3D VENOUS ANATOMY SHORT REVIEW

Functional Anatomy of the foot venous system

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Abstract The venous anatomy of the foot is quite different from that of other areas in the body, where veins are usually categorized as superficial, deep, and perforating. In the foot, however, the venous system is better understood as having two functional units-medial and lateral-each with its own network of superficial, deep, and perforating veins (PVs). This way of looking at it contrasts with the classification used for other parts of the lower limb, providing a unique insight into the foot's anatomy and function. The medial functional unit consists of the medial plantar veins, medial PVs, and the (superficial) marginal vein, while the lateral functional unit includes the lateral plantar veins along with the lateral and calcaneal PVs. The plantar veins are situated deep within the plantar pump. Certain dorsal perforating veins connect directly to the initial segments of the anterior tibial and fibular veins. Interestingly, some perforating veins in the foot are either valveless or possess valves in an "inverted" anatomical position, which allows blood to flow from deep to superficial veins under normal physiological conditions. These PVs act as the main outlet from the foot pump to the superficial venous system, promoting upward flow in both the great and small saphenous systems during the systolic phase of the foot's pump. Although the volume of blood pushed with each step is small, an effectively working foot pump is essential for aiding venous return from the limb.

Keywords foot venous pump; plantar veins; foot perforating veins; chronic venous disease; origin of the saphenous trunks

Abbreviations

ATVs, anterior tibial veins
CDU, color doppler ultrasound
CVD, chronic venous disease
CVI, chronic venous insufficiency
DCTV, direct CT venography
GSV, great saphenous vein
FMSPV, first metatarsal space perforating vein
LPVs, lateral plantar veins
mmHg, millimeters of mercury
MPVs, medial plantar veins
PSVP, plantar subcutaneous venous plexus
PV/PVs perforating vein/s
SFDs, static foot disorders
SSV, small saphenous vein

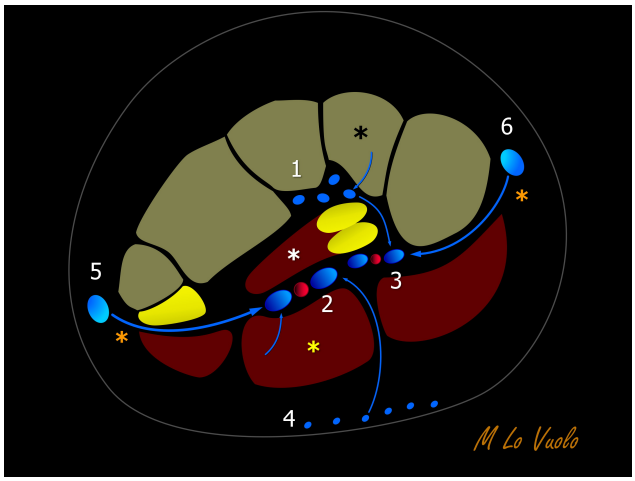


*Figure 1 - Coronal view of the tarsus showing the arrangement of foot veins in three layers: a) veins within the tarsal fossa (1), which drain the spongy bone (black *), b) plantar veins: the lateral plantar (2) and medial plantar (3) veins, and c) the plantar subcutaneous venous plexus (4). The superficial lateral (5) and medial (6) marginal veins drain into the plantar veins through perforating veins (orange *). The lateral plantar veins (2) are anatomically dominant, situated between the quadratus plantaris (white *) and abductor hallucis (yellow *) muscles. In contrast, the medial plantar veins (3) are surrounded by fibrous and tendinous structures (depicted in yellow). This anatomical distinction explains why, from a functional perspective, the lateral plantar veins form the core of the foot pump. This diagram has been modified from Prof. Gillot.*



Figure 2 - A. In healthy individuals without CVD, a mildly dilated plantar subcutaneous venous plexus (PSVP) with a vein diameter of 1-2 mm, due to valveless veins, is termed "Bourceret's venous sole". B. In contrast, significant PSVP dilation resulting from venous hypertension due to chronic superficial or deep reflux is more accurately termed "Lejars' venous sole".

I/ Introduction: investigation techniques

Anatomical dissection with colored segmentation

A technique originally described by Prof. C. Gillot, has been utilized in our anatomical research on the foot pump[1-2]. This study involved 400 limbs from 200 non-embalmed cadavers at the "Don des Corps" department of Descartes University in Paris, France. After washing the venous system of the lower limbs and injecting latex, we performed anatomical dissection using "color segmentation" with various dyes to enhance vein identification.

Color Doppler ultrasound

We employed Color Doppler Ultrasound (CDU) to investigate the PVs of the foot, focusing on their anatomical and hemodynamic patterns, as well as their connections to the foot pump.

Direct CT Venography

Additionally, Direct CT Venography (DCTV), also referred to as direct phlebo-CT, was used to create 3D models of the venous system in the feet of living patients, showing a strong correlation with our dissection findings. DCTV was indicated only for patients with complex venous disease or recurrent varicose veins following surgery (REVAS). The protocols for acquisition and reconstruction of DCTV, along with the results, have been detailed in previous studies[3-5].

DCTV offers an accurate depiction of the venous anatomy of the foot, featuring interactive 3D assessment capabilities, including virtual dissection and access to virtual reality techniques. These functionalities, especially the virtual dissection of the limb, are not only beneficial for managing complex clinical cases but also serve educational purposes and enhance our understanding of venous anatomy[6-8].

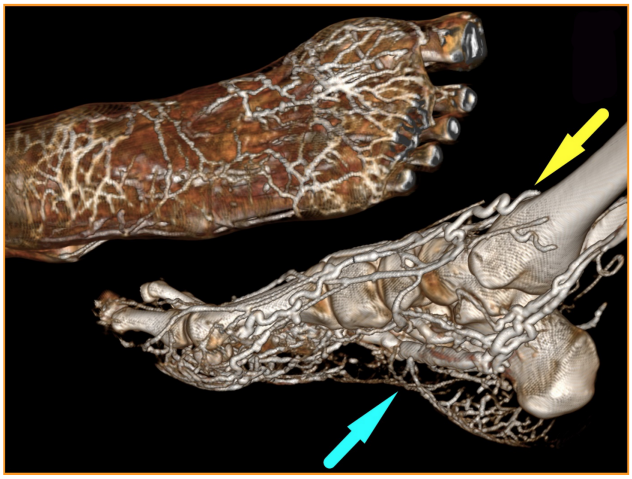


Figure 3 - A 3D reconstruction of direct CT venography showing substantial dilation of the plantar subcutaneous venous plexus (light blue arrow), accurately referred to in this clinical case as "Lejars' venous sole". This dilation results from prolonged venous hypertension in a patient with May-Thurner syndrome and chronic venous insufficiency (CVI). Epifascial varices are visible over the anterior surface of the ankle (yellow arrow).

