Thieme

Anatomy of Perforating veins of the lower limb

Anatomie der Perforansvenen der unteren Extremität

Authors
Jean-François Uhl[1], Claude Gillot[2, †]

Affiliations
1 Unesco Chair of Digital Anatomy – Paris University
2 Department of Anatomy – Paris University

Key words
anatomy, perforating veins, 3D modeling, duplex US

Schlüsselwörter
Anatomie, Perforansvenen, 3-dimensionale Modellierung, Duplex-Sonografie

Bibliography
Phlebologie 2021; 50: 59–75
DOI 10.1055/a-1246-6030
ISSN 0939-978X

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

Correspondence
Jean-François UHL, MD
Anatomy department – Paris University,
45 rue des saints-Pères, 75006 Paris, France
jeanfrancois.uhl@gmail.com

ABSTRACT

The perforating veins (PVs) of the lower limbs are not just straight and direct communications between the deep and the superficial venous networks, they are commonly making a complex multi-branched network. Despite their great anatomical variability, their location is remarkably constant and predictable. This is due to their close relationship with the muscular veins, explained by the hemodynamical levels along the limb. This constitutes a help for their assessment by sonographers in daily practice.
The anatomical contents of this paper came from the following sources: Anatomical dissections by C. Gillot, after latex injection, then colored segmentation of more than 400 limbs. 3D reconstructions from CT venography of 1200 limbs and pre-surgical skin venous mapping of 25 000 limbs.
We successively describe: Landmarks of the limb, perforating veins of foot, leg and ankle, calf, interperforator anastomosis, accompanying arteries of leg PVs, popliteal fossa PVs, thigh PVs.

ZUSAMMENFASSUNG

Die Perforansvenen (PV) der unteren Extremitäten sind nicht nur gerade und direkte Verbindungen zwischen den tiefen und oberflächlichen Venennetzen, sondern bilden gemeinsam ein weit verzweigtes Netz. Trotz ihrer starken anatomischen Variabilität ist ihre Position bemerkenswert konstant und prognostizierbar. Dies ist durch ihre enge Beziehung zu den Muskelvenen bedingt und durch die hämodynamischen Ebenen entlang der Extremität zu erklären. Sie sind bei der Beurteilung durch Ultraschalluntersucher in der täglichen Praxis eine Hilfe.
Der anatomische Inhalt dieses Artikels stammt aus folgenden Quellen: Anatomische Präparationen von C. Gillot nach Latex-Injektion und anschließender farblicher Unterteilung von über 400 Extremitäten. Dreidimensionale Rekonstruktionen von CT-Venografien von 1200 Extremitäten und präoperativen Hautvenenvermessungen von 25 000 Extremitäten.
Es wird Folgendes beschrieben: Referenzpunkte der Extremität, Perforansvenen des Fußes, Beins und Sprunggelenks, der Wade, Anastomosen zwischen den Perforansvenen, Begleitarterien der Bein-PVs und Oberschenkel-PVs.

Introduction

A perforating vein (PV) – vena perforantis – is defined by a vein joining the deep to the superficial venous system, which perforates the deep fascia, also called aponeurosis. Perforating veins are provided with one-way valves along the whole limb, and are physiologically oriented from superficial to deep, except for the foot PVs. (see paragraph 2)

Anatomical landmarks of the lower limbs

The knowledge of limb's divisions and reference points is essential for anatomical description [1]. Among the latter, we have to mention the following (red dots in ▶ **Fig. 1**):
1 – Malleolar apex, 2 – Apex of the gastrocnemius muscle, 3 – Knee joint, 4 – femoral condyles.

The divisions of the limb are shown by straight lines:
A: 4 cm above the malleolar apex, B: 4 cm below the knee joint (soleus arch level), C: 12 cm above the knee joint (adductor's hiatus level), D: Scarpa's triangle apex level.

These four lines allow us to recognize 5 anatomical regions: foot, ankle, leg, knee and thigh.

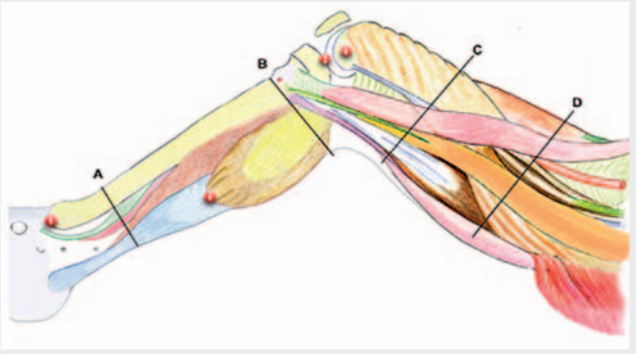
FOOT below the malleolar apex, ANKLE from malleolar apex to line A, LEG between lines A and B, KNEE between lines B and C, THIGH between lines C and D

GENERAL DESCRIPTION [1, 2] of perforating veins (PVs)

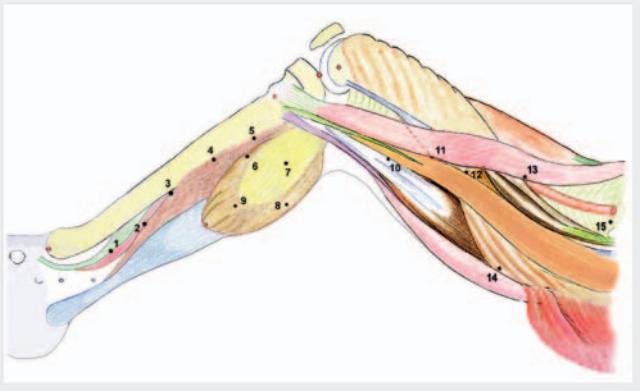
We will describe successively, according to Gillot's Atlas: ANKLE, LEG (numbers 1 to 5), CALF (numbers 6 to 9), KNEE, femoral THIGH PVs. (numbers 10 to 12) and other thigh PVs (numbers 13 to 15) see ▶ **Fig. 2**.

The perforating veins have been renamed for a better international understanding in an UIP consensus document in 2002. The old and new terminology [4, 5] is shown on ▶ **Table 1**.

A more detailed anatomical topography of the leg including the distances from the floor is shown in scheme ▶ **Fig. 3**, based on a tibial length of 35 cm. Since the perforators relate to the anatomy and function of muscular veins, their location is quite constant, and predictable. This is related to the hemodynamical



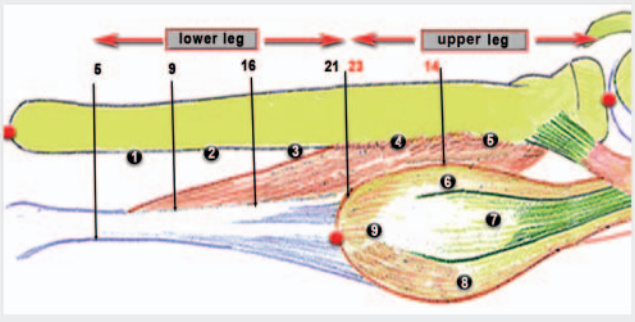
▶ **Fig. 1** Lower limb's anatomical landmarks. Reference points and regions (Source: Gillot C. Atlas of the superficial venous network of the lower limbs. Editions Phlébologiques Françaises; 1980) 1 = Malleolar apex, 2 = apex of the gastrocnemius, 3 = knee joint, 4 = femoral condyle. FOOT below the malleolar apex, ANKLE from malleolar apex to line A, LEG between lines A & B. KNEE between lines B & C, THIGH between lines C & D.



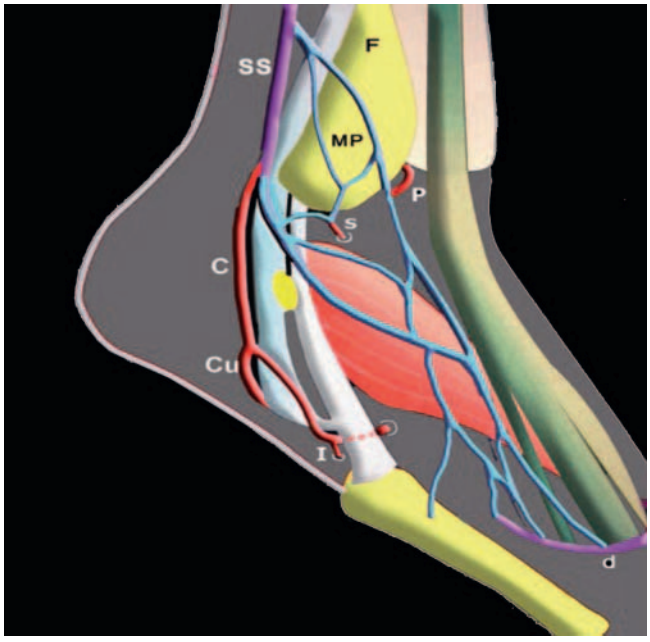
▶ **Fig. 2** Location of the main perforating veins (PVs) of the limb (Source: Gillot C. Atlas of the superficial venous network of the lower limbs. Editions Phlébologiques Françaises; 1980). ANKLE, LEG (numbers 1 to 5), CALF (numbers 6 to 9), THIGH PVs (numbers 10 to 12). 1 = Lower posterior tibial, 2 = Higher posterior tibial 3 = Inferior paratibial, 4 = lower superior paratibial, 5 = higher superior paratibial, 6 = Anterior calf PV, 7 = central calf PV, 8 = Posterior calf PV, 9 = Inferior (polar) calf PV 10 = PV of the Hunter canal 11 = Lower PV of femoral canal, (formerly Dodd's PV), 12 = Higher PV of femoral canal, 13 = PV of the apex of the scarpa triangle, 14 = PV of the adductor magnus, 15 = Direct femoral vein PVs (connected to the lymph node venous networks of the groin [6]).

▶ **Table 1** Terminologies of the Perforating veins of the lower limb [4, 5].

old eponyms (English)	new terminology (English)	latin vena perforans	german Perforansvene	french veine perforante
Cockett	posterior tibial	posterior tibialis	Posteriore tibiale	Tibiale postérieure
Sherman	inferior paratibial	paratibialis inferior	Inferiore paratibiale	Paratibiales inférieures
Boyd	superior paratibial	paratibialis superior	Superior paratibiale	Paratibiales supérieures
May	inter gemalar	intergemellaris	Intergemelläre	inter gémellaire
Bassi	para achilean	para achilean	Paraachilläre	Para achilléenne
Gillot	medial gastrocnemius	Gastrocnemius medialis	Gastrocnemius medialis	Polaire du gastrocnémien médial
Thierry	popliteal fossa	fossa poplitea	Der Fossa poplitea	Externe de la fosse poplitée
Dodd	femoral canal (femoral canal)	Femoralis	Des Femoralkanals	du canal fémoral
Hunter	adductor canal	Hunter	Des Addukotrenkanals	Huntérienne
Hach	posterolateral thigh	V femoris posterior	Posterolaterale PV des Oberschenkels	postéro-latérale de cuisse



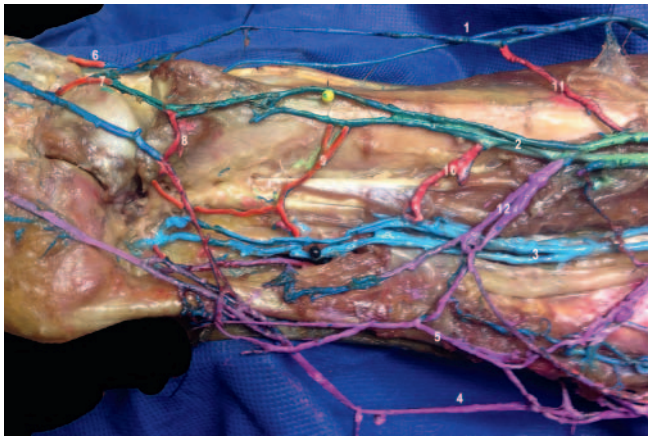
▶ **Fig. 3** Locations of the leg and calf PVs for a tibia length of 35 cm. (Source: Gillot C. Atlas of the superficial venous network of the lower limbs. Editions Phlébologiques Françaises; 1980). Lower leg perforator's measurements are taken from the malleolus. Upper leg perforators measurements are taken from the knee joint. 1 = Lower posterior tibial (5 to 9 cm), 2 = Higher posterior tibial (from 10 to 16 cm), 3 = inferior paratibial (from 17 to 21 cm), 4 = lower superior paratibial (from 15 to 23 cm), 5 = higher superior paratibial (from 6 to 14 cm), 6 = Anterior calf PV, 7 = central calf PV, 8 = Posterior calf PV, 9 = Inferior (polar) calf PV.



