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Vascular venous anatomy of the calcaneal fillet flap for tibial stump reconstruction: Anatomical study focused on reduction of vascular complications

Alessandro Crosio [a,b,*], Elisabetta Mijno [b], Luca Monticelli [b], Francesca Fissore [b], Francesco Giacalone [b], Maddalena Bertolini [b], Davide Ciclamini [c], Paolo Titolo [a,b], Bruno Battiston [b]

[a] SSD Orthopedic and Traumatologic Microsurgery – AOU City of Health and Science – CTO Hospital, Via Zuretti 29, 10126, Turin, Italy
[b] Orthopedics and Traumatology 2, Specialized in Hand and Upper Limb Surgery – AOU City of Health and Science – CTO Hospital, Via Zuretti 29, 10126, Turin, Italy
[c] Department of Health Sciences – UOC Orthopedics and Traumatology. University of Eastern Piedmont, Via Solaroli, 17, 28100, Novara, Italy

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ABSTRACT

Introduction: Traumatic lower-limb amputations and severe leg injuries may necessitate below-knee amputation when replantation or reconstruction is not feasible. In these situations, tibial bone and soft tissue may be insufficient to preserve the knee. The use of tissue from the amputated part, particularly the foot fillet flap, can allow knee salvage with significant functional benefit. The foot fillet flap is a composite flap that can be designed as pedicled or free, depending on injury characteristics. However, venous insufficiency remains a potential complication. This study investigated the venous drainage of the flap using cadaveric specimens.
Materials and methods: Five fresh-frozen lower limbs were prepared and injected with colored latex into both the superficial and deep venous systems. Flaps were then dissected to analyze venous drainage pathways.
Results: Injection of the superficial system demonstrated that medial and lateral dorsal skin territories were not interconnected. Both territories showed perforating connections with the anterior tibial veins. Additional connections were identified between the deep system and the peroneal veins. These findings indicate that in large foot fillet flaps, approximately 230 cm^2 in size, reliable venous drainage requires inclusion of both the medial system (great saphenous vein or tibial veins) and the small saphenous vein. Alternatively, the anterior tibial veins may provide sufficient outflow, as they appear capable of collecting venous blood from both systems.
Conclusions: For extensive foot fillet flaps, optimal venous drainage can be achieved either by combining medial and lateral systems or by utilizing the anterior tibial veins. From a practical perspective, extending the plantar and medial ankle skin—territories drained by the posterior tibial and great saphenous veins—may allow reliance on a single venous system, thereby reducing the risk of venous congestion.

1. Introduction

Traumatic lower-limb amputation, though uncommon, represents a catastrophic event with profound functional and psychological consequences. In many cases, replantation is not a viable option due to factors such as the severity and level of injury, the presence of life-threatening associated trauma, advanced patient age, comorbid conditions, prolonged ischemia time, or avulsion of proximal structures.[1–3]

In such circumstances, every effort should be directed toward preserving stump length and, when possible, maintaining critical joints. Retaining an adequate stump length has been shown to decrease energy expenditure during ambulation by up to 30 % compared with shorter below-knee amputations. Equally important is the provision of stable, durable soft-tissue coverage, which ensures proper prosthetic fitting, enhances functional performance, and improves overall patient comfort—factors that ultimately translate into better long-term outcomes and quality of life.[4,5]

Although the underlying concept may appear straightforward,

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* Corresponding author. SSD Orthopedic and Traumatologic Microsurgery – AOU City of Health and Science – CTO Hospital, Via Zuretti 29, 10126, Turin, Italy.
E-mail address: alessandro.crosio@gmail.com (A. Crosio).