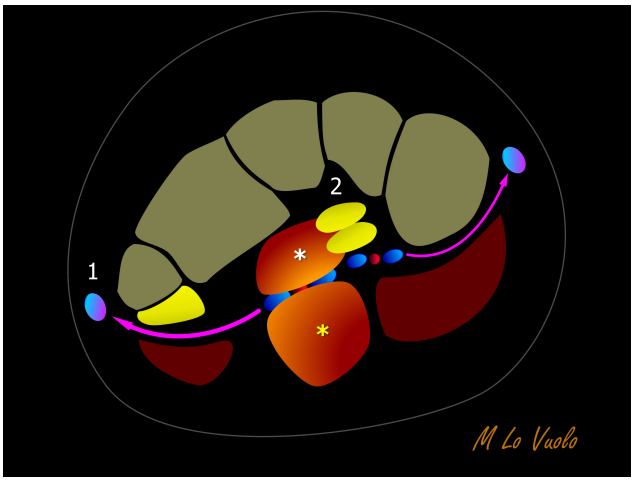


*Figure 4 - Coronal view of the tarsus. Due to their intermuscular course, the lateral plantar veins (LPVs) are compressed by the contraction of the quadratus plantaris (white *) and abductor hallucis (yellow *) muscles during the systolic phase of the foot pump while walking. The increased venous pressure within the LPVs is then relieved, with a reversal of flow through the perforating veins toward the lateral marginal vein (1) or a venous plexus that may replace it. In contrast, the medial plantar veins are enclosed by fibrous and tendinous structures (2), making their contribution to the ejected volume of the foot pump less significant. This anatomical distinction underscores why, from a functional perspective, the LPVs serve as the primary component of the foot pump. This diagram has been modified with permission from Prof. Gillot.*

II/ Classical description of the foot veins

Starting with a classical approach, foot veins are divided into three categories: superficial, deep, and perforating veins (PVs). Next, we will present a more practical, functionally-oriented view to show how these venous structures operate dynamically during walking.

A coronal section of the tarsus (Fig. 1) reveals three distinct layers of foot veins: the superficial layer, found in the subcutaneous tissue of both the dorsal and plantar surfaces; the muscular layer, which includes the plantar veins; and the bony layer, consisting of veins located within the tarsal fossa.

1-The superficial venous layer of the foot

Consists of two main areas: the veins located in the sole and those found on the dorsum of the foot.

a. Veins of the sole

In the sole, a fine network of superficial subcutaneous veins drains into the marginal veins. This drainage is facilitated by small veins that contain valves, which help to prevent the backward flow from the marginal veins. However, if these valves are partially or completely absent, it can lead to a slight dilation of the plantar subcutaneous venous plexus (PSVP), a condition referred to as the "sole veins of Bourceret"[9]. It is important to mention that these veins have often been incorrectly identified as the foot's "venous pump" (Lejar's venous sole)[10].

This misunderstanding likely arose from anatomical injection artifacts seen in patients with significant venous stasis due to chronic venous disease, rather than in those who are healthy (Figs. 2, 3).

b. Veins of the Dorsal Foot

The medial marginal vein begins in the first metatarsal space PV and, at the level of the tibial malleolus, extends as the great saphenous vein (GSV) (Figs. 4-10).

The lateral marginal vein, which is often replaced by a venous network instead of being a single vein (Figs. 11, 12), also starts in the first metatarsal space PV. At the level of the fibular malleolus, it continues as the small saphenous vein (SSV).

In addition to the marginal veins covered by a superficial fascia, tributaries network is present as a more superficial layer variably developed on the dorsal venous layer foot and the anterior surface of the ankle as shown on Fig.12.

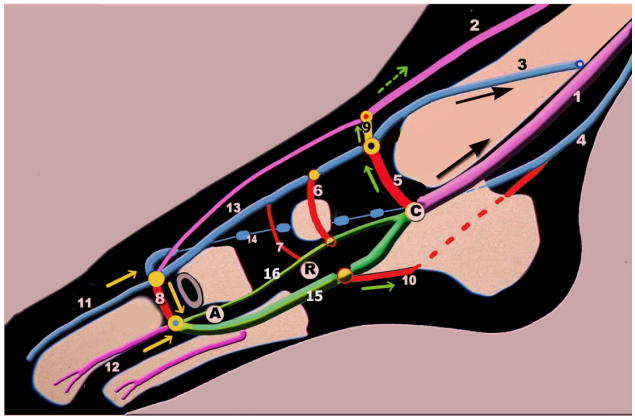


Figure 5 - Functional hypothesis for the foot vein-pump: Suction pole (A), reservoir (plantar veins, R), and ejection pole (calcaneal confluence, C). The diagram displays the posterior tibial (1) and anterior tibial (2) veins, great (3) and small (4) saphenous veins, the dorsal vein of the hallux (11), medial plantar (16) and lateral plantar (15) veins, medial marginal vein (13), and the lateral marginal plexus, represented as a dotted line (14). It also illustrates the following perforating veins: submalleolar (5), navicular (6), cuneal (7), dorsal (9), calcaneal (10) and the one of the first metatarsal space (8).

