

TT is a complex anatomic passage with contents running in separate osteo-fibrous compartments[4–10]. Additionally, the anatomy of the tibial nerve (TN) in this area is highly variable, with different bifurcation patterns, numbers and origins of terminal branches[4,7,9,11,12]. Ultrasound is a non-invasive and easily accessible diagnostic modality that allows good soft tissue evaluation and may be convenient for TT examination due to its superficial location. High-resolution ultrasound has proven to be a valuable method in diagnosing and treating pathologies of the foot and ankle region[3,4,6,8,13–16]. It allows the depiction of small but clinically important structures in this complex anatomical area[6,15,16].

Several studies have demonstrated the possibilities of ultrasound-guided interventional procedures for TT for symptom relief and treatment of TTS[2,4,6,15,17–19]. Ultrasound-guided hydro-dissection of the tarsal tunnel may be offered for symptom alleviation in patients with TTS[4]. Similarly, ultrasound-guided perineural injection of the Baxter's nerve (BN) for selective nerve block could present a therapeutic alternative for patients with chronic heel pain caused by Baxter's neuropathy[6,18]. Minimally invasive ultrasound-guided tarsal tunnel decompression could be a potential therapeutic option for patients with proximal and distal TTS[4,15,17,19]. A detailed understanding of the complex and variable TT anatomy is needed to correctly assess this anatomical region as part of the diagnostic pathway and plan ultrasound-guided procedures[4,8,11,12]. This paper presents the sonographic anatomy of the TT correlated with cadaveric findings.

Materials and methods

Anatomical dissection

The study protocols were approved by the National Medical Ethics Committee of the Republic of Slovenia (approval number: 0120-459/2018/3). Anatomical dissection was performed on a defrosted adult human cadaver ankle-foot specimen with no signs of trauma, surgery or any major deformity.

An incision was made posterior to the medial malleolus at the medial border of the Achilles tendon. Skin flaps were raised from 10 cm proximal to the medial malleolus up to the plantar surface of the foot. Soft tissues were cleared over the medial malleolus to expose the flexor retinaculum. The flexor retinaculum was then removed to expose TT contents.

The contents of the TT were dissected to reveal the relevant anatomical structures: PTT, FDLT, FHLT and the neurovascular bundle. The sheath of the neurovascular bundle was then incised to separate and demonstrate the various components, namely, the tibial nerve (TN) and its branches (medial plantar nerve (MPN), lateral plantar nerve (LPN) and medial calcaneal nerve (MCN)), the posterior tibial artery (PTA), and the posterior tibial vein (PTV) and their branches. Adipose and connective tissues were carefully removed, and the vascular bundle was cut proximal to the TT and rotated to expose the deeper-lying TN and its branches.

The overlying abductor hallucis (AH) muscle was cut from its calcaneal origin and rotated towards the forefoot for better visualization of the terminal neural branches; a part of the deep fascia of the AH muscle was preserved. In our specimen, we showed the bifurcation of TN into MPN and LPN, and identified two MCN branches ramifying from TN and continuing superficially into the subcutaneous tissue. In addition, BN was identified as the first branch of LPN. Lastly, we have coloured the structures of the neurovascular bundle for easier differentiation; neural structures were coloured green, arteries were coloured red, and veins were coloured blue.

Ultrasound examination

A linear 18–5 MHz probe was used on an Arietta 850 Fujifilm ultrasound machine to obtain sonographic scans of the TT on a healthy volunteer. The volunteer was lying with the medial ankle facing upwards[16]. The ultrasound probe was positioned posterior to the medial malleolus in a transverse oblique plane with the posterior aspect of the probe rotated towards the calcaneus, parallel to the Dellon-Mackinnon malleolar-calcaneal axis (DMA), a reference line from the centre of the medial malleolus to the centre of the calcaneus[16,20]. We scanned the medial ankle by elevator technique, from the level of the distal third of the tibia, where the flexor retinaculum starts to form, and continued distally to the point where plantar nerves enter the plantar surface of the foot. The angle of the probe placement was decreased slightly at the level of the distal TT so that the probe was more parallel to the plantar surface as the medial septum and the lateral and the medial tunnel are better visualized by placing the probe in this position. The position of the ultrasound probe may be appreciated in Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6.