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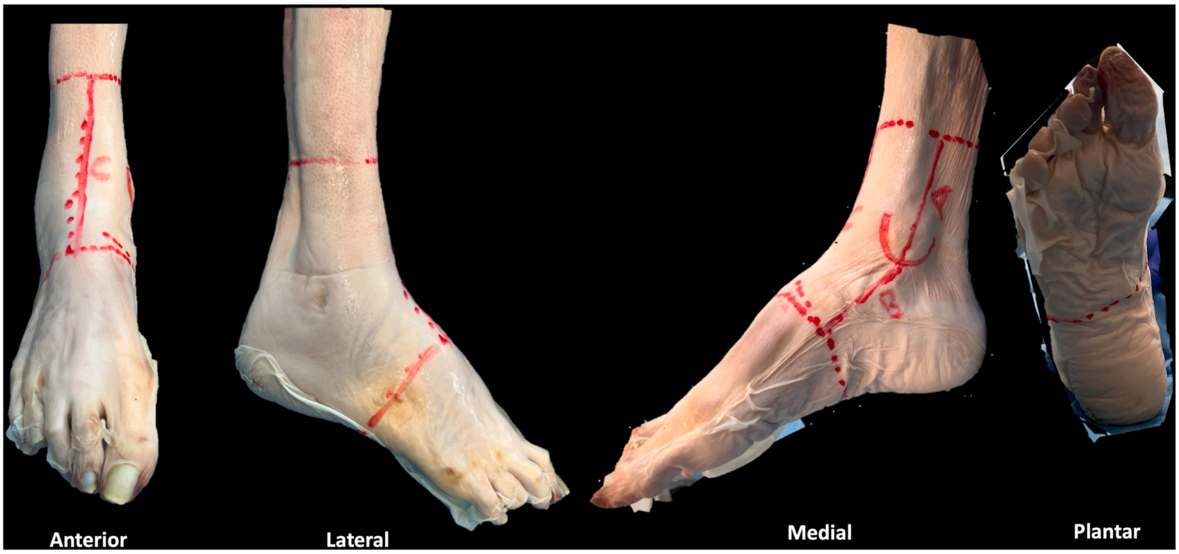

Fig. 1. Fillet flap design according to Januszkiewicz[9].

functional outcomes must be assessed from a broader perspective. Stumps fashioned approximately 6 cm below the tibial tuberosity and fitted with well-designed, well-tolerated prostheses generally provide excellent functional results. However, when traumatic amputation or complex leg fractures result in insufficient stump length or preclude conventional reconstruction, fillet flaps offer a valuable alternative. They allow preservation of function and coverage without creating additional donor-site morbidity.

In this context, the foot fillet flap can be employed. This composite flap, vascularized by the dorsalis pedis artery, the posterior tibial artery, or both, can be raised either as a pedicled or a free flap. It represents an effective reconstructive option for extensive defects, as it makes use of viable adjacent tissue while avoiding further donor-site sacrifice.

The literature reports considerable variability in flap design, vascular supply, and composition, which has led to the development of different technical approaches. For instance, Ghani[6] described a pedicled flap based on both the anterior and posterior tibial vessels that ultimately failed due to venous thrombosis from flap coiling. Tos[7] reported venous congestion in 3 of 8 patients, despite the addition of venous anastomoses, although no arterial failures were observed. By contrast, Wu[8] reported successful outcomes with flaps averaging 160 cm^2, using only great saphenous vein anastomosis, and observed no venous complications.

Despite the generally favorable results, venous congestion remains a critical risk. Both published experiences and the authors' own clinical observations confirm that such complications can be devastating, potentially leading to partial or even total flap loss.

Given the complexity of the venous anatomy of the lower limb and foot, this study sought to clarify the principal venous pathways involved in the foot fillet flap. The objective was to provide guidance for venous anastomosis planning and improve vein selection during flap insetting.