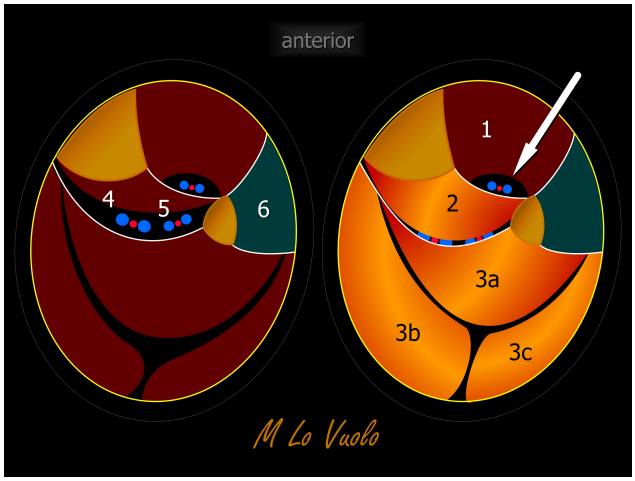


Figure 6 - During normal gait, especially in the stance phase (when the foot contacts the ground), the dorsiflexor muscles (1) in the anterior compartment of the leg can be relaxed, while the plantar flexors (2) and triceps surae (3) in the posterior compartment are active (contracted). As a result, extrinsic compression of the posterior tibial (4) and fibular (5) veins temporarily impedes venous return through these veins. However, the anterior tibial veins (arrow) remain fully open, providing an alternative collateral pathway. The muscles of the triceps surae-soleus (3a), medial gastrocnemius (3b), and lateral gastrocnemius (3c)-are also labeled. Lateral compartment of the leg (6).

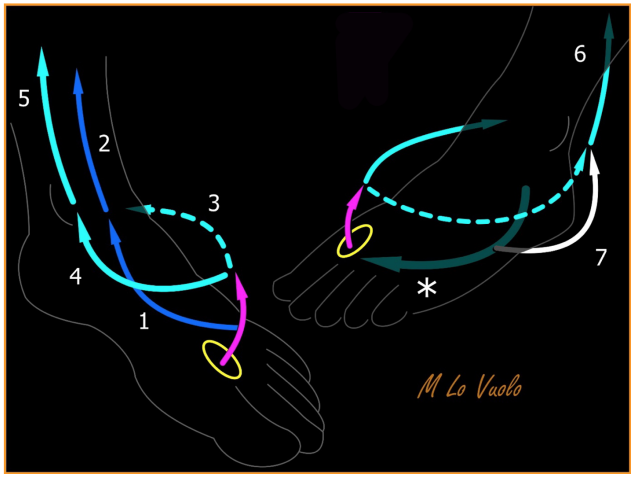


Figure 7 - When the muscles of the posterior compartment of the leg contract, temporarily impeding venous return from the foot through the posterior tibial and peroneal veins, alternative deep and superficial pathways can bypass this physiological obstruction. From the perforating vein in the first metatarsal space (magenta arrow), a deep communicating vein (1) directly connects to the anterior tibial veins (2). Simultaneously, venous return is redirected through either the plexiform or single lateral marginal vein (3) and the medial marginal vein (4), shunting blood towards the great (5) and small (6) saphenous trunks. Additionally, originating from the lateral plantar veins (*), the calcaneal perforating vein (7) also joins the small saphenous vein at its origin.

2-Deep venous layers of the Foot

As shown in Fig. 1, the deep veins of the foot are structured in two distinct layers: a "bony" venous layer and a "muscular" venous layer. The bony veins are situated within the concave area of the tarsal osseous arch, and are responsible for draining the cancellous (spongy) bone. The lateral plantar veins (LPVs), located between the quadratus plantaris and the flexor hallucis longus muscles (Fig. 1), serve as the main venous reservoir of the foot. From both anatomical and functional viewpoints, they play a crucial role in the foot-pump mechanism.

The medial venous plantar pedicle is about 5 cm long, relatively straight, and made up of 2-3 veins linked by several anastomoses. In contrast, the lateral venous plantar pedicle is longer, measuring around 12 cm, wider (with vein diameters ranging from 2-4 mm), and has a more curved shape. At the back, the medial and lateral plantar veins meet at the "calcaneal confluence of the plantar veins", which leads to the posterior tibial veins (PTVs) (Figs. 13, 14). These veins are the main pathway for blood flow from the foot. Surrounded by muscles, the LPVs get compressed while walking, helping to push blood back toward the PTVs during the systolic phase of the foot-pump cycle.

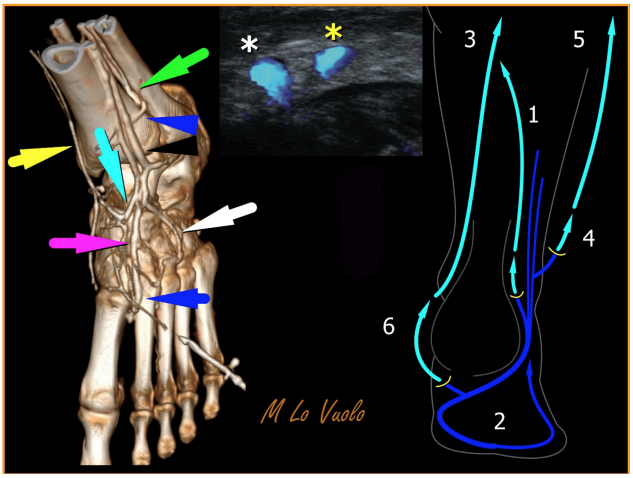


*Figure 8 - Venous connections to the anterior tibial origin (black arrowhead) include not only the perforating vein from the first metatarsal space (blue arrow) via a deep communicating vein (magenta arrow), but also a lateral dorsal deep communicating vein (white arrow) and a medial dorsal perforating vein (light blue arrow) coming from the GSV (yellow arrow). Through a deep communicating vein (blue arrowhead) the fibular veins (green arrow) can decompress toward the ATVs as well. When present, the Achillean tributary (1) provides an additional pathway to redirect blood flow from the plantar veins (2) toward the small saphenous vein (3), helping to relieve the physiological venous hypertension in the foot due to temporary closure of the posterior tibial and peroneal veins. A transverse CDU image taken during foot pump systole indeed shows increased flow through both the Achillean tributary (yellow *) and the small saphenous vein (white *). In individuals without CVD, a systolic reversed flow through the inferior posterior tibial PV (Cockett I, 4) may be observed, suggesting a decompressive role toward the posterior accessory great saphenous vein (5). Calcaneal perforating vein (6), joining the origin of the SSV (3).*

In Fig. 5, we propose a hypothesis about the function of the foot vein-pump: a venous return model like the calf venous pump (Fig. 6). From both anatomical and functional viewpoints, the plantar veins - particularly the lateral plantar veins - are central to this mechanism, which can be broken down into three parts: the suction pole (A), the reservoir (the plantar veins, B), and the ejection pole (C), also referred to as the "calcaneal confluence of plantar veins". When walking, during the relaxation phase of the plantar muscles (plantar flexion), a pressure gradient (syphon-like effect) aspirates blood from nearby veins into the reservoir via the suction pole. During muscle contraction (the systolic or ejection phase of the foot pump), the rise in venous pressure within the reservoir pushes blood through the ejection pole towards both the deep veins (posterior and anterior tibial veins) and the superficial veins (the great and small saphenous veins).