▶ **Fig. 4** The lateral foot PVs (Scheme from right foot, lateral view). Cuboid intertendinous (I) and infratendinous (Cu) perforators join in a common trunk (C), which is the 3 rd root for the SSV (SS) trunk origin. F = fibula, MP = lateral malleolar plexus, d = superficial dorsal venous arch, P = lateral dorsal PV of the ankle, which connects to the anterior tibial veins, s = lateral inframalleolar perforator, which connects to the peroneal veins.

levels of the limb, explained in more details on paragraph 3. Therefore, the landmarks and distances displayed in this figure become useful not just for skin mapping but for treatment as well, according to tibia's length. In clinical practice, sonographers can use these landmark distances, according to the tibia length, for a quicker assessment of the leg PVs

▶ **Fig. 5** Calcaneal PV and Achillean tributary of the SSV. Drawing from anatomical dissection (right limb, medial view)1 = achillean tributary, 2 = SSV, 3 = calcanean PV, 4 = infra malleolar PV, 5 = PV connecting with the AT veins, 6 = posterior tibial PVs (superior), 7 = posterior tibial PVs (middle), 8 = posterior tibial PVs (inferior), 9 = inferior paratibial PV, 10 = Polar calf PV 11 = anterior accessory saphenous of the GSV, 12 = medial marginal vein, GS = GSV.

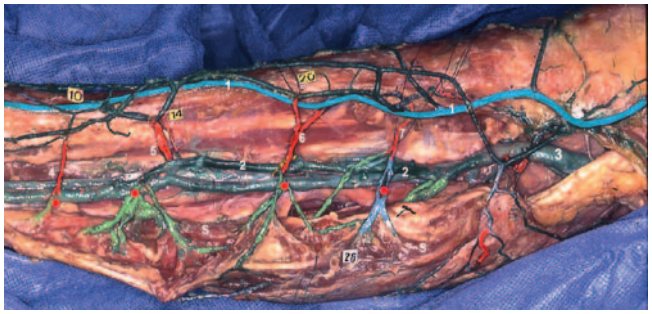


▶ **Fig. 6** Lower leg and ankle Anatomical dissection (left limb, lateral view, after removing the fibula). This outstanding dissection by C. Gillot shows several transverse connections between the venous axes displayed: an information that – to the best of my knowledge – cannot be found in anatomy books. This unique final result was possible only after having removed the fibula. 1 = anterior tibial (AT) veins, 2 = peroneal veins, 3 = posterior tibial (PT) veins, 4 = Achillean tributary, 5 = SSV, 6 = dorsal PV of the ankle which gives origin to the AT veins, 7 = dorsal PV of the ankle which gives origin to the peroneal (peroneal) veins, 8, 9 and 10 = deep communicating veins between peroneal and PT veins, 11 = deep communicating veins between peroneal and AT veins, 12 = perforators from the SSV system into the peroneal veins.

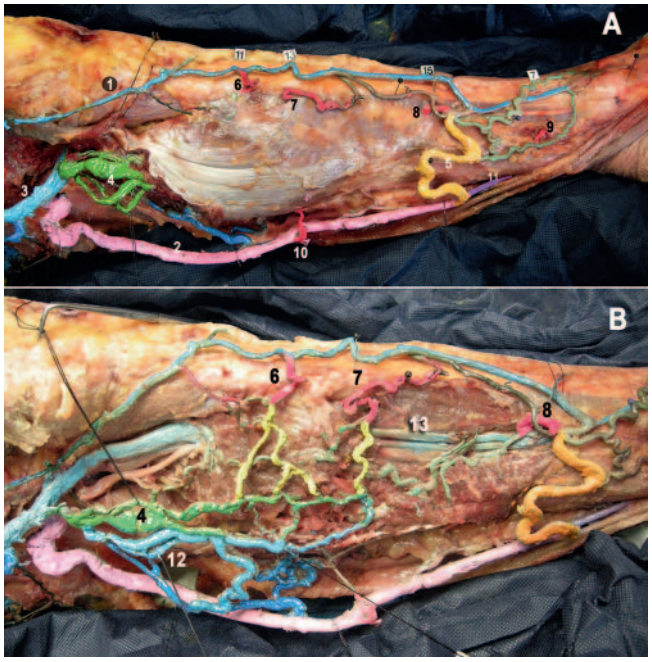
The perforating veins of the foot [6–9]

Hemodynamical key features of Foot PVs [9]

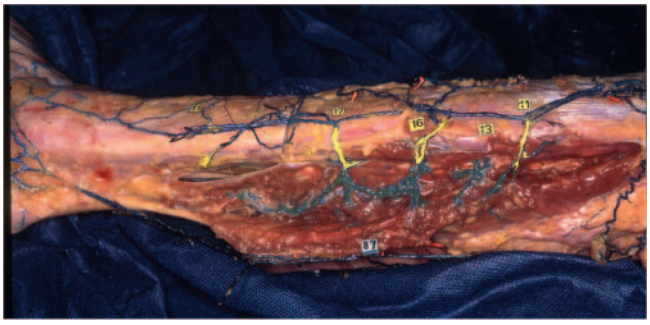
Perforating veins of the foot show a distinctive feature, which is unique in the venous system of the lower limbs. Some of them are either valveless – allowing bidirectional flow – or have valves in the inverted position, enabling "inverted" flow: from deep towards superficial veins. So, from a hemodynamic point of view, foot veins



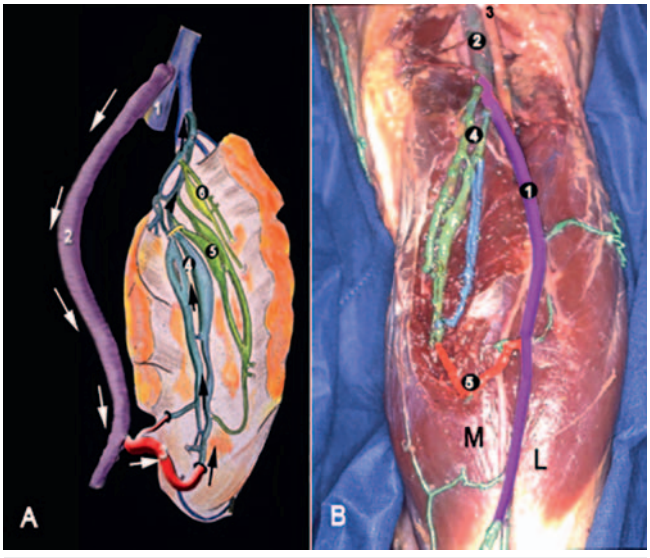
▶ **Fig. 7** Medial PVs and hemodynamic levels. Anatomical dissection (right limb, medial view). On the medial surface of the leg, PVs are displayed together with their hemodynamic levels at 10, 14 and 20 cm from the medial malleolus. 1 = GSV (in light blue) Tributaries of the GSV (in dark blue) give origin to the main PVs. 2 = posterior tibial (PT) veins 3 = Popliteal vein 4 = inferior posterior tibial PV 5 = Superior posterior tibial PV 6 = Inferior paratibial PV, 7 = Superior paratibial PV. Two groups of veins drain the soleus muscle (S): medial soleal veins (MSVs) and lateral soleal veins. MSVs are shown (in green) in this figure. Please note how they converge towards specific points (red circles), corresponding to the draining points of perforating veins.



▶ **Fig. 8** Medial PVs of the leg **A** and their deep connections **B**. Gillot's dissection of a left limb (medial view) after dissection of the skin and fascia **A** and after dissection of deep plan **B**. The patient had a refluxing SPJ and insufficient SSV trunk, which is found dilated (2). A transverse superficial communicating vein (5) shunted reflux towards the GSV trunk (1) and the superior posterior tibial PV (8) in the lower leg. Deep dissection displays connections between medial gastrocnemius (12) and soleal (4) veins, and to superficial veins through perforators as well. 3 = popliteal vein, 6 = superior paratibial PV, 7 = lower paratibial PV, 8 = superior posterior tibial PV9 = inferior posterior tibial PV, 10 = central calf PV, 13 = posterior tibial veins.



▶ **Fig. 9** Lateral PVs and hemodynamic levels. Anatomical dissection (right limb, lateral view). Lateral soleal veins, shown on the lower half of the picture, are colored in green. They converge towards specific points, to receive the peroneal PVs (in yellow) at the hemodynamic levels displayed on yellow labels: 11,17 cm from the lateral malleolus and 11, 13 and 16 cm from the knee joint.

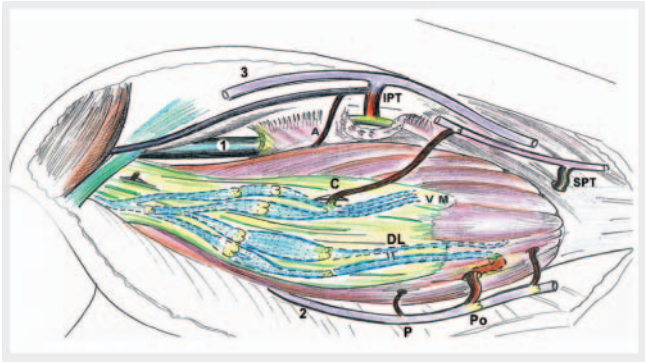


▶ **Fig. 10** The calf PVs and their connections with gastrocnemius veins (saphenogemellar arcade). **A** Schematic presentation of the polar PV (3). The direction of venous flow is indicated by white arrows. 1 = popliteal vein, 2 = SSV, 3 = polar PV, 4 = ventromedial component (VMC) of medial gastrocnemius veins, 5 = dorsolateral component (DLC) of medial gastrocnemius veins, PV 6 = dorsal veins of the Soleus muscle. **B** Anatomical dissection of a right leg (posterior view) showing the SSV (1) and its posterior PV of the calf., 2 = popliteal vein 3 = tibial nerve 4 = medial common gastrocnemius venous trunk 5 = posterior PV of the calf M = medial gastrocnemius muscle L = lateral gastrocnemius muscle.

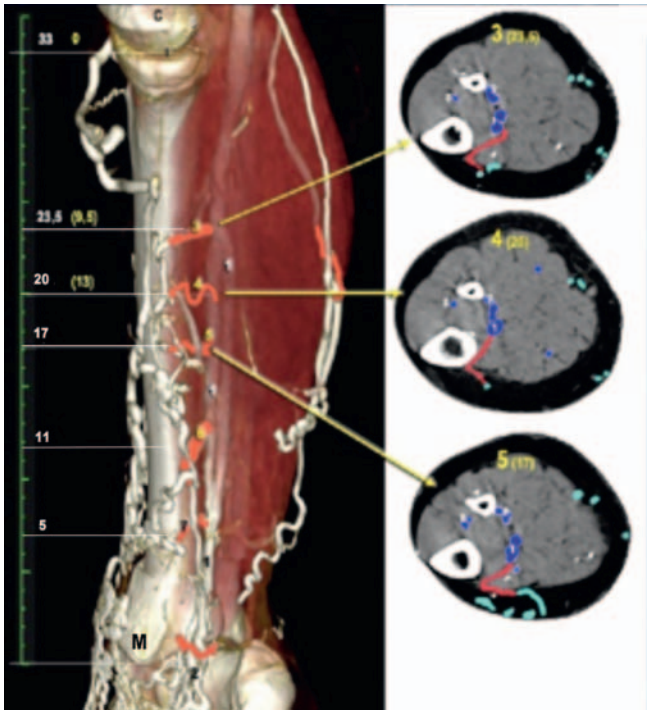
should not be classified as deep and superficial, but considered as medial and lateral anatomical/functional units instead.