An axial view of the TT region was obtained at different levels so that all relevant anatomical structures were imaged: the proximal TT, TT at the level of neurovascular bundle bifurcation, at the level of the distal TT and the visualization of BN between AH and quadratus plantae (QP) muscle.

Tarsal tunnel anatomy

The TT is a shallow, superficial fibro-osseous canal at the posteromedial aspect of the medial malleolus. The medial wall of the distal tibia, medial wall of the talus and medial wall of the calcaneus form the osseous floor, and the flexor retinaculum extends over the tunnel as a fibrous roof[1–3,5,7,11,13,16]. The flexor retinaculum represents a continuation of the calf aponeurosis. It continues distally as a fascia of the abductor hallucis muscle; therefore, its proximal and distal margins are difficult to define[7].

The TT houses three muscle tendons: PTT, FDLT, and FHLT. Lying between FDLT and FHLT is the neurovascular bundle comprising PTA and the accompanying PTV and TN. In the distal TT segment, TN divides into its terminal branches. Based on the division of TN, the TT may be divided into a proximal TT, containing TN, and a distal TT, containing the terminal branches of TN[3,7].

Proximal tarsal tunnel

From anterior to posterior, the proximal TT contains the following structures: PTT, FDLT, PTA, PTV, TN, and FHLT (Fig. 1). Each tendon lies in its own fibro-osseous compartment[7,8,10,21]. PTT, which has a typical tendinous fibrillar ultrasound appearance and lies in a shallow groove in the medial malleolus, is the most anteriorly located structure on an axial view of the proximal TT[16]. Posterior to PTT lies FDLT, which is usually about half the size of PTT[16]. Posterior to FDLT lies the neurovascular bundle with PTA and accompanying PTV and TN. The accurate identification of vascular structures can be aided by doppler ultrasound. Generally, nerves can be visualized under the vessels[4]. TN can be visualized as superficial and anterior to FHLT and presents with a fascicular or beehive-like echo pattern[16]. The flexor retinaculum, which appears as a hyperechoic fibrillar band on an ultrasound, extends over the TT from the medial malleolus to the medial calcaneus (Fig. 1)[8].

Distal tarsal tunnel

From anterior to posterior, the distal TT contains PTT, FDLT, FHLT, and terminal branches of the neurovascular structures. PTT is the most anteriorly located structure on an axial view of the distal TT. Next to it lies the FDLT, which in its distal course gradually runs posteriorly towards the sustentaculum tali on an axial view of TT. Posterior to the two tendons, the terminal branches of TN can be observed: MPN running anteromedially and LPN running posterolaterally, both with accompanying terminal branches of PTA and PTV (Fig. 2)[3,11]. BN can be visualized posterior to LPN. FHLT lies below MPN and runs posteriorly to the sustentaculum tali[8].

At the level of the distal TT, the medial septum separates the medial tunnel containing MPN and the lateral tunnel containing LPN[4,5,7,9,11,17]. The medial septum presents a possible nerve entrap-

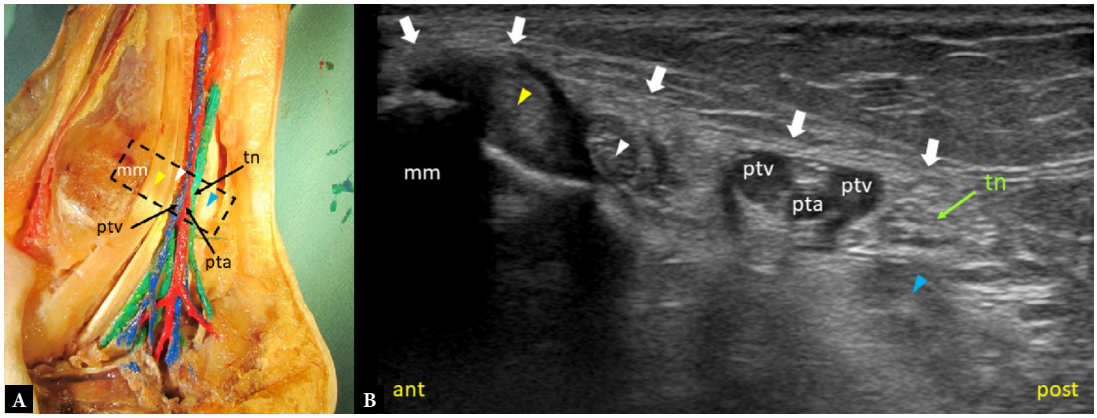

Fig. 1. *An anatomic section of the tarsal tunnel (**A**) and an axial ultrasound image showing the proximal tarsal tunnel (**B**). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) the posterior part. Tibial nerve (tn), posterior tibial artery (pta), posterior tibial veins (ptv), tibialis posterior tendon (yellow arrowhead), flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), medial malleolus (mm), flexor retinaculum (thick white arrows)*