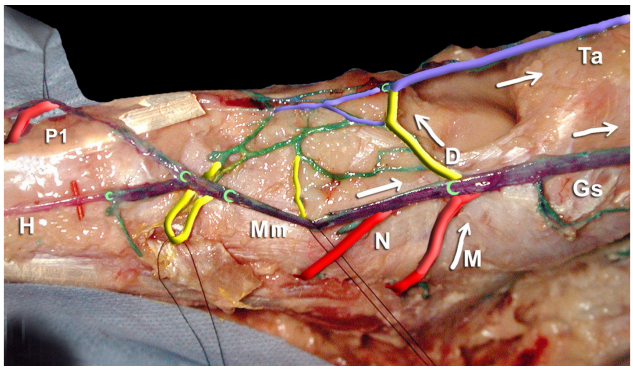


Figure 9 - Anatomical dissection post-latex injection. The colored segmentation in this dissection facilitates the identification of anatomical structures. Three veins converge to form the GSV: the medial marginal vein (Mm), medial dorsal PV (D), and submalleolar PV (M). Additional venous structures are also depicted: the anterior tibial vein (Ta), the first metatarsal space PV (P1), the navicular PV (N), the dorsal vein of the hallux (H) and the dorsal venous plexus (colored in green).

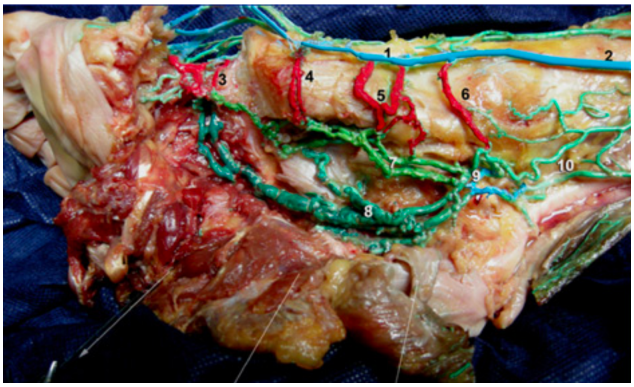


Figure 10 - Anatomical dissection post-latex injection with colored segmentation. Medial view of the foot following resection of the first metatarsal bone. The medial marginal vein (1) continues as the GSV (2). The medial (7) and lateral (8) plantar veins converge anteriorly at the perforating vein of the first metatarsal space (3) and posteriorly at the calcaneal confluent (9), which forms the origin of the posterior tibial veins (10). Moving from posterior to anterior, three perforating veins are visible: the submalleolar perforating vein (6), the navicular perforating vein (5), and the cuneal perforating vein (4).

3-Anatomy of foot perforating veins

As previously mentioned, these perforating veins (PVs), connected to the plantar veins on either side, are integral to the two functional units (medial and lateral) of the foot. The medial foot PVs connect with the medial plantar veins and the origin of the great saphenous vein (Fig. 10). The lateral and calcaneal foot PVs join with the lateral plantar veins and the origin of the small saphenous vein (Fig. 11).

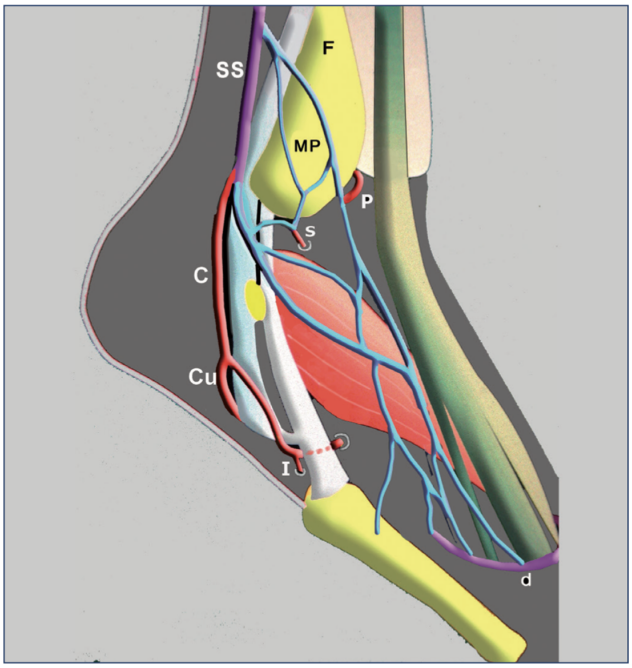


Figure 11 - The superficial dorsal venous arch (d) frequently continues as a lateral marginal plexus, as shown here, rather than as a single vein (see next Figure). Moving from anterior to posterior, additional anatomical structures are identified: the intertendinous perforating vein (I), which joins with the cuneal perforating vein (Cu) to form the lateral perforating vein common trunk (C). At its posterior end, the lateral marginal plexus connects with the fibular veins via the lateral dorsal perforating vein (s) and with the anterior tibial veins via the medial dorsal perforating vein (P). Behind the fibular (F) malleolus, the small saphenous vein (SS) originates from the confluence of the three elements shown in this diagram: the lateral perforating vein (C), the lateral marginal plexus (or single vein), and the malleolar venous plexus (MP).

Medial perforating veins of the foot

The first metatarsal space PV is typically larger than others, with an approximate diameter of 4 mm and, in some cases, it is duplicated (Fig. 14). It originates from the medial marginal vein, forming a connection between the plantar veins and the origin of the great saphenous vein (GSV). Moving from anterior to posterior, three additional perforating veins are identified: the cuneal, the navicular and the submalleolar PVs (Figs. 9, 10). The medial dorsal PV connects the GSV to the origin of the anterior tibial veins (Fig. 8). The confluence of three veins (medial marginal, submalleolar PV and medial dorsal PV) gives origin to the GSV trunk at the level of the tibial malleolus (Fig. 13).