THE MEDIAL FOOT PVs

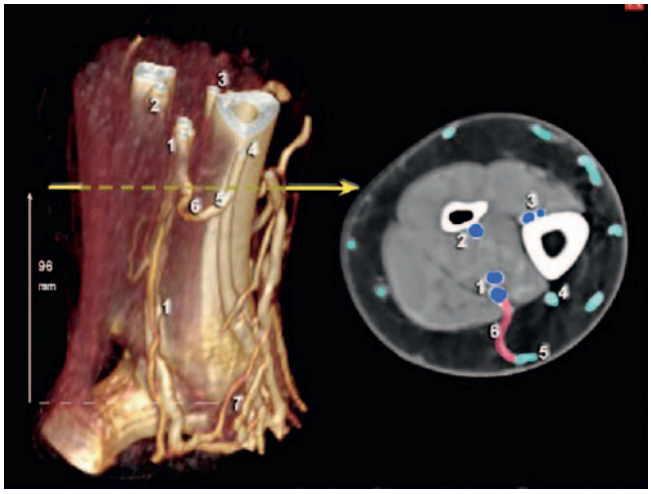
1. Located at the forefoot, the perforator of the first intermetatarsal space is usually the largest. It connects the medial marginal vein (MMV) to the plantar veins. On the opposite end, over the anterior surface of the medial malleolus, the MMV gives the main root, out of 3, to form the GSV.



▶ **Fig. 11** The calf PVs and their connections with gastrocnemius veins. Po = Polar calf PV, P = Posterior calf PV, C = Central calf PV, A = Anterior calf PV, SPT = superior paratibial PV. IPT = inferior paratibial PV, 1 = popliteal vein, 2 = SSV, 3 = GSV, VM = Ventromedial component of medial gastrocnemius veins, DL = dorsolateral component of medial gastrocnemius veins.



▶ **Fig. 12** Virtual dissection by CTV showing medial leg PVs. 1 = PT veins; 2 = Calcaneal crossroad; 3 = Superior paratibial PV (upper Boyd) located at 23.5 cm from the medial malleola; 4 = Superior paratibial PV (lower Boyd) located at 20 cm from the medial malleola; 5 = Inferior paratibial PV (Sherman) located at 17 cm from the medial malleola; 6 = Posterior tibial PV (upper Cockett) located at 11 cm from the medial malleola; 7 = Posterior tibial PV (lower Cockett) located at 5 cm from the medial malleola; 8 = AT veins; 9 = Fibular veins C = Medial femoral condyle I = knee joint level M = Medial malleola.



▶ **Fig. 13** Ankle & lower leg PVs. 3D reconstruction from CTV through virtual rendering technique (VRT). 1 = PT veins; 2 = Peroneal veins; 3 = AT veins; 4 = GVS; 5–6 = Posterior tibial PV (Cockett) at 9.6 cm from the medial malleolus. Formerly superior posterior tibial PVs were known as Cockett III, while mid posterior tibial PVs were known as Cockett II. The latter are currently called inferior posterior tibial PVs, while formerly known Cockett I is now included within the perforators of the ankle group).

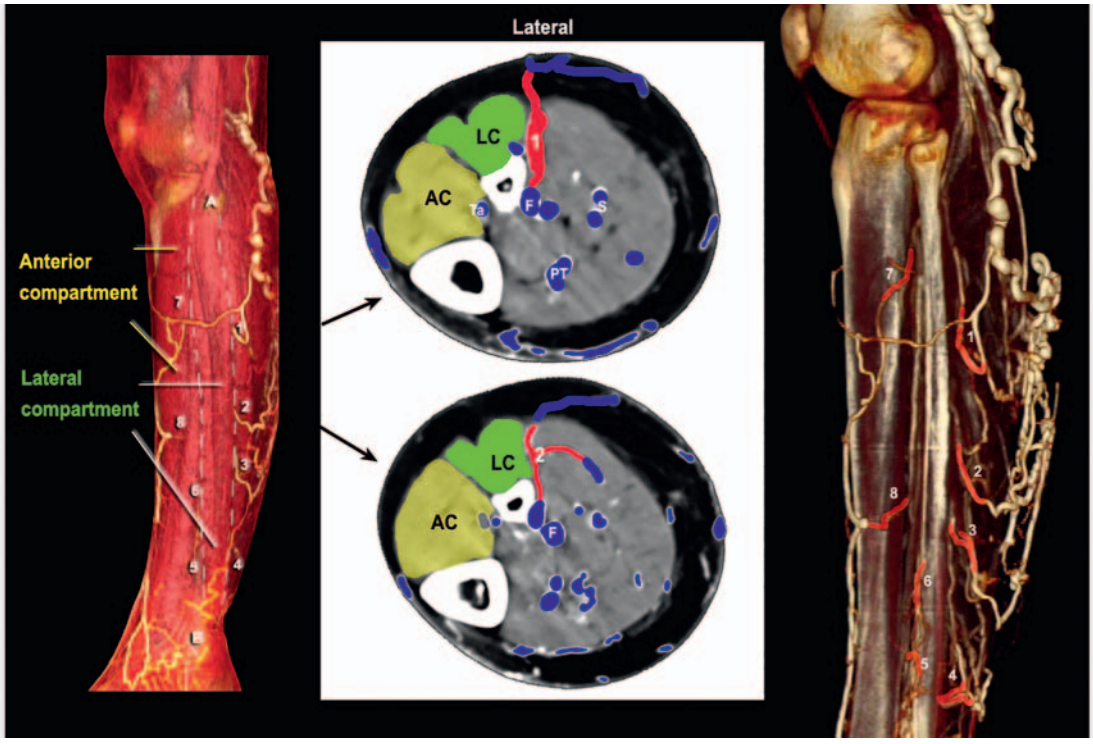
2. At the medial side of the foot, there are 3 main perforators:
   - inframalleolar or inframalleolar PV: considered to be the second root for the GSV origin.
   - navicular PV: running close to the navicular bone at midfoot.
   - cuneiform PV, which courses near to the medial cuneiform bone.
3. the third root for the GSV origin is the medial dorsal PV of the ankle, which connects to the anterior tibial veins

The dorsal foot and ankle PVs originate from the venous network of the dorsal foot and gives birth to the peroneal and anterior tibial veins (▶ **Fig. 4**)

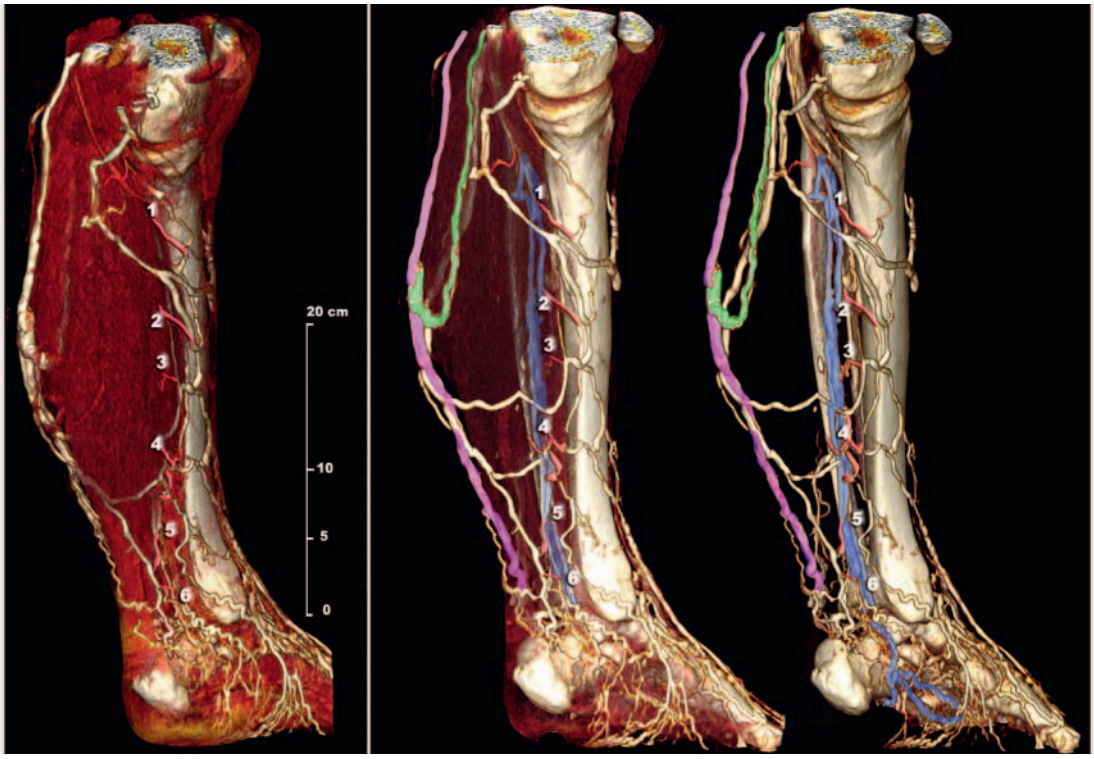
The lateral foot PVs. The intertendinous and infratendinous PVs are cuboid perforators that share a common trunk. This trunk is the 3rd root for the SSV since it joins the 2nd and 1st roots (lateral malleolar plexus & plexiform lateral marginal vein respectively) to form the SSV trunk. The infratendinous and intertendinous perforators are so called because of their path: below the peroneus longus tendon and between the latter and the peroneus brevis tendon respectively (▶ **Fig. 4**).

The posterior foot PV: At the posterior part of the foot we find the calcaneal PV, which originates from the calcaneus plexus and is usually connected to the Achillean tributary of the SSV. The Achillean tributary runs medially to the Achille's tendon to drain into the SSV at the lower third of the calf (▶ **Fig. 5, 7**).

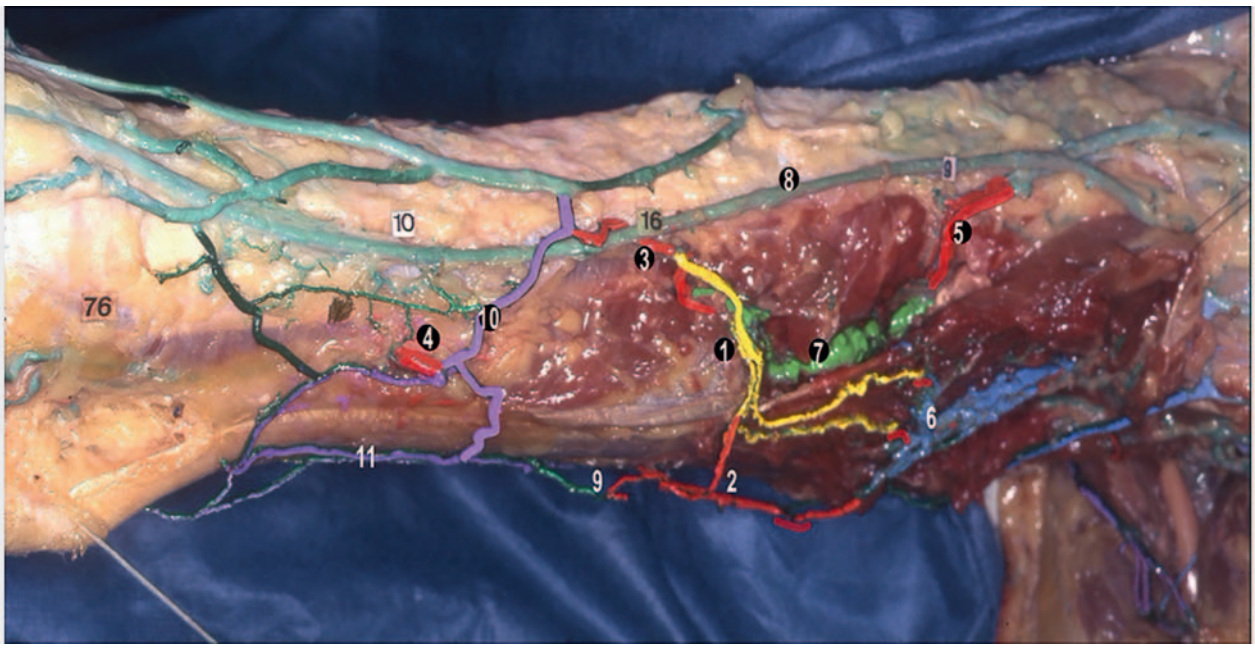
During the systolic phase of the calf pump, extrinsic muscular compression of posterior tibial and peroneal veins blocks venous return through this path. Flow coming from the foot is then shunted to alternative superficial routes, mainly the GSV and the SSV.