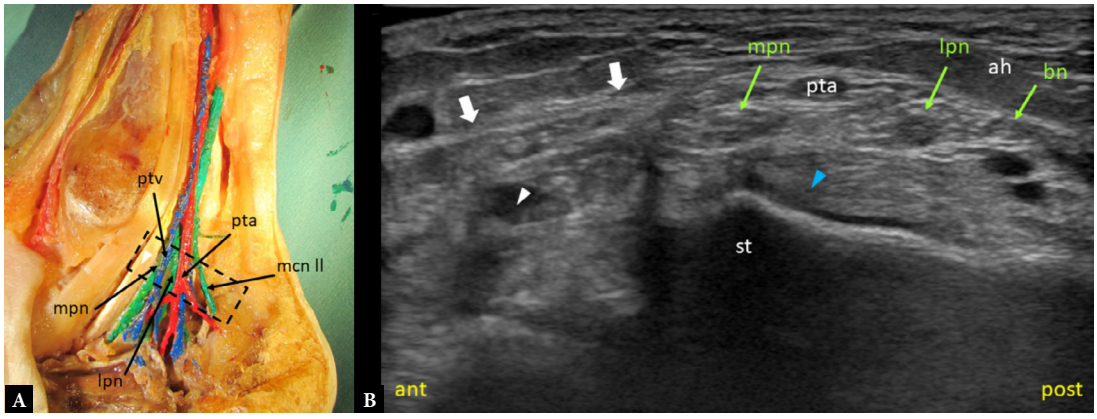

Fig. 2. *An anatomic section of the tarsal tunnel (**A**) and an axial ultrasound image showing the distal tarsal tunnel above the level of posterior tibial artery bifurcation (**B**). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) indicates the posterior part. Medial plantar nerve (mpn), lateral plantar nerve (lpn), Baxter's nerve (bn), posterior tibial artery (pta), posterior tibial vein (ptv), calcaneal nerve second branch (mcn ll). Flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), flexor retinaculum (thick white arrows), sustentaculum tali (st), abductor hallucis muscle (ah). On Fig. 2 A, MPN and LPN run anterior to PTA. On Fig. 2 B, PTA runs between MPN and LPN*

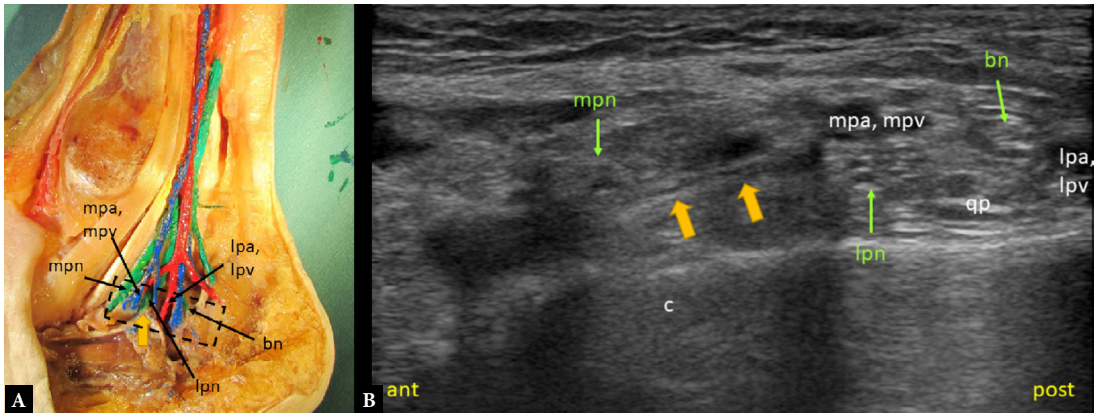

Fig. 3. *An anatomic section of the tarsal tunnel (**A**) and an axial ultrasound image showing the distal tarsal tunnel below the level of posterior tibial artery bifurcation (**B**). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) the posterior part. Medial septum (thick orange arrow), medial plantar nerve (mpn), lateral plantar nerve (lpn), Baxter's nerve (bn), medial plantar artery and veins (mpa, mpv), lateral plantar artery and veins (lpa, lpv). Quadratus plantae muscle (qp), calcaneus (c). On Fig. 3 A, the Baxter's nerve runs posteroinferior to LPA and LPV and anterosuperior on Fig. 3 B*