Lateral perforating veins of the foot

Along the lateral aspect of the foot, two veins are identified as crossing over the lateral fibular tendons; when moving from anterior to posterior: the intertendinous perforating vein and the cuneal perforating vein. These veins often converge to form the common trunk of the lateral perforating vein (Figs. 15,16).

The confluence of this common trunk with the lateral marginal vein (or plexus) and the malleolar venous plexus gives rise to the small saphenous vein (SSV) (Fig. 11).

On the opposite side, at the rear of the foot, the calcaneal perforator originates from the "calcaneal confluence of plantar veins". This perforator may give rise to the Achillean tributary of the SSV, which drains into the latter at the lower third of the leg (Figs. 10, 13).

First described by Prof. C. Gillot, the Achillean tributary plays an important role as a direct communication between the plantar veins and the SSV. This connection is particularly significant during normal gait, when the fibular and posterior tibial veins are closed (Fig. 6).

Dorsal perforating veins of the foot and ankle

Three veins are typically observed at this level. The medial dorsal perforating vein connects the origin of the great saphenous vein to the origin of the anterior tibial veins (Figs. 8, 9). The other two unnamed perforating veins, which lack a direct anatomical link to the plantar veins, arise from the dorsal venous network of the foot and contribute to the formation of the fibular and anterior tibial veins (Fig. 16).

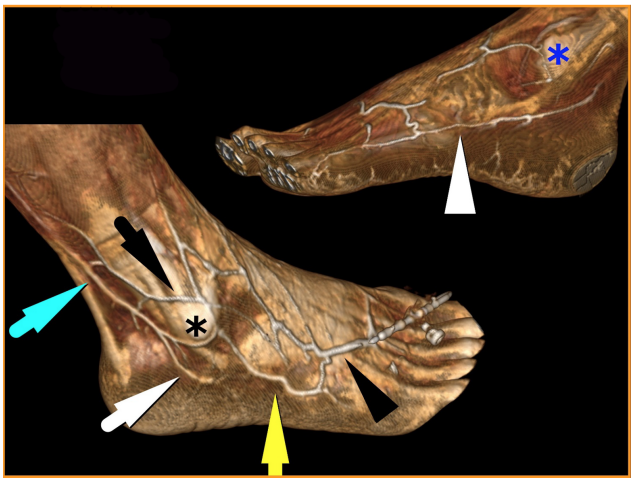


Figure 12 - In a living subject, the superficial dorsal venous arch (black arrowhead) continues as the lateral marginal (yellow arrow) and malleolar (black arrow) venous plexuses. Along with the lateral perforating vein (white arrow), these structures give rise to the SSV (light blue arrow). In another subject, the lateral marginal vein

appears as a single structure (white arrowhead). Fibular malleolus (*).

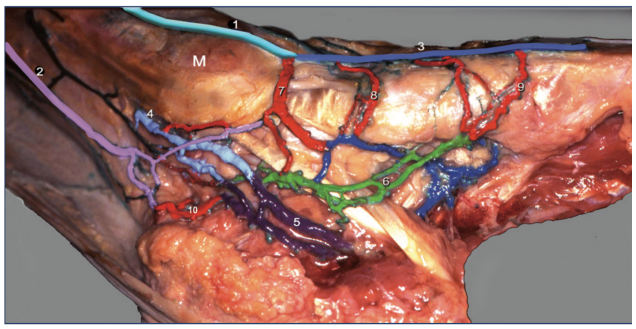


Figure 13 - An anatomical dissection following latex injection and color segmentation. Along the medial aspect of the foot, the medial marginal vein (3) continues at the level of the medial malleolus (M) as the great saphenous vein (1). The lateral (5) and medial (6) plantar veins converge posteriorly at the calcaneal confluence, which gives rise to the posterior tibial veins (4). Moving from anterior to posterior, three medial perforating veins are visible: the cuneal (9), navicular (8), and submalleolar (7) perforating veins. A calcaneal perforating vein (10) ascends as the Achillean tributary (2) of the small saphenous vein.

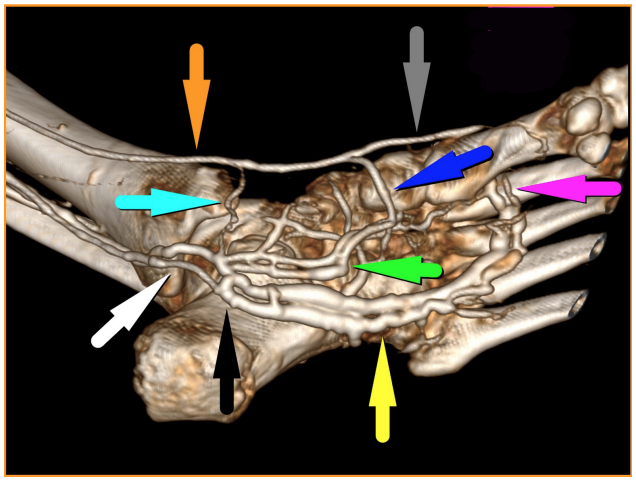


Figure 14 - This 3D reconstruction of direct CT venography shows the lateral plantar veins (yellow arrow), which are notably more prominent than the medial plantar veins (MPVs, green arrow). Anteriorly, the first metatarsal space perforating vein is duplicated (magenta arrow) in this patient. Posteriorly, the plantar veins converge at the "calcaneal confluence of the plantar veins" (black arrow), giving rise to the posterior tibial veins (white arrow). As part of the medial functional unit of the foot, the cuneal perforating vein (blue arrow) at the midfoot connects the MPVs to the medial marginal vein (grey arrow). In the hindfoot, the submalleolar perforating vein (light blue arrow) connects the calcaneal confluence to the origin of the great saphenous vein (orange arrow).