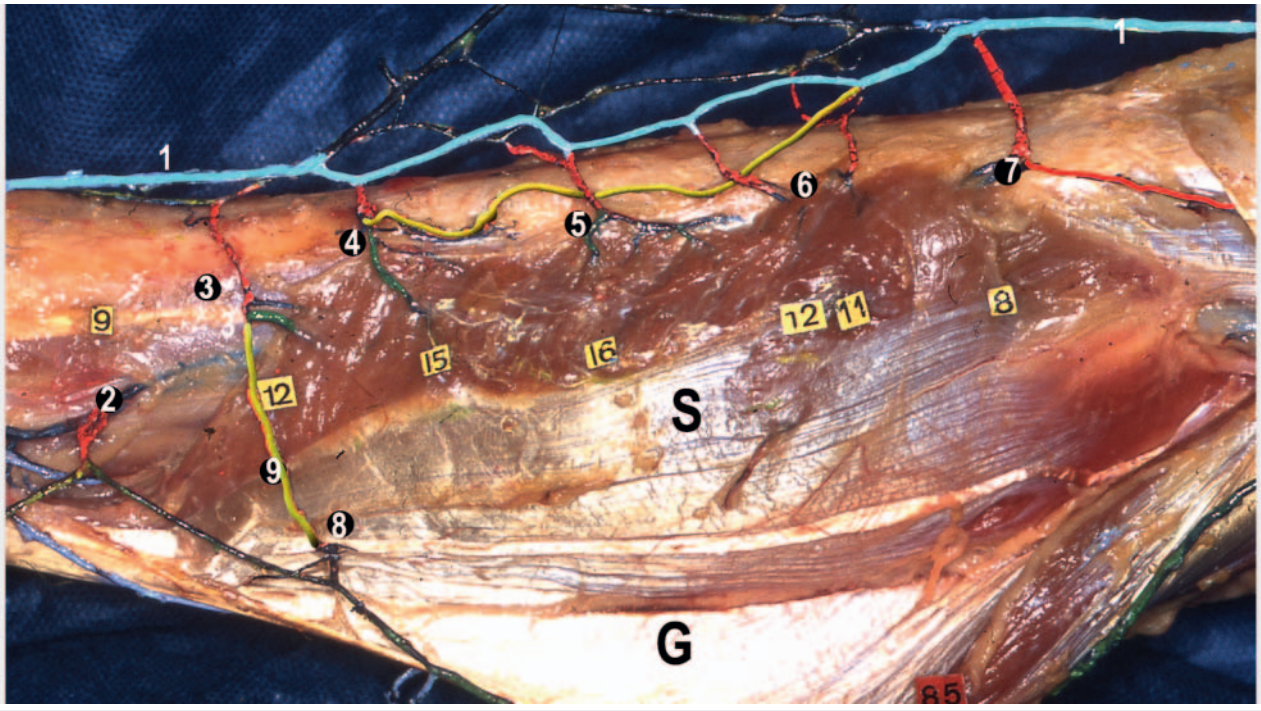
▶ **Fig. 14** Anterior and lateral leg PVs. 3D reconstruction from CTV through virtual rendering technique (VRT) PT = PT veins, F = peroneal veins, Ta = anterior tibial veins, S = soleal veins, 1–2–3–4 = peroneal PVs (draining into the lateral group of soleal veins), 5–6 = lower anterior tibial PVs, 7–8 = higher anterior tibial PVs, AC = anterior compartment of the leg (in yellow), LC = lateral compartment of the leg (in green). Please note that the soleus muscle is drained by two groups of veins: medial soleal and lateral soleal veins, the latter being the largest ones.



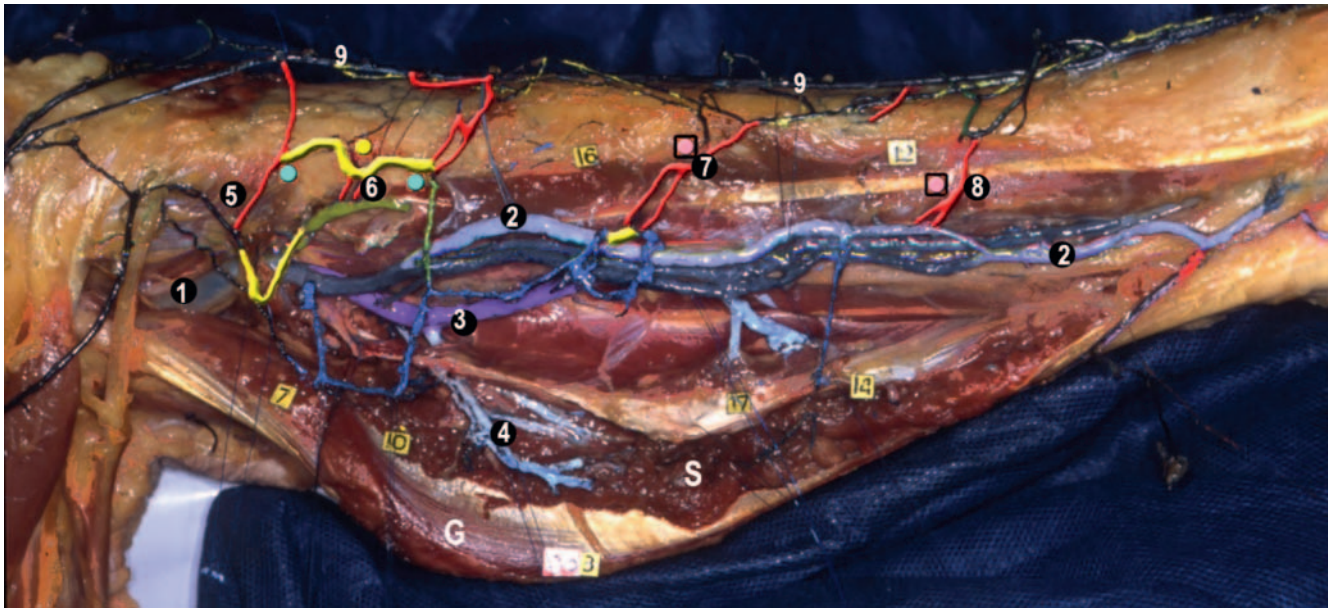
▶ **Fig. 15** Leg perforators and gastrocnemius veins. Virtual dissection from CTV. 1 = upper superior paratibial PV, 2 = lower superior paratibial PV, 3 = inferior paratibial PV, 4 = superior posterior tibial PV, 5 = middle posterior tibial PV 6 = inferior posterior tibial PV. PVs are in red. The SSV is colored in purple, the medial GV in green and the PT veins in blue.



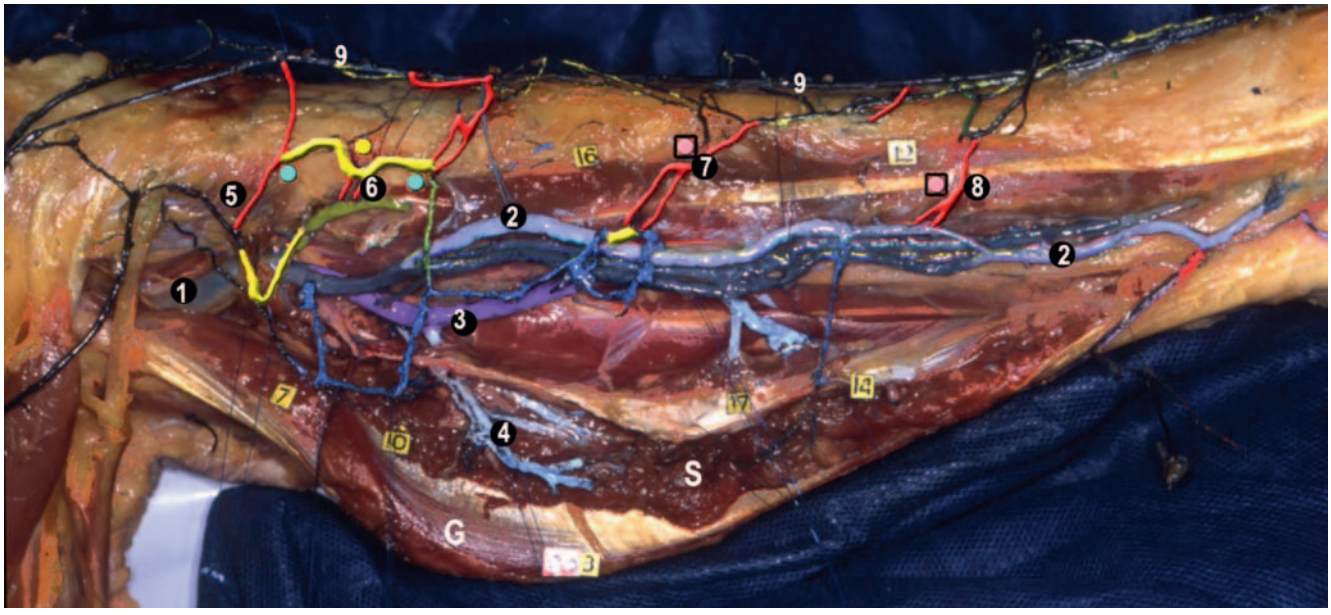
▶ **Fig. 16** Horizontal interperforator anastomoses (IPA). Dissection by C. Gillot after latex injection and segmentation (right leg, medial view). Transverse anastomosis (1, in yellow) at midleg, linking an inferior paratibial (3) to a medial gastrocnemius perforator (2). 4 = superior posterior tibial PV (in red), 5 = superior paratibial PV (in red), 6 = medial gastrocnemius vein, 7 = medial soleal vein, 8 = GSV, 9 = para-achillean (formerly Bassi's PV), 10 = transverse superficial communicating vein of the lower leg, 11 = SSV. Please note that neither the superior (5) nor the inferior (3) paratibial PVs spring from the GSV trunk in this particular case. Numbered labels indicate PVs hemodynamic levels.



▶ **Fig. 17** Longitudinal and horizontal interperforator anastomoses. Anatomical dissection by C. Gillot, after latex injection and color segmentation (right leg, medial view). Longitudinal interperforator anastomosis joining several (4 to 7) medial PVs at the upper leg. This case clearly shows the connection of most medial PVs through a long uninterrupted anastomosis (in yellow). Both PVs and anastomosis run below the aponeurosis of the Soleus muscle (S) which was detached from the tibial bone. The superficial origin of perforators, from the GSV trunk (1) and tributaries, is clearly visible. The yellow labels indicate PVs hemodynamic levels: at 9,12,15,16 cm from the medial malleolus and 8,11,12 cm from the knee joint. A horizontal IPA (9) is also displayed, linking a lower posterior tibial perforator (3, in red) to the polar perforator (8) at the apex of the calf, 2 = ankle PV, 4 = higher posterior tibial PV, 5 = inferior paratibial PV, 6–7 = superior paratibial PVs, 8 = polar calf PV, G = gastrocnemius muscle.