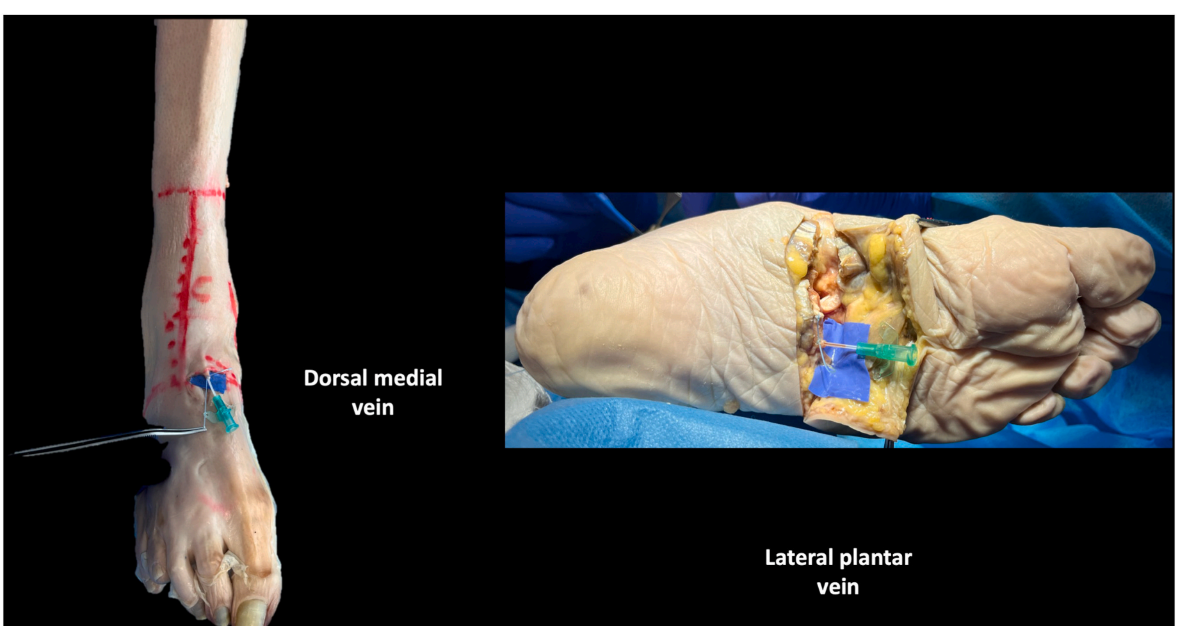

Fig. 2. Injection technique. a) Cannula inserted in the dorsal medial vein. b) Cannula inserted in the plantar lateral vein.

Table 1
Flap dimensions expressed in cm, area is in cm^2.

Specimen	Flap Lenght Medial	Flap Lenght Lateral	Flap Width Caudal	Flap Width Cranial	Area
DS	11	12	17	19,5	209,3
DV	11,5	13,5	19	17,5	228,9
D	12	13,5	17,5	19,5	235,1
D	11	12,5	17,5	19	213,9
S	12	13	18	18,5	228
					223,04

2. Materials and Methods

Five fresh-frozen lower limbs were used for this study. Harvesting of the calcaneus fillet flap was performed according to the technique previously described by Januszkiewicz,[9] as illustrated in Fig. 1.

After peripheral skin incision, the dorsal medial and lateral veins of the foot, the lateral plantar artery, the greater and small saphenous veins, and the posterior tibial artery were identified and isolated. The proximal vessels were transected.

The distal superficial and deep veins were then cannulated with a 19G cannula, and the venous system was flushed with 40 ml of physiological saline. In one specimen, the venous valves were disrupted during the flushing procedure, as saline was observed exiting from the saphenous vein. The cannulated vessels are shown in Fig. 2. Once clear effluent was obtained, the distal veins were ligated, followed by the proximal veins, and liquid latex (Reschimica, Via Borromini 50–50028 – Barberino Tavarnelle, Florence, Italy) was injected. Approximately 20 ml of latex was administered per vascular segment.

The injection protocol followed the method described by Wong.[10]

In one specimen, both dorsal veins were injected with pink latex (**superficial group, S**).

In three specimens, only the lateral plantar vein was injected with blue latex: two were classified as the **deep group (D)**, and one specimen, in which the venous valves were disrupted, was classified as **deep without valves (DV)**.

In the last specimen, both the deep lateral vein (blue) and the medial dorsal vein (pink) were injected simultaneously (**deep and superficial group, DS**).

Flap harvesting was completed approximately 5 h after injection to allow the latex to solidify.

Additionally, the surface area of the skin component of each flap was measured and recorded. The local distribution of the injected latex within the deep and superficial venous systems was analyzed and documented.