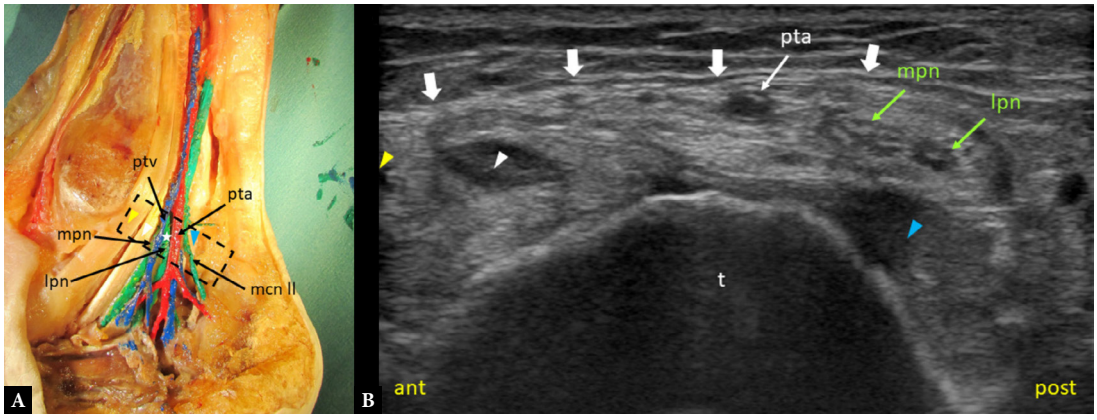

Fig. 4. *An anatomic section of the tarsal tunnel (***A***) and an axial ultrasound image showing the tarsal tunnel at the level of tibial nerve division (***B***). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) indicates the posterior part. Tibial nerve division site (white asterisk), medial plantar nerve (mpn), lateral plantar nerve (lpn), posterior tibial artery (pta), posterior tibial vein (ptv), calcaneal nerve second branch (mcn ll). Flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), tibialis posterior tendon (yellow arrowhead), flexor retinaculum (thick white arrows), talus (t). On Fig. 4 A, MPN and LPN run anterior to PTA. On Fig. 4 B, PTA runs anterior to MPN and LPN*

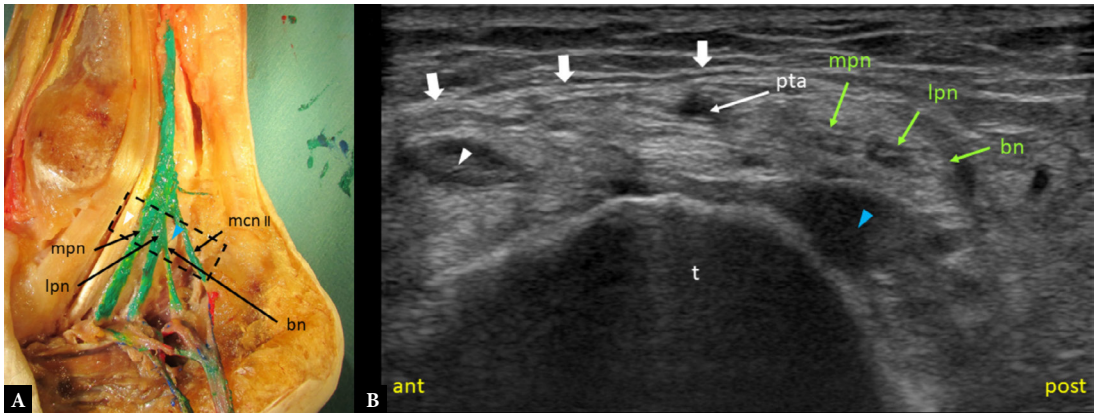

Fig. 5. *Anatomic section of the tibial nerve and its branches (***A***) and an axial ultrasound image showing the tarsal tunnel at the level of Baxter's nerve branching point (***B***). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) indicates the posterior part. Baxter's nerve (bn) branched off lateral plantar nerve (lpn) just below the level of tibial nerve (tn) bifurcation. Baxter's nerve (bn), medial plantar nerve (mpn), lateral plantar nerve (lpn), posterior tibial artery (pta). Flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), flexor retinaculum (thick white arrows), talus (t). Tibial nerve (tn), medial calcaneal nerve first branch (mcn l), medial calcaneal nerve second branch (mcn ll)*