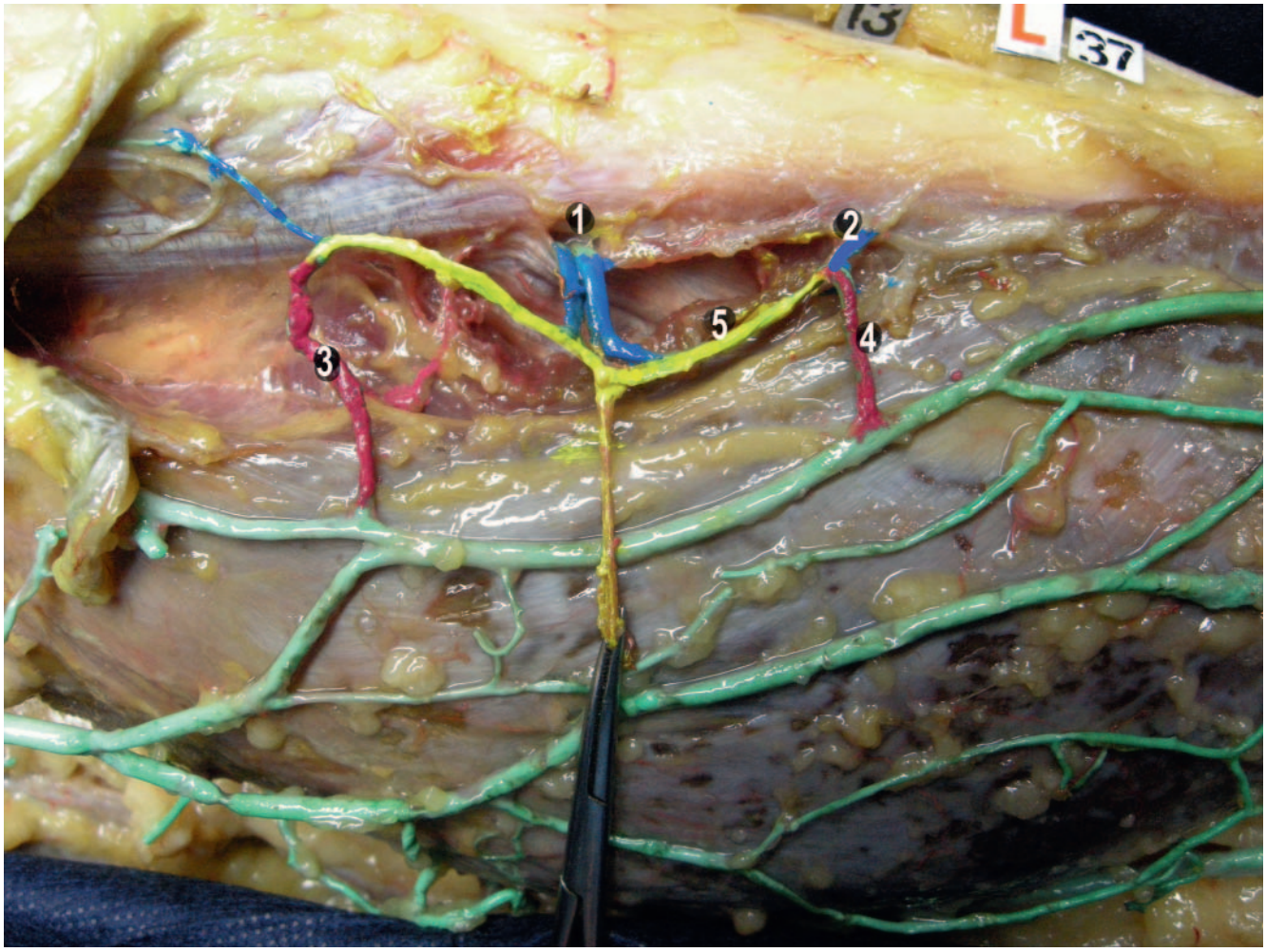
▶ **Fig. 18** Longitudinal anastomosis of paratibial PVs. Dissection of a left leg (medial view). 1 = popliteal vein, 2 = PT veins, 3 = peroneal veins, 4 = medial soleal veins, 5 = upper superior paratibial PV, 6 = lower superior paratibial PV, 7 = inferior paratibial PV, 8 = posterior tibial PV, 9 = GSV tributaries, S = Soleus muscle, G = gastrocnemius muscle.



▶ **Fig. 19** Complex PVs anatomical pattern. Anatomical dissection by C. Gillot after latex injection and color segmentation (right leg, medial view). This case illustrates the anatomical complexity that PVs connections can reach. Perforating veins subfascial links should not be understood as a single joining between superficial and deep veins but, instead, as a complex (occasionally plexiform) network composed of multiple bonds. Medial PVs of the leg (in red) form a plexiform network extended between the GSV (1) and its accessories (2) on one end, and convergent medial soleal veins (3) on the opposite side. Yellow labels indicate PVs hemodynamic levels: at 10,12,18 cm from the medial malleolus and 9, 13 and 16 cm from the knee joint. 4 = ankle PV 5 = lower posterior tibial PV 6 = upper posterior tibial PV 7 = inferior paratibial PV 8 = superior paratibial PVs S = Soleus muscle G = partially resected gastrocnemius muscle.

Leg & ankle perforating veins [11]

At different levels, horizontal or oblique anastomoses (deep communicating veins) between posterior tibial, anterior tibial and fibular veins may be present (▶ **Fig. 6**). These are not randomly distributed, but located at several levels, which define the hemodynamic levels, explain the fixed location of the leg perforator veins, and allow for venous blood flow exchange when needed.



▶ **Fig. 20** Longitudinal IPA Anatomical dissection of upper left leg (medial view). A vertical IPA is shown (5), linking superior paratibial perforators (1,2 in blue). The longitudinal anastomosis (5) has a double connection (3,4) to the GSV trunk. The saphenous network (GSV and tributaries) are painted in green.

Leg PVs landmarks and theory of hemodynamic levels by Gillot [1]

The anatomic and functional interaction between leg's muscular veins and PVs, allows us to know in advance the location of perforators, which is quite steady when related to the tibia's length (▶ **Fig. 3**). This is according to the theory of the hemodynamical levels of C. Gillot: PVs are closely connected to the muscular veins which represent the active part of the pumps. Their fixed location is explained by anatomy of the muscular veins.

Leg PVs can be divided into 2 groups: medial (▶ **Fig. 7, 8**) and lateral (▶ **Fig. 9**)

Medial lower leg perforator's measurements [1] are taken from the malleolus, including the following groups on the medial surface: ankle PVs (–2 to 4 cm), inferior posterior tibial PVs (5 to 9 cm), superior posterior tibial PVs (10 to 15 cm) and inferior paratibial PVs (16 to 20 cm).

Upper leg perforator's measurements are taken from the knee joint. These are the superior paratibial PVs (6 to 14 cm), the inferior paratibial PVs (15 to 23 cm). The superficial connection of the medial PVs is variable, according to the anatomy of the superficial communicating veins of the leg

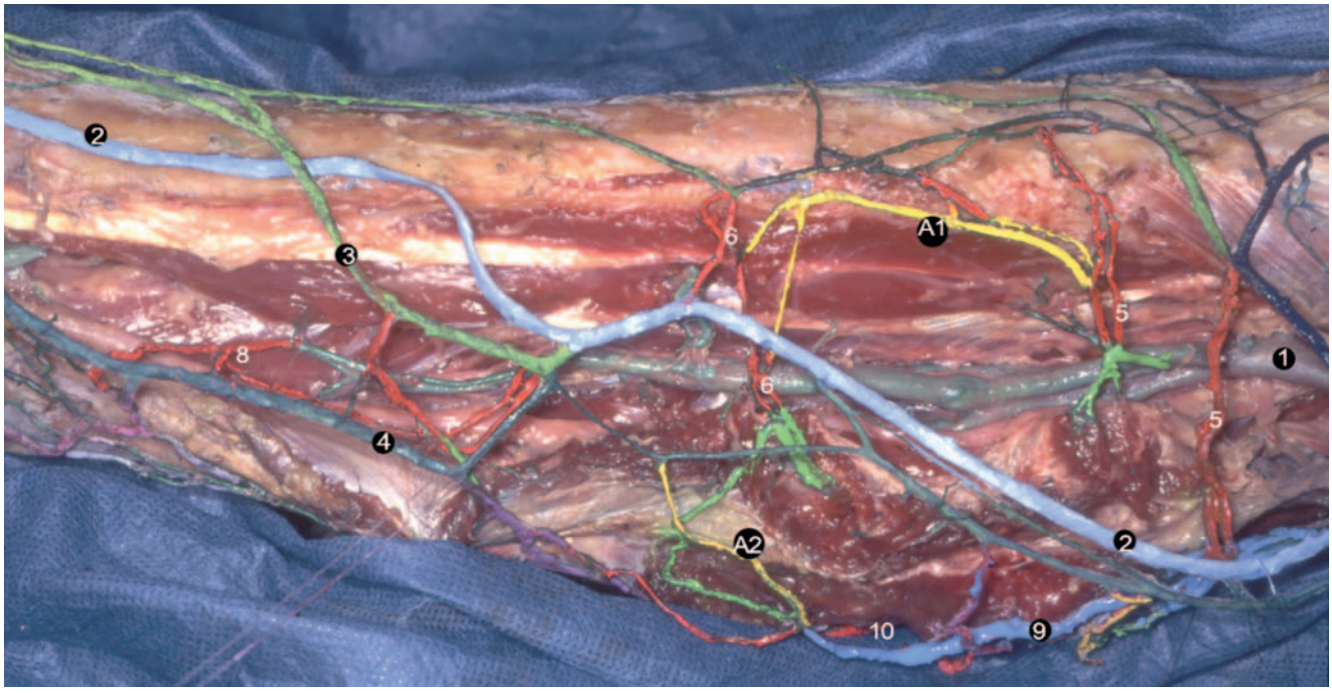
On the lateral surface of the leg, peroneal PVs, in yellow (▶ **Fig. 9**) are located on the same level than the medial leg PVs (in red). They drain into the peroneal veins.

Calf perforating veins [1, 12]

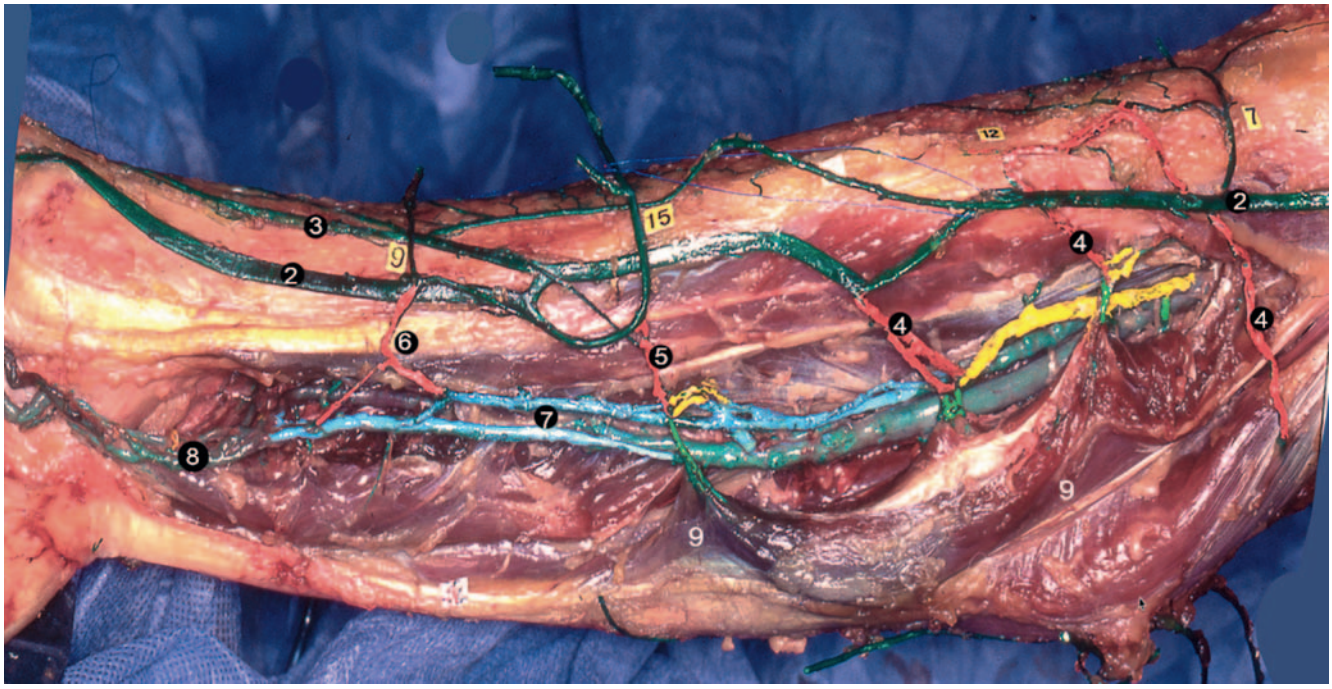
They can be divided into 4 groups: anterior, posterior, central and inferior perforators. The latter, formerly known as Gillot's perforator, is also called the "polar" PV since it is located at the apex of the calf (lower end of the medial gastrocnemius muscle, see ▶ **Fig. 1,** Point 2).

The central and anterior PVs usually drain into the soleal veins. To do so, they have to run through the gastrocnemius muscle. Thus, they are also known as trans-gemellar PVs of the soleus.