3. Results

Table 1 summarizes the flap dimensions and the distribution of injected dye.The surface area of each flap was calculated using the shoelace formula. The mean flap area was 223.04 cm^2.

3.1. Dye distribution

- **Fillet flap Superficial (S)**:

Simultaneous injection of the dorsal medial and lateral veins (pink). Complete filling of both superficial and deep venous systems was observed. It can be noted in Fig. 3 that the main superficial vessels were filled by latex, it is notable also the communicating vessels between lateral and medial superficial system and the anterior tibial veins filled by both. Instead no communications are present between lateral and deep tibial systems.

- **Fillet flaps D (2 specimens)**:

Injection of the deep plantar medial vein (blue). Valves were competent, and only the deep posterior tibial venous system was filled.

- **Fillet flap DV**:

Injection of the deep plantar lateral vein (blue). Venous valves were

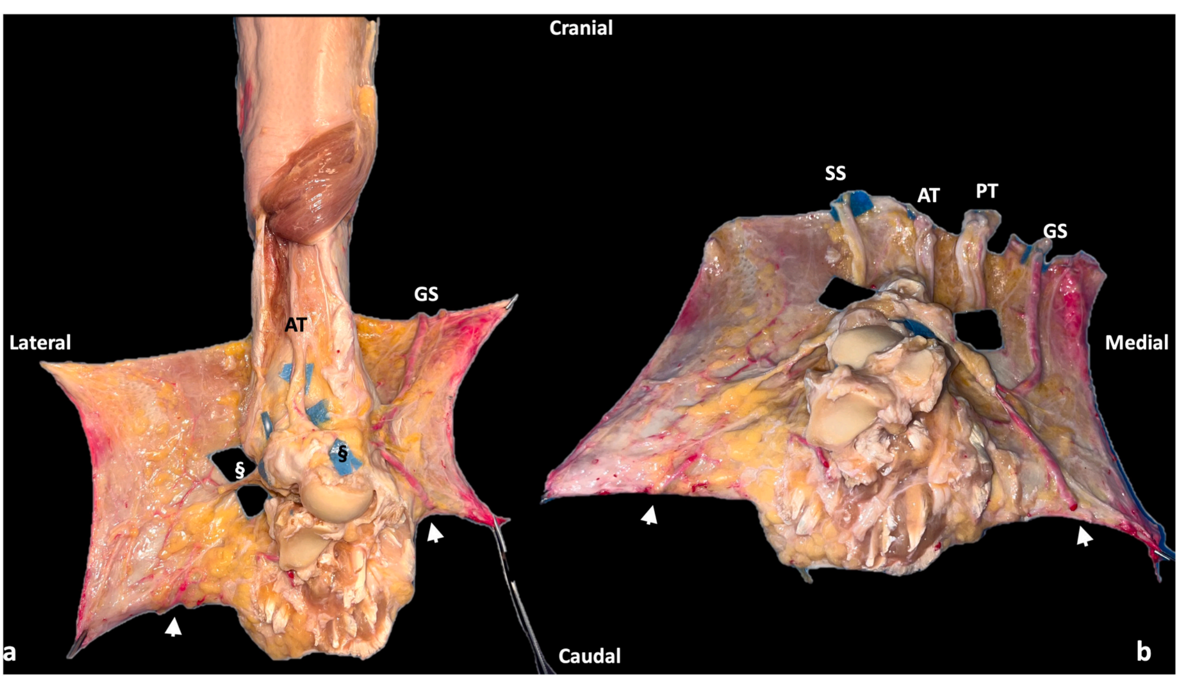

Fig. 3. Fillet flap specimen. a) Injection of both dorsal systems (arrow tips) highlights the connections between the superficial lateral system and the anterior tibial system (§). b) Completely dissected flap: venous injection of dorsal lateral and medial skin (arrow tips) demonstrates the connection with the anterior tibial system (black background). A few venules drain toward the small saphenous vein. Abbreviations: PT = posterior tibial artery; AT = anterior tibial artery; GS = great saphenous vein; SS = small saphenous vein.