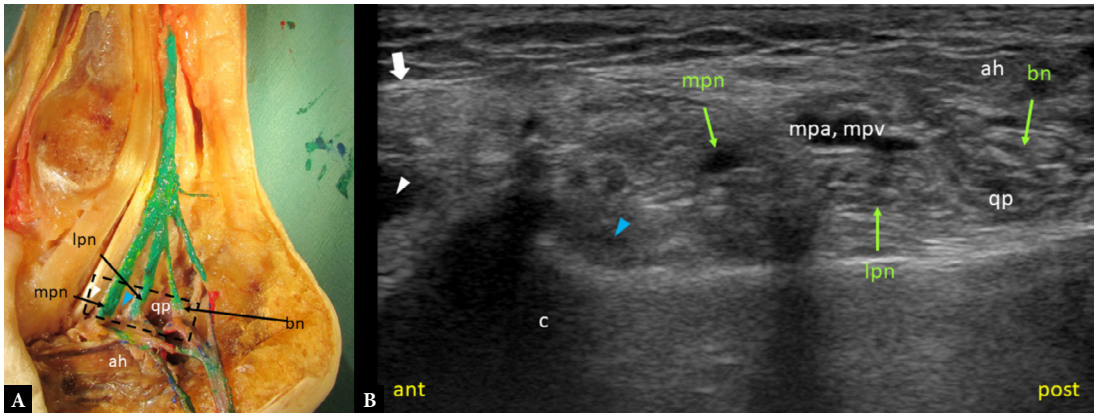

Fig. 6. *An anatomic section of the tibial nerve (***A***) and an axial ultrasound image showing the distal tarsal tunnel (***B***). Dashed rectangle indicates probe placement. Anterior (ant) indicates the anterior part of the tarsal tunnel, and posterior (post) indicates the posterior part. Baxter's nerve (bn) can be seen between the abductor hallucis (ah) and the quadratus plantae (qp) muscle. In Fig. A, ah was cut from its posterior origin and its posterior portion is not visible. Tibial nerve (tn), medial plantar nerve (mpn), lateral plantar nerve (lpn), medial plantar artery and veins (mpa, mpv). Flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), flexor retinaculum (thick white arrow), calcaneus (c).*