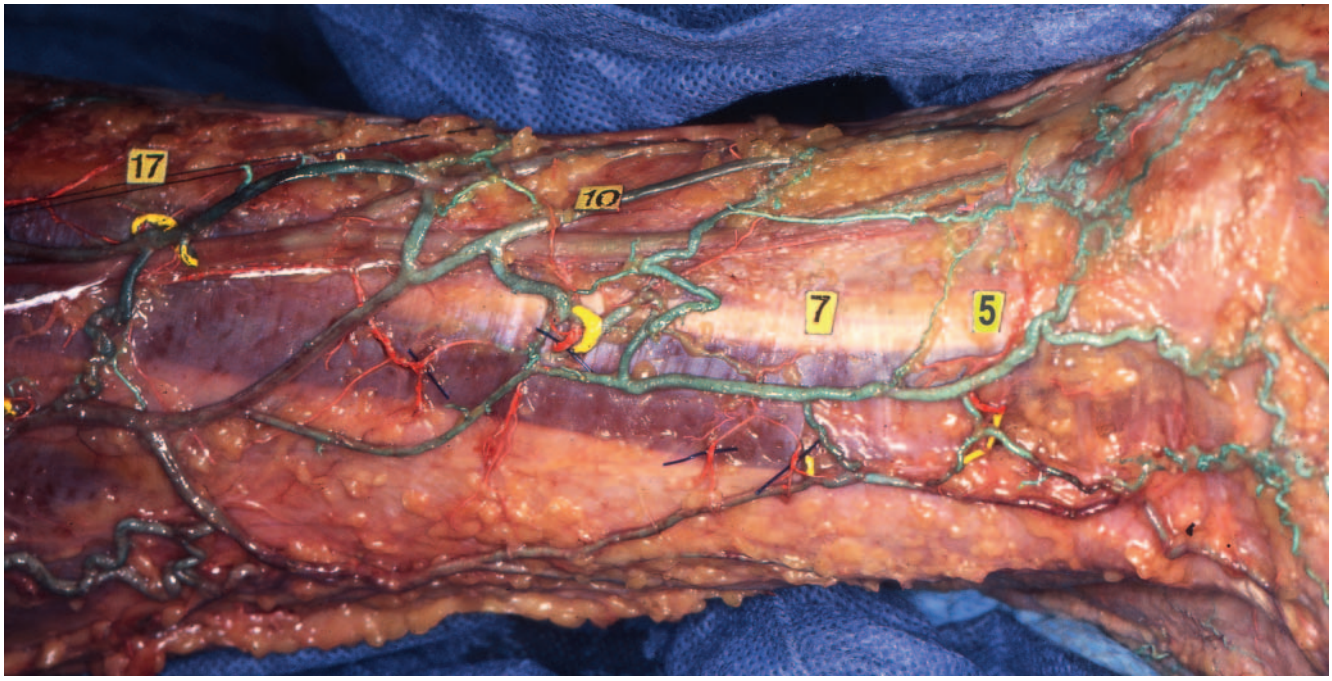
The polar PV of the calf is frequently present and plays an important functional role, due to its direct connection (end-to-end anastomosis) to the powerful pump of the medial gastrocnemius



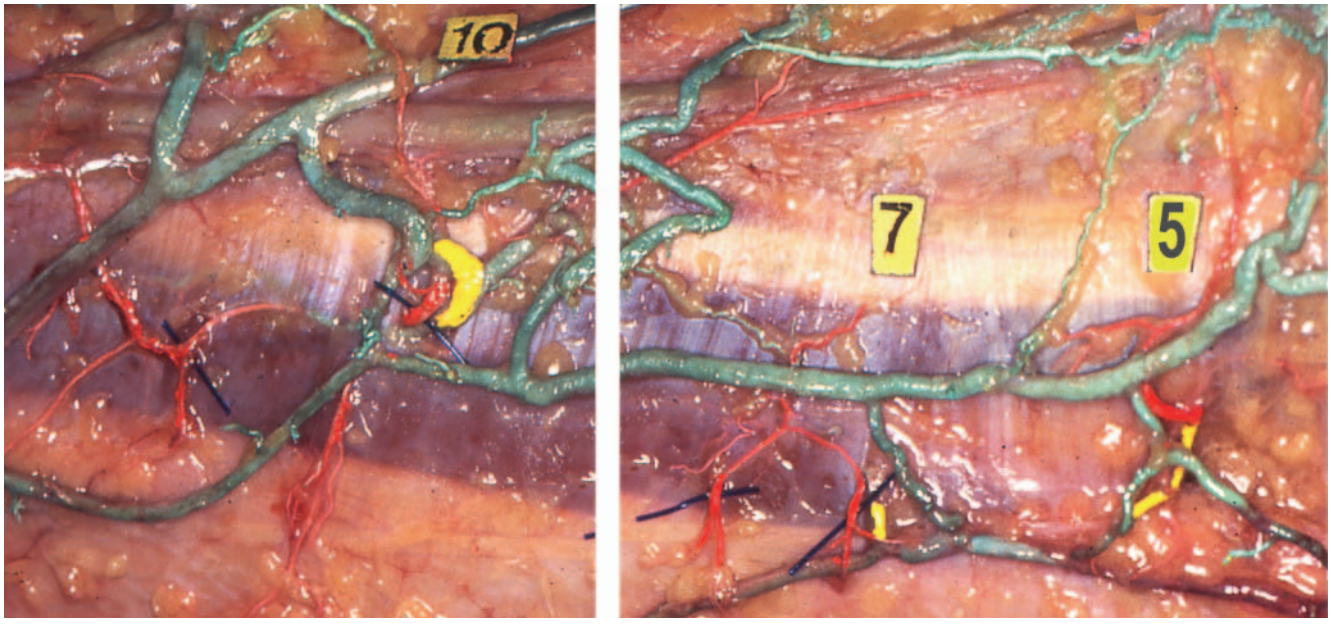
▶ **Fig. 21** Longitudinal IPA. Anatomical dissection by C. Gillot of a right leg (below the knee, medial view) (medial below-knee view of a right leg) PVs are colored in red, IP anastomosis (A1 & A2) in yellow. A vertical anterior IPA is displayed (A1), between superior (5) and inferior (6) paratibial PVs. An additional oblique posterior IPA (A2) is shown. PVs are colored in red. 1 = popliteal vein, 2 = GSV, 3 = anterior accessory GSV, 4 = posterior accessory GSV, 5 = superior paratibial PVs, 6 = inferior paratibial PVs, 8 = superior posterior tibial PV, 9 = oblique superficial communicating vein of the calf, 10 = calf PVs.



▶ **Fig. 22** Longitudinal IPA. Anatomical dissection by C. Gillot of a right leg (below the knee, medial view). Vertical IPA (in yellow), connecting superior (4) and inferior (5) paratibial PVs, PVs are colored in red, 2 = GSV, 3 = anterior accessory GSV, 6 = superior posterior tibial PV, 7 = PT veins, 8 = calcaneal confluence of plantar veins, 9 = soleus muscle. Please notice the hemodynamic levels (yellow labels) 9 and 15 cm from the medial malleolus and 7 and 12 cm from the knee joint.



▶ **Fig. 23** Accompanying arteries of the leg PVs. Anatomical dissection after double (arterial and venous) latex injection and color segmentation. Arteries are shown in red, while veins are displayed in green. Left lower leg (medial view). Following the course of PVs (in yellow), several tiny arteries are visible on the posteromedial aspect of the lower leg. Yellow labels indicate PVs hemodynamic levels: posterior tibial perforators at 5, 7 and 10 cm from the medial malleolus and inferior paratibial PV at 17 cm from the same anatomical landmark.



▶ **Fig. 24** Accompanying arteries of the leg PVs. Enlarged from previous figure, these pictures display greater anatomical detail. Running close to their accompanying arteries (in red), PVs are shown in yellow.

muscle. This key anatomical feature allows SSV reflux to re-enter the popliteal vein through the gastrocnemius veins. White arrows in (A) indicate the direction of the reflux circuit.

The posterior or dorsal (D) calf PV. At the level where the leg reaches its maximum diameter, the posterior PV connects to the dorsolateral component (DLC) of medial gastrocnemius veins through an end-to-end anastomosis. Likewise, through and end-to-end anastomosis, the inferior (polar or Gillot's) PV ends either in the DLC or in the ventromedial component (VMC) of medial gastrocnemius veins, as shown in ▶ **Fig. 10, 11**.

The central (C) calf PV drains into the DLC of medial gastrocnemius veins at the same level than the posterior calf PV.

The anterior (A) calf PV drains into the VMC of medial gastrocnemius veins and into soleal veins as well. To do so, it splits into 2 or more subfascial connections. One of them terminates as an end-to-end anastomosis with the VMC. The other one runs through the gastrocnemius muscle to drain into the soleal veins. It is known as the "transgemellar" PV of the soleus muscle.

▶ **Fig. 25** Posterior tibial artery branches. Anatomical dissection of a right leg (medial view). Ankle is on the left of the picture while upper leg is on its right. In this case, arterial red latex injection was performed prior to the dissection. Many tiny arteries are shown, branching from the posterior tibial artery. (The red and blue plastic tubes are used to enhance the tributaries connections).

Leg perforating veins by CTV [2, 14–17]

3D reconstruction from CT Venography is made possible through virtual rendering technique (VRT) ▶ **Fig. 12–15**.

Interperforator anastomoses (IPA)

The rate of after surgery recurrent leg's PVs insufficiency is very high (about 76 % after 3 years follow-up) according to André Van Rij [17], and usually underestimated.

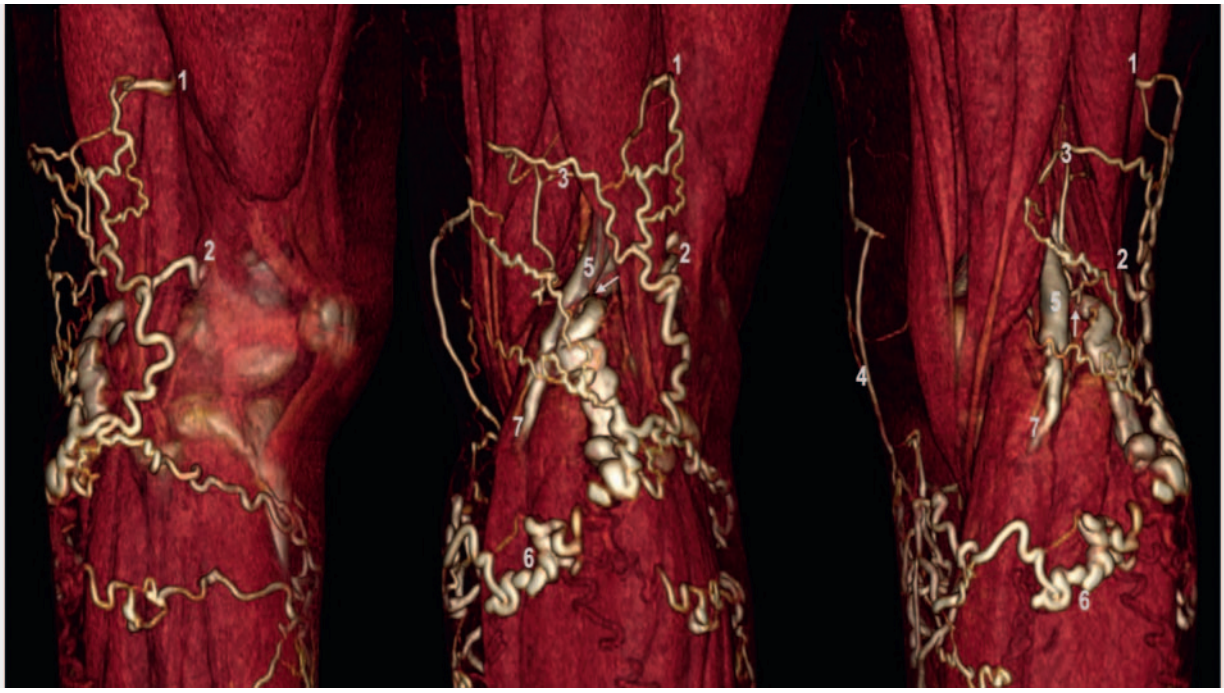
In our dissection series of non-embalmed cadavers, after latex injection and color segmentation, multiple deep connections between perforators are visible in a significant (60 %) number of cases. We call them the interperforator anastomoses (IPA).

They may result in a complex network of venous connections, usually more apparent on the medial aspect of the leg (close to the tibial bone), difficult to assess by ultrasound and potentially accountable for treatment's failures. Two types of IPA can be differentiated: horizontal and vertical, the latter being more frequent (▶ **Fig. 16–19, 21–24**).