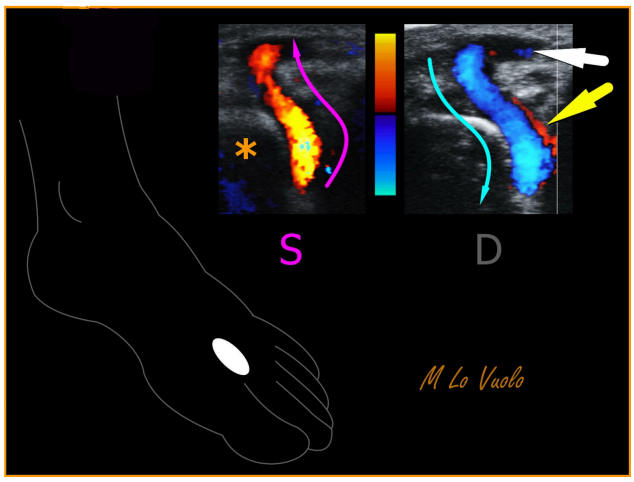


Figure 15 - A CDU transverse scan at the level of the first metatarsal space in a young person without venous disease. During foot pump systole (S), an outward flow from deep veins to superficial veins is observed, which reverses to inward flow during foot diastole (relaxation phase, D). In the absence of venous disease, this finding confirms that some perforating veins of the foot facilitate physiological decompression of venous hypertension as needed. Superficial dorsal venous arch (white arrow), perforating artery (yellow arrow), first metatarsal bone (*).

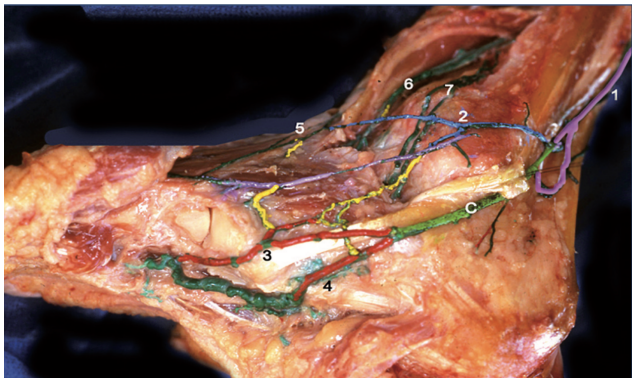


Figure 16 - An anatomical dissection of Prof C. Gillot following latex injection and color segmentation. Along the lateral aspect of the foot, moving from anterior to posterior, the following structures are identified: the intertendinous perforating vein (PV, 3) merges with the cuneal PV (4) to form the common trunk of the lateral PV (C). The confluence of this trunk with the malleolar venous plexus (2) gives rise to the small saphenous vein (1). Also displayed are the medial dorsal perforating vein (5), the anterior tibial veins (6), and the fibular veins (7).

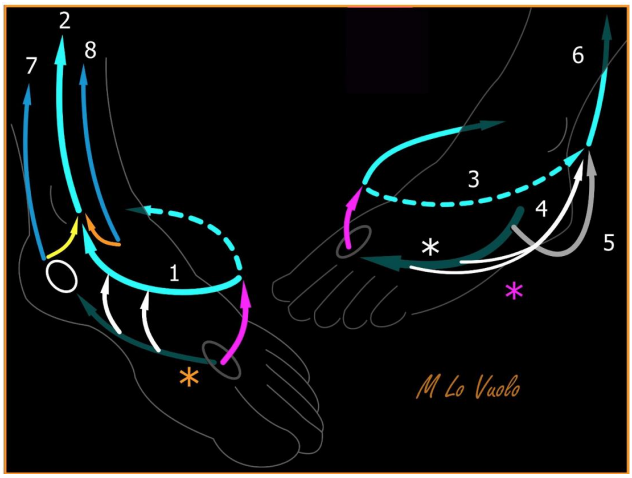


Figure 17 - In this anatomical variant, originating from the calcaneal confluence (blue arrow) on the medial aspect of the foot, a calcaneal perforating vein (blue arrowhead) extends toward the contralateral side (yellow arrow) to join the origin of the small saphenous vein (SSV). In another subject, a lateral calcaneal perforator (black arrow) originating from the ipsilateral plantar veins (orange arrow) continues upward as the SSV (white arrow).

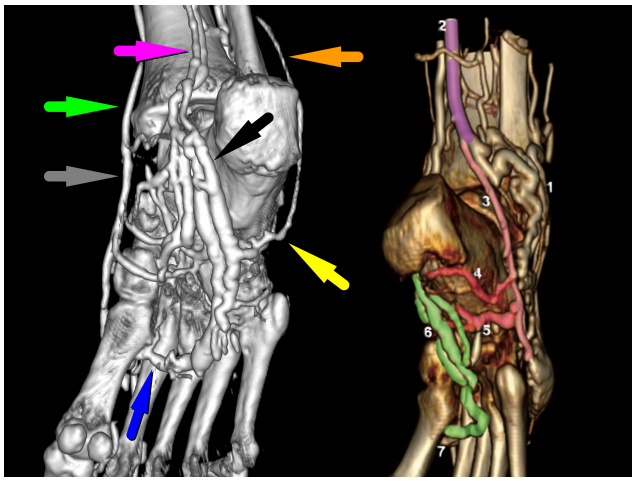


Figure 18 - 3D reconstructions from direct CT venographies in two different subjects with chronic venous hypertension. Varicose network of the lateral marginal plexus (1) is clearly visible, and the dilated lateral plantar veins are highlighted in green. A calcaneal perforator (yellow arrow), originating from the distended lateral plantar veins (black arrow), ascends as the small saphenous vein (SSV, orange arrow). The confluence of the common trunk of the lateral PV (3) with the lateral marginal plexus (1) gives rise to a markedly dilated SSV (2). Additional structures displayed include the first metatarsal space perforating vein (blue arrow and 7), calcaneal (4) and cuneal (5) perforating veins, as well as the medial marginal vein (grey arrow), great saphenous vein (green arrow), and posterior tibial veins (magenta arrow).