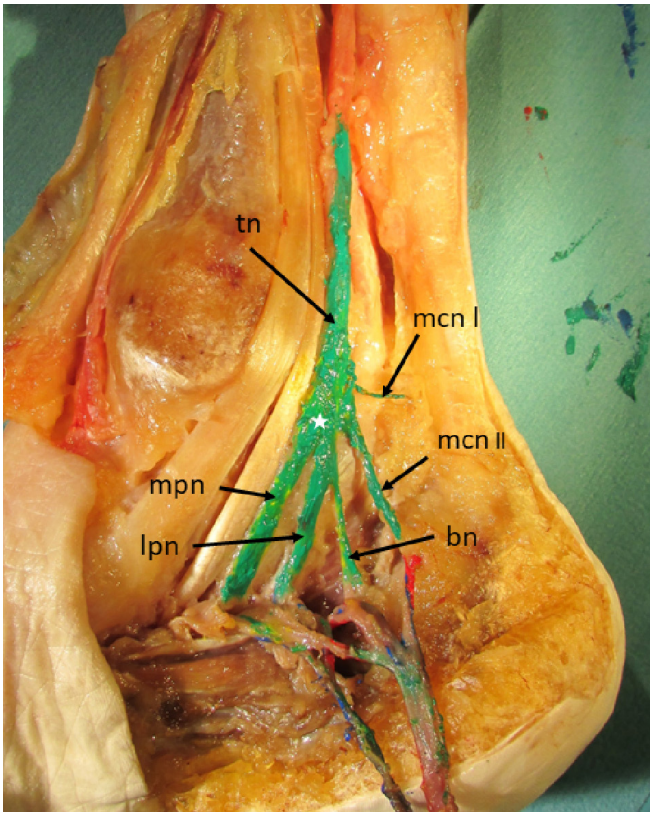

Fig. 7. *An anatomic section of the tibial nerve and its terminal branches. Neural structures are coloured green. Vascular structures are removed for better visualization. Tibial nerve (tn), medial calcaneal nerve first branch (mcn l), medial calcaneal nerve second branch (mcn ll), medial plantar nerve (mpn), lateral plantar nerve (lpn), Baxter's nerve (bn), tibial nerve division site (white asterisk)*

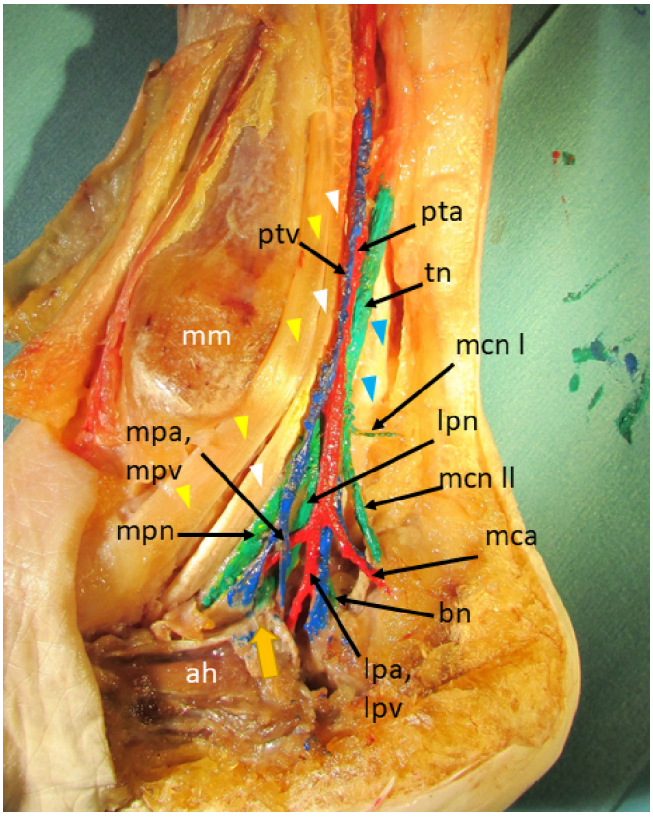

Fig. 8. *An anatomic section of the tarsal tunnel. Neural structures are coloured green; arteries are coloured red; veins are coloured blue. Tibial nerve (tn), posterior tibial artery (pta), posterior tibial vein (ptv), medial calcaneal nerve first branch (mcn l), medial calcaneal nerve second branch (mcn ll), medial plantar nerve (mpn), lateral plantar nerve (lpn), Baxter's nerve (bn), medial plantar artery and medial plantar veins (mpa, mpv), lateral plantar artery and lateral plantar veins (lpa, lpv), medial calcaneal artery (mca), tibialis posterior tendon (yellow arrowhead), flexor digitorum longus tendon (white arrowhead), flexor hallucis longus tendon (blue arrowhead), medial intermuscular septum (thick yellow arrow), medial malleolus (mm), abductor hallucis muscle (ah)*

ment site[2,4]. It can be identified on ultrasound as a hyperechoic fibrillar structure between MPN and LPN in the distal TT (Fig. 3)[4,8,17]. At the level of distal TT, the QP muscle can be seen at the base of TT[3].

Terminal branches of the tibial nerve in the distal tarsal tunnel

TN has three terminal branches: MPN, LPN and MCN[1–3,5,7,13,16]. The fourth branch, BN, usually branches from LPN. MPN and LPN are mixed nerves that provide motor innervation for the intrinsic muscles of the foot. In addition, they provide sensory innervation for the medial and lateral aspects of the plantar surface of the foot. Sensory branches of MPN innervate the first three and a half of the fourth toe, while LPN innervates the remaining portion of the fourth and the fifth toe[7]. TN usually divides into MPN and LPN inside the TT, less commonly proximally to the TT, and rarely below the level of the TT (Fig. 4)[1,7,9,11,12,20]. TN branching site can be identified by scanning the TT by elevator technique and following the distal path of the TN (Fig. 4).