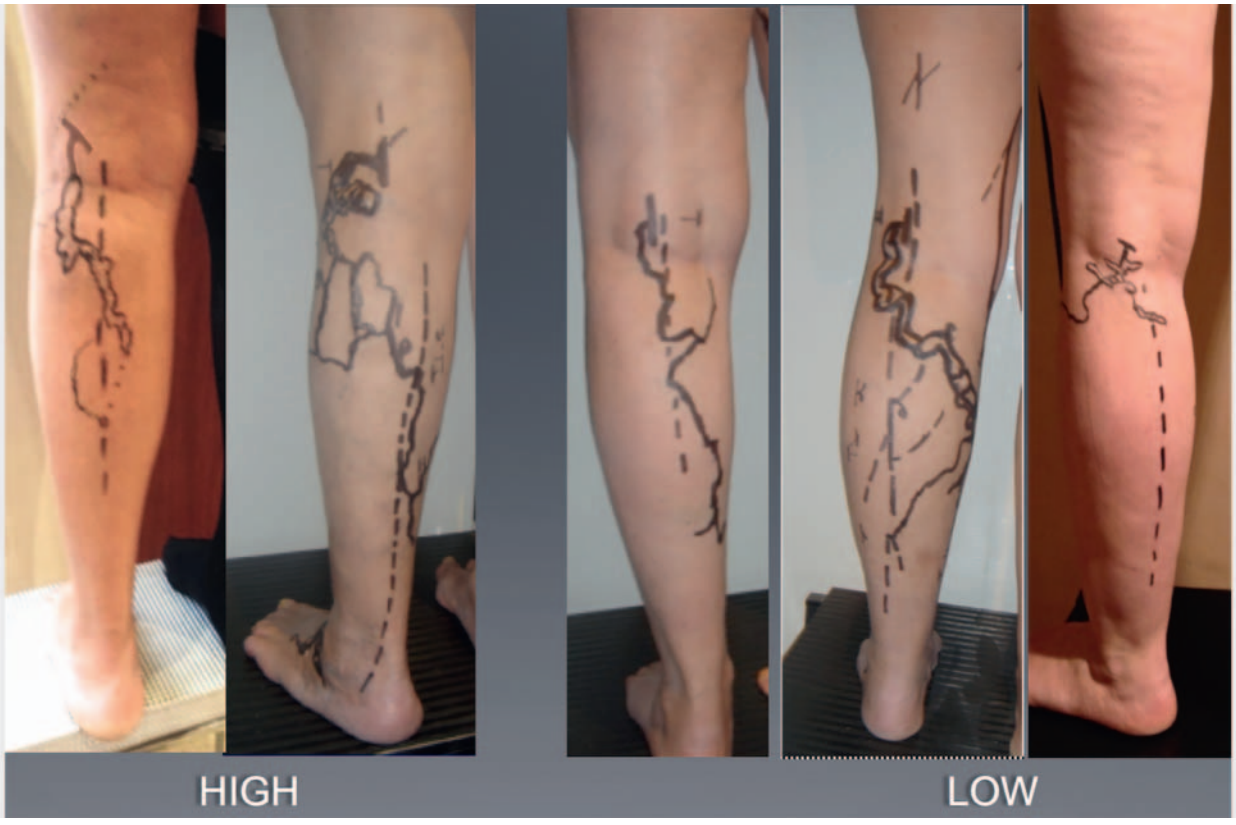
Vertical IPA usually connect paratibial perforators in the upper half of the leg, although they may extend downwards to include posterior tibial PVs as well. Since IPA arches run below the muscular fascia, they are overlooked and consequently not treated when there may be a need to.

Horizontal IPA are a less frequent finding, at the lower leg connecting posterior tibial perforators, occasionally including

▶ **Fig. 26** Skin map of politeal fossa perforator.

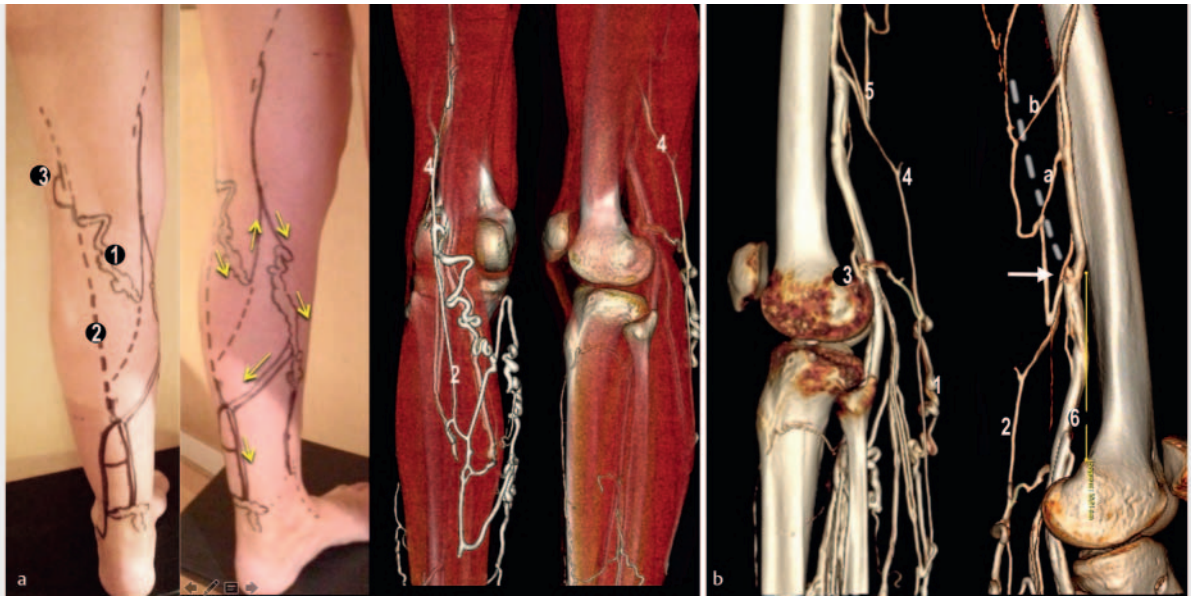


▶ **Fig. 27** Primary PFP insufficiency. 3D reconstruction from CTV through virtual rendering technique. 1 = higher femoral canal PVs, 2 = lower femoral canal PV connected to the GVS, 3 = Hunterian PV, 4 = competent GSV, 5 = popliteal vein, 6 = calf varix fed by the PFP (white arrows show popliteal origin), 7 = medial GV.

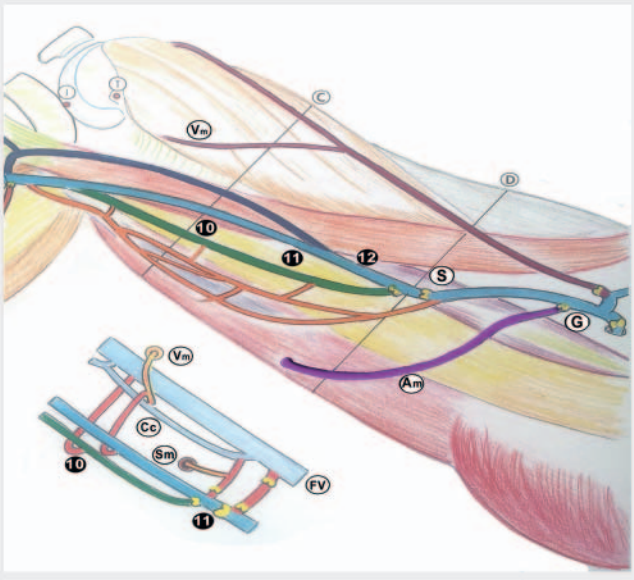


▶ **Fig. 28** Skin maps of popliteal fossa perforators. Interrupted line: SSV. Left high connection to the popliteal vein (> 3 cm above the sapheno-popliteal junction) Right low connection to popliteal vein.

▶ **Fig. 29** Primary insufficiency of PFP. Skin map and virtual dissection from CTV. 1–2 = higher femoral PVs, 3 = lower PV connected to the GVS, 4 = GSV trunk 5 = calf varix fed by the PFP (white arrows indicates the connection between PFV and popliteal vein), 6 = competent SSV.



▶ **Fig. 30** Differential diagnosis of insufficient PFP: Skin map and virtual dissection from CTV. Yellow arrows show the reflux path. This clinical case illustrates a differential diagnosis that must be considered. Rather than an insufficient PFV, this is an upper calf varix (1) fed by SPJ (3) reflux. 2 = competent SSV trunk 3 = SPJ on the lateral surface of the popliteal vein, 1 cm above the femoral condyle 4 = thigh extension of the SSV 5 = deep communicating vein draining upwards into DFV 6 = popliteal vein a–b = competent high hunterian PVs. Please note the femoral vein permanent occlusion (broken line following a thrombosis), starting at level of the adductor's hiatus (white arrow). Due to the obstruction, a SPJ ligation would probably lead to popliteal fossa recurrence.



▶ **Fig. 31** THIGH PVs (Source: Gillot C. Atlas of the superficial venous network of the lower limbs. Editions Phlébologiques Françaises; 1980). Femoral PVs (black circles): 10 = Hunterian PV, 11 = lower femoral canal PV, 12 = higher femoral canal PV. Other thigh PVs (white circles): Vm = PV of the vastus medialis muscle, S = PV of the apex of Scarpa's triangle, Am = PV of the adductor magnus muscle, G = LNVN. Scheme on the bottom left represents the deep connection of the femoral PVs: FV = femoral vein, Cc = Collateral canal of the FV, S = PV of the apex of Scarpa's triangle Sm = PV of the semimembranosus muscle.

calf perforators as well (▶ **Fig. 27**). In a way, also soleal veins could be considered as deep intramuscular connections between PVs, since they converge towards their draining points (▶ **Fig. 20**).

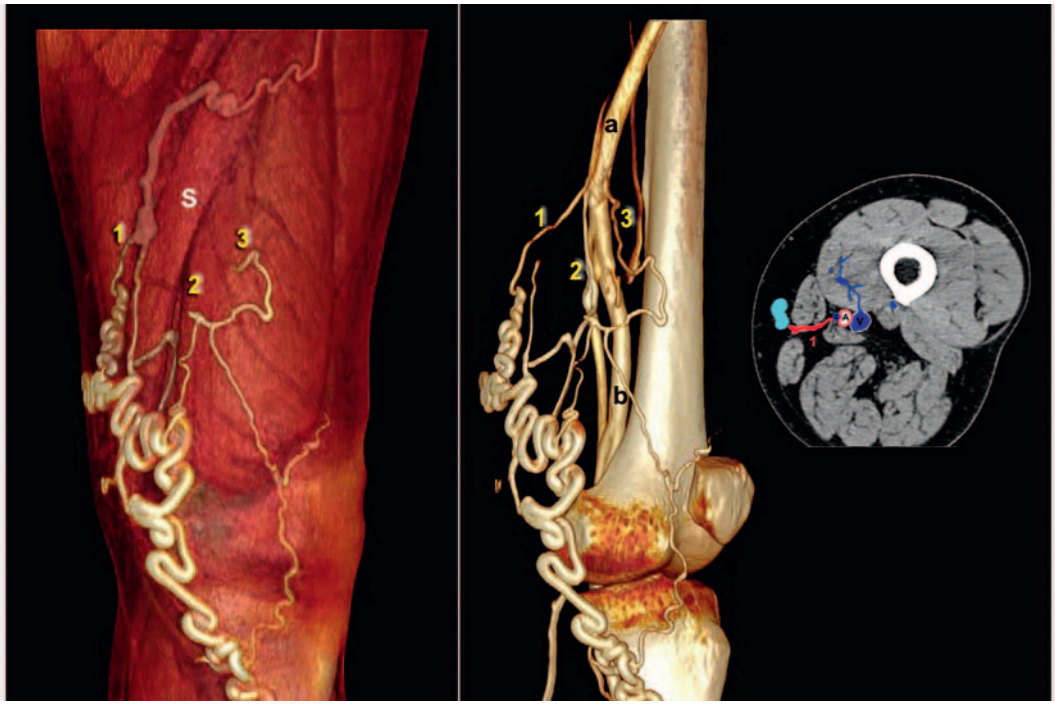
Accompanying arteries of leg PVs (▶ Fig. 25)

This interesting, previously unpublished, anatomical study by C. Gillot enable us to learn the risk of potential harm during insufficient PVs treatment. At the transfascial segment of their course, PVs run closer to their accompanying artery and nerve. Facing the risk of arterial injection, ultrasound-guidance is a must.