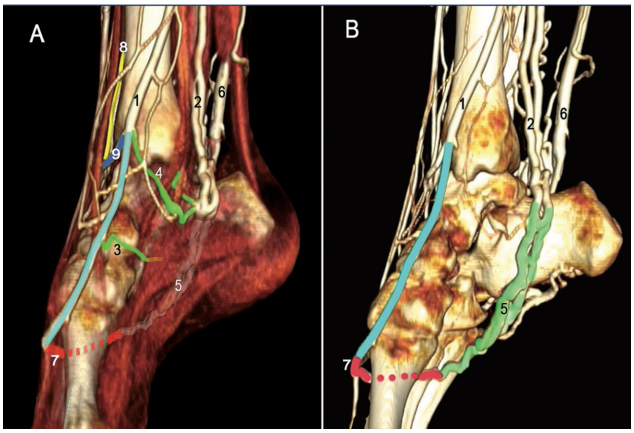


Figure 19 - 3D reconstructions from direct CT venography of the same foot, shown with and without muscles and tendons. From anterior to posterior, the first metatarsal space perforating vein (7) connects the medial marginal vein (colored in light blue) to the lateral plantar veins (5). Additional structures include the navicular perforating vein (3), submalleolar perforating vein (4), posterior tibial veins (2), and small saphenous vein (6). The medial dorsal perforating vein (9) links the great saphenous vein (1) to the anterior tibial veins (8).

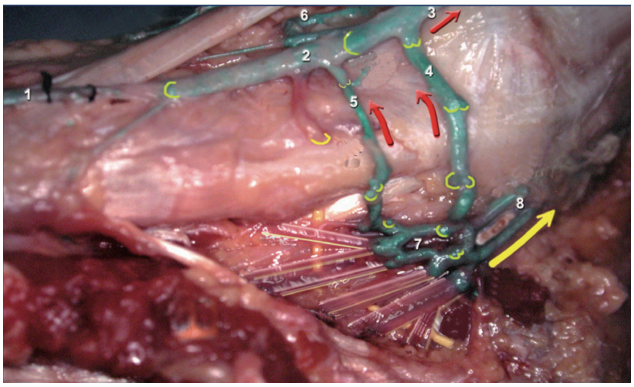


Figure 20 - An anatomical dissection following latex injection and color segmentation on the medial aspect of the right foot. Moving from anterior to posterior, the following structures are identified: the dorsal vein of the hallux (1), the medial marginal vein (2) continuing as the great saphenous vein (3), the navicular (5), and submalleolar (4) perforating veins. Also shown are the calcaneal confluence (7) and the origin of the posterior tibial veins (8). During foot pump systole, venous return is propelled from the calcaneal confluence toward the posterior tibial veins (yellow arrow) and simultaneously directed to superficial veins (red arrows) with a "reversed" yet physiological flow through perforating veins. The medial dorsal perforating vein (6) connects the great saphenous vein to the anterior tibial veins.

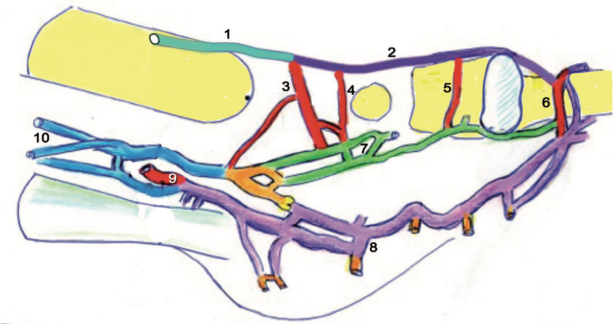


Figure 21 - As a final summary, the two functional units of the foot are displayed. Moving from anterior to posterior in the medial unit, we identify the medial marginal vein (2) and the great saphenous vein (1), which are connected to the medial plantar veins (7) via the cuneal (5), navicular (4) and submalleolar (3) perforating veins. The lateral (8) and medial (7) plantar veins converge anteriorly into the first metatarsal space perforating vein (6) and posteriorly at the calcaneal confluence (colored in orange), which gives rise to the posterior tibial veins (10). Arising from the calcaneal confluence or a lateral plantar vein, the calcaneal perforating vein (9) joins the origin of the small saphenous vein on the opposite side of the foot.

III. Foot Functional Units and Perforating Vein Hemodynamics

As a unique feature in the lower limbs, some perforating veins of the foot are either valveless or have valves in the "inverted" orientation[21]. This arrangement allows for flow from deep veins to superficial veins when necessary.

In Figs. 17-20, the position of the valves, marked in yellow, within the **medial** perforating veins of the foot, illustrates the "reversed yet physiological" flow toward the superficial veins during foot pump systole in the gait functional cycle. When the fibular and posterior tibial veins are closed (Fig. 6), this reversed flow enables decompression toward not only the great saphenous vein (GSV) and small saphenous vein (SSV) but also the anterior tibial veins (Figs. 8, 9, 15).

From an anatomical and functional standpoint, it's important to consider the venous structures of the foot as consisting of two separate functional units-medial and lateral-rather than following the conventional classification into deep and superficial veins seen in other areas (Figs. 21, 22).

Medial Functional Unit

The medial functional unit includes the medial plantar veins, the medial marginal vein, the medial dorsal perforating vein, and the medial perforating veins of the foot.

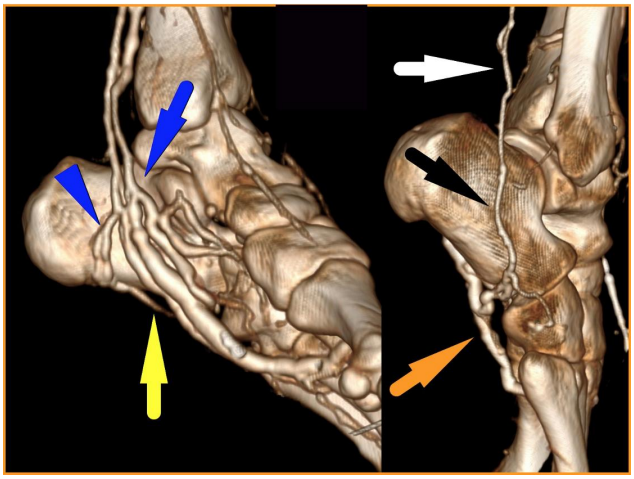


Figure 22 - In this anatomical variant, originating from the calcaneal confluence (blue arrow) on the medial aspect of the foot, a calcaneal perforating vein (blue arrowhead) extends toward the contralateral side (yellow arrow) to join the origin of the small saphenous vein (SSV). In another subject, a lateral calcaneal perforator (black arrow) originating from the ipsilateral plantar veins (orange arrow) continues upward as the SSV (white arrow).