The third TN terminal branch, the MCN, has variable anatomy and most commonly originates from TN and less frequently from LPN[1,4,7,9,11,12,21]. A few cases of MCN originating from MPN have been reported (9,11). MCN is a sensory branch innervating the surface of the heel[5,7,12,21]. The site of MCN branching has been described to occur proximally to or inside the TT[4,9,12,15,20]. MCN is reported to branch off proximally to BN[4,6,12]. Up to 5 branches of MCN have been reported[9,11]. Occasionally, the first branch of MCN can originate high above the flexor retinaculum; a distance of more than 150 mm above DMA has been recorded[9]. When MCN bifurcates above the level of the flexor retinaculum, it can run superficially and does not necessarily enter the TT[9,15]. Due to its small size, MCN is difficult to visualize on ultrasound[3,16]. We were unable to locate MCN during our ultrasound examination. The anatomic dissection of TN with two MCN branches arising from TN can be observed in Fig. 7.

BN, also called Inferior Calcaneal Nerve or First Branch of LPN, most commonly originates from LPN or, less frequently, as a branch of TN[3,4,6,8,9,11,12]. BN innervates the abductor digiti minimi muscle and provides sensory innervation for the calcaneus[4–6,8]. The site of BN branching can be either proximal, distal to or be inside the TT (Fig. 5)[9,11]. Up to two branches of BN have been reported, with one branch being the most common variation[11,12]. BN perforates the medial septum and runs between the AH and the QP muscle[3–6,8]. During an ultrasound examination, LPN should be followed by the

elevator technique to find the branching point of BN from its posterior border (Fig. 5)[4,6]. If no branch originating from LPN can be visualized, TN should be examined by the same technique[6]. When BN originates from TN, one has to be careful not to mistake it for MCN. BN branches off distally to MCN; thus, the more proximally bifurcating TN branch usually represents MCN and the second, more distally originating branch, represents BN[6,9,12]. However, it is also important to trace the distal course of each nerve branch as both MCN and BN can originate from either TN or LPN, and there can be multiple branches of MCN. Both continue posteriorly, but MCN terminates subcutaneously, whereas BN runs between the AH and QP muscle before continuing to the plantar surface (Fig. 6)[6].

The vascular structures have branching patterns similar to those of the nervous structures and also present with high anatomical variability[11]. PTA generally bifurcates distally to TN into the medial plantar artery (MPA), lateral plantar artery (LPA), and medial calcaneal artery (Fig. 8)[11].

Anatomical variations in the presented figures

We decided to perform ultrasound examination on a healthy volunteer because it allowed us to image TT vascular structures. This would not be possible on a cadaver specimen. However, there are anatomical differences between the two samples. Firstly, in our cadaver specimen, we identified two MCN nerves ramifying from the posterior part of TN. We were unable to identify MCN during our ultrasound examination. Secondly, there are differences between the anatomic relations of the contents of the neurovascular bundle, most notably at the level of the distal TT above PTA bifurcation (Fig. 2) and at the level of TN division (Fig. 4). At the level of the distal TT above PTA bifurcation (Fig. 2), MPN and LPN run anterior to PTA in our cadaver specimen (Fig. 2 A), whereas MPN runs anterior to PTA and LPN runs posterior to PTA in our healthy volunteer (Fig. 2 B). At the level of TN division (Fig. 4), MPN and LPN run anterior to PTA in our cadaver specimen (Fig. 4 A), whereas MPN and LPN run posterior to PTA in our healthy volunteer (Fig. 4 B). Additionally, a difference between the Baxter's nerve and LPA and LPV anatomic relation can be observed on the image showing the distal tarsal tunnel below the level of posterior tibial artery bifurcation (Fig. 3) with the Baxter's nerve lying posteroinferior to LPA and LPV in our cadaver specimen (Fig. 3 A) and anterosuperior to LPA and LPV in our healthy volunteer (Fig. 3 B).

Conclusion

We presented the anatomic-sonographic correlation of the tarsal tunnel and showed that high-resolution ultrasound is a useful diagnostic imaging modality for its assessment.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: ZS. Writing of manuscript: NH. Collection, recording and/or compilation of data: NH, EC. Critical review of manuscript: ZS, VS, EC.

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