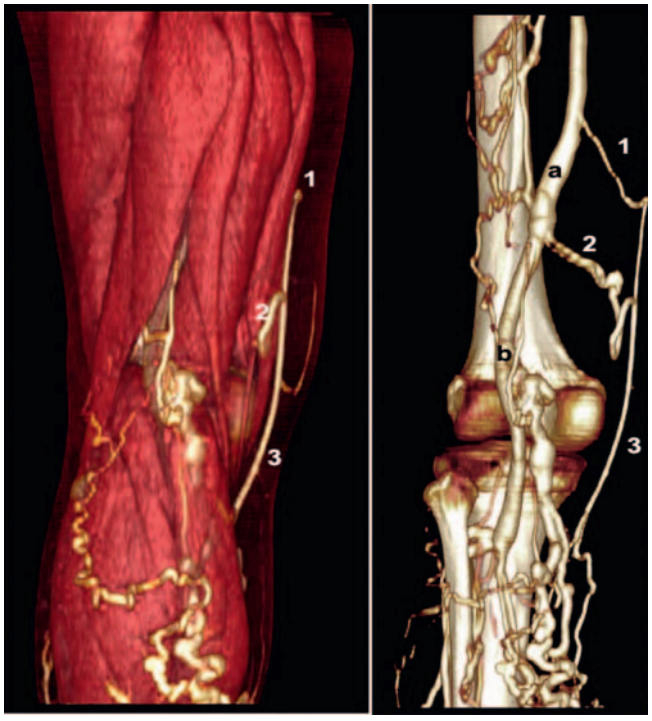
Popliteal fossa perforating vein (PFP)

With a prevalence of about 4 % in chronic venous disease patients [19], the popliteal fossa perforating vein (PFP formerly named Thierry's [18] vein) is identified as an insufficient large tortuous vessel, running along the posterior surface of the knee and upper leg, and feeding a regional varicose cluster without connections to the saphenous trunks. The odds ratio for a PFV after SPJ disconnections is 5.7 as reported by Delis [19].

The PFV usually ends in the lateral surface of the popliteal vein 2 cm above the saphenopopliteal junction (▶ **Fig. 26, 28–30**, although its draining point can be either higher or lower (1–2 cm below the popliteal crease).



▶ **Fig. 32** Thigh PVs. Virtual dissection by CTV (VRT). Left thigh, medial view and axial slice. 1 = femoral canal PV feeding the varix, 2–3 = femoral canal PVs perforating the vastus medialis muscle and connected with its muscular veins, a = femoral vein, b = popliteal vein, A = femoral artery, S = soleus muscle. The slice on the right also shows the course of the main PV (1) behind the Sartorius. Postoperative CTV: the GSV is not visible (removed by stripping).



▶ **Fig. 33** Thigh PVs. Virtual dissection by CTV (VRT). Left thigh, posterior view. Notice that both femoral canal PVs and Hunter's PV are direct PVs connected to the GSV trunk. The calf varix is fed by a non saphenous lateral network of the knee. 1 = femoral canal PV; 2 = Hunter's PV; 3 = GSV trunk: a = femoral vein; b = popliteal vein.

Mainly 3 conditions must be differentiated from the PFV [19]:

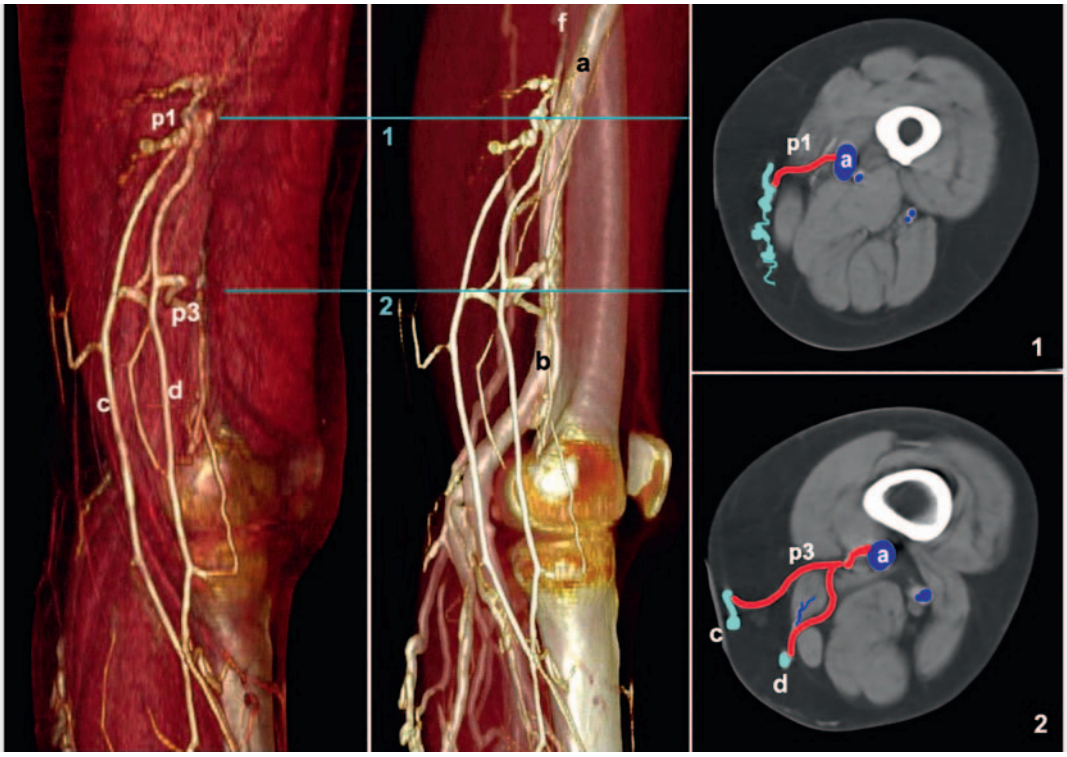
1. a dystrophic insufficient upper SSV
2. popliteal component of sciatic nerve varices (also called sciatic-peroneal varices)
3. a long SPJ stump after SPJ surgical ligation.

Thigh perforating veins

They could be classified into 5 groups[1]: (▶ **Fig. 31**)

1. Femoral PVs: the main PVs of the thigh including Hunter's PV and 2 PVs of the femoral canal (higher and lower – formerly Dodd PVs)
2. muscular PVs (Sartorius, vastus medialis, vastus lateralis, biceps, semimembranosus)
3. PV of the apex of the Scarpa's triangle
4. Lymphnode venous networks (LNVN) PVs
5. posterior thigh muscular PVs:
   - adductor magnus
   - postero-lateral (also called Hach PV)

Case reports of thigh PVs shown by 3d reconstruction from CTV (▶ **Fig. 32–34**).



▶ **Fig. 34** Thigh PVs. 3D reconstructions from CTV and axial images. Lower thigh PVs (p1, p3) and their origins from the GSV trunk (d) are shown, c = anterior accessory GSV, a = femoral vein, b = popliteal vein, f = deep femoral vein.

ABBREVIATIONS USED

AAGSV	anterior accessory of GSV
AT	anterior tibial vein
CDU	color duplex ultrasound
CFV	common femoral vein
CT	computed tomography
CTV	CT venography
CVD	Chronic venous disorder
DUS	Duplex ultrasound
DV	Deep femoral vein**
EIV	external iliac vein
FV	femoral vein
GSV	great saphenous vein
GV	gastrocnemius veins
IPA	interperforator anastomosis
LNVN	lymph node venous networks
Po	popliteal vein
PT	posterior tibial vein
PV	perforating vein
SFJ	saphenous femoral junction
SM	semimembranosus muscle
SPJ	sapheno-popliteal junction
SSV	small saphenous vein
TE*	thigh extension (of the SSV)
VRT	Volume rendering technique

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Gillot C. Atlas of the superficial venous network of the lower limbs. Editions Phlébologiques Françaises. CD-Rom version (Uhl F.J) available in French, English and Spanish 1980.

[2] Uhl JF, Gillot C. Embryology and 3D anatomy of the superficial venous system of the lower limbs. Phlebology 2007; 22 (5): 194–206

[3] Uhl JF, Lo Vuolo M, Labropoulos N. Anatomy of the lymph node venous networks of the groin and their investigation by ultrasonography. Phlebology 2016; 31 (5): 334–343

[4] Caggiati A, Bergan JJ, Gloviczki P et al. Nomenclature of the veins of the lower limbs. J Vasc Surg 2002; 36: 416–422

[5] Cavezzi A, Labropoulos N, Partsch H et al. Duplex Ultrasound Investigation of the Veins in ChronicVenous Disease of the Lower Limbs-UIP Consensus Document. Part II. Anatomy. EJVES 2006; 31: 288–299

[6] Uhl JF, Gillot C. The foot venous pump. Anatomy and physiology. Phlebolymphology 2010; 17: 151–158

[7] Uhl JF, Gillot C. Anatomy of the foot venous pump: Physiology and influence on chronic venous disease. Phlebology 2012; 27: 219–230

[8] Uhl JF, Gillot C, Chahim M. Foot static disorders: a major risk factor of CVD? Phlebology 2012; 27: 13–18

[9] Uhl JF, Lo Vuolo M, Gillot C. Anatomy of the perforator veins of the foot and ankle. Phlebolymphology 2017; 24 (2): 105–112

[10] Lo Vuolo M. Venous Ultrasound. A comprehensive approach. Lower extremities and pelvis. Atlas and Texts. Info & sales: bcweurope@gmail.com

[11] Gillot C. Superficial veins of the leg. Morphologie (French) 1999; 83 (260): 19–28. PMID: 10417989

[12] Uhl JF, Gillot C. Anatomy of the veno-muscular pumps of the lower limb. Phlebology 2015; 30 (3): 180–193

[13] Uhl JF, Verdeille S, Martin-Bouyer Y. Three-dimensional spiral CT venography for the pre-operative assessment of varicose patients. VASA 2003; 32 (2): 91–94

[14] Uhl JF, Verdeille S, Martin-Bouyer Y. Pre-operative assessment of varicose patients by veno-CT with 3D reconstruction 3rd International workshop on multislice CT 3D imaging Springer Verlag Ed pavone. Debatin. 2003: 51–53

[15] Uhl JF, Caggiati A. (2005) Three-Dimensional Evaluation of the Venous System in Varicose Limbs by Multidetector Spiral CT. In: Catalano C, Passariello R, (eds) Multidetector-Row CT Angiography. Medical Radiology (Diagnostic Imaging). Springer: Berlin, Heidelberg: doi:https://doi.org/10.1007/3-540-26984-3_15

[16] Uhl JF, Chahim M, Verdeille S et al. The 3D modeling of the venous system by MSCT venography (CTV): technique, indications and results. Phlebology 2012; 27: 270–288

[17] Van Rij A, Hill G, Gray C et al. A prospective study of the fate of venous leg perforators after varicose vein surgery. J Vasc Surg 2005; 42: 1156–1162

[18] Thiery L. Surgical anatomy of the popliteal fossa. Phlébologie 1986; 39: 30–36

[19] Delis KT, Knaggs AL, Hobbs JT et al. The nonsaphenous vein of the popliteal fossa: prevalence, patterns of reflux, hemodynamic quantification, and clinical significance. J Vasc Surg 2006; 44 (3): 611–619

[20] Ricci S, Georgiev M, Jawien A et al. Sciatic nerve varices. Eur J Vasc Endovasc Surg 2005; 29 (1): 83–87

[21] Mendoza E. Duplex-Untersuchung von Perforansvenen. Phlebologie 2014; 43: 206–209. doi:http://dx.doi.org/10.12687/phleb2211-4-2014

[22] Mendoza E, Lattimer CR, Morrison N (eds.). Duplex Ultrasound of Superficial Leg Veins. 187 2014. doi:10.1007/978-3-642-40731-4_9, © Springer-Verlag

** synomyme: deep femoral vein.

* synomymes: thigh extension, dorsal extension, cranial extension, post-axial extension of SSV.