Moving from anterior to posterior, the medial perforating veins are the cuneal, navicular and submalleolar PVs (Figs. 13, 14).

Lateral Functional Unit

The lateral functional unit is composed of the lateral plantar veins and two perforating veins: the lateral and the calcaneal PVs (Figs. 11, 16, 17, 18, 21).

This anatomical arrangement explains why, even when the fibular and posterior tibial veins are closed (Fig. 6), the foot can still decompress via alternative venous routes. These routes may be deep, through the anterior tibial veins, or superficial, via the saphenous trunks and the posterior accessory vein of the GSV (Fig. 8). The perforating veins of the foot enable such a "physiological shunting".

The occurrence of reversed flow in the perforating veins of the lower leg (below the calf muscle pump), ankle, and foot during muscle activity often indicates physiological shunting/decompression, rather than perforating vein insufficiency.

Diagnostic Imaging Insights

Color Doppler ultrasound combined with provocative maneuvers, offers a dynamic functional assessment of venous flow. This widely accessible and affordable non-invasive diagnostic method -when performed by skilled practitioners-can demonstrate that "reversed yet

physiological" flow is frequently seen in patients who do not have chronic venous insufficiency (Fig. 15).

IV. The Plantar Venous Pump (Clinical Practice and dynamic testing)

The existence of the plantar venous pump is confirmed in daily practice whenever a phlebologist or ultrasonographer performs what is often misnamed as the "Lejars' plantar compression maneuver".

With the patient standing still, manual compression of the plantar veins-while scanning with color or spectral Doppler at the ankle-causes an acceleration (commonly referred to as "augmentation") of blood flow through the posterior tibial veins. This significant and immediate response results from the compression of the plantar venous "reservoir" by the maneuver.

Although the volume of blood ejected with each step is small, a properly functioning foot pump plays a vital role in facilitating venous return from the limb. Static foot disorders (SFDs), such as flat foot or hollow foot, impair this function and exacerbate the clinical manifestations of chronic venous disease (CVD).

Therefore, SFDs should be recognized as a major risk factor for CVD, as highlighted in previous publications by our group and others[14,15].

In clinical practice, it is essential to identify SFDs and, when present, correct them using an insole. Doing so not only alleviates symptoms associated with SFDs but also improves symptoms of chronic venous insufficiency.

This supports an established concept: approximately 60% of so-called "venous symptoms" are not primarily of venous origin[16].

Varicose Veins of the Foot

Varicose veins in the foot may result from a weakness zone in the ankle[17,18]. Furthermore, longstanding massive saphenous reflux that reenters the deep veins of the foot can lead to volume and pressure overload.

During foot pump activity, repetitive pressure peaks-through perforating veins with reversed flow-can directly impact superficial veins, ultimately causing localized varicosities.

Comments on the Stages of Lower Limb Venous Return

Under normal circumstances, the venous system in the foot is generally effective at ensuring upward venous return, even when the venous pump is not active. When standing, the hydrostatic pressure in the great saphenous vein (GSV) can reach around 90 mmHg[22] because of gravity.

However, after walking 10 to 25 meters, the ankle venous pressure can decrease significantly, dropping to about 25 mmHg during the diastolic phase of the calf muscle pump. This decrease is a result of blood volume displacement, which is aided by the coordinated action of several venous pumps throughout the lower limb.

In individuals with chronic GSV reflux, severe ambulatory venous hypertension hinders this drop in diastolic pressure, leading to minimal or no reduction in venous pressure while walking[22].

In normal physiology, each systole of the foot pump ejects approximately 20-30 mL of blood, which corresponds to the reservoir capacity of the plantar veins. At the calcaneal confluence, the posterior tibial veins are directly connected to the plantar veins and can be regarded as an extension of this venous reservoir.

REMINDER

Anatomically dominant and intermuscular, the lateral plantar veins form the core of the foot pump

The slight dilation of the plantar subcutaneous venous plexus (PSVP), observed as a physiological finding in healthy individuals, should be referred to as the "sole veins of Bourceret".

The significant dilation of the PSVP, identified as a pathological finding associated with chronic venous hypertension, should be described as the "Lejars venous sole".

The absence-or inverted position-of valves in some perforating veins of the foot allows for reversed yet physiological flow from deep veins to superficial veins (Fig. 15).

Conclusion

A unique feature of the lower limb venous system is the presence of some valveless perforating veins-or those with inverted valves-in the foot. These veins enable a physiological shortcut for flow from the deep plantar venous pump to superficial veins. When venous return through the fibular and posterior tibial veins is impeded (Fig. 6), these physiological shunts provide alternative routes for ascending flow. This mechanism explains the ultrasound finding of flow acceleration or "augmentation" within both saphenous trunks during calf muscle contraction (Figs. 7, 8).

The foot pump reservoir-composed of the plantar veins-is emptied during either manual plantar compression or during gait when the foot presses against the ground. Blood ejected by the foot pump is, therefore, deep flow rather than superficial flow coming from the plantar subcutaneous venous plexus.

In the clinical assessment of chronic venous disease (CVD) patients, it is essential to rule out static foot disorders (SFDs) as a potential cause of impaired foot pump function.

In addition to the pressure from the foot against the ground during walking, the plantar veins-particularly the lateral ones that are encased in muscles-show that there is a muscular mechanism that helps facilitate venous return (Fig. 4).

To prevent postoperative deep vein thrombosis (DVT) in high-risk patients, passive foot pump activity is recommended[19,20]. This can be achieved through upward massage, automatic intermittent pneumatic compression, or simple elastic compression extending from the base of the toes.

The human foot venous pump is the first unit activated during the gait functional cycle, initiating venous return against gravity. It is followed by the calf muscle pump and other venous pumps, working in tandem to propel blood back to the heart.

Declaration

The authors of this paper Dr J.F UHL (myself) and M Lo Vuolo (MLV) solemny declare and confirm that they have the copyright ownership of the figures published in this paper.

Figs 1,3,4,6,7,8,12,14,15,17,18,22 are original and belong to MLV. Others were already published by me in my atlas book (I am the editor) and in Phlebology (Phlebology 2012;27:219–230) figs 6,9,12,14,17,20,21.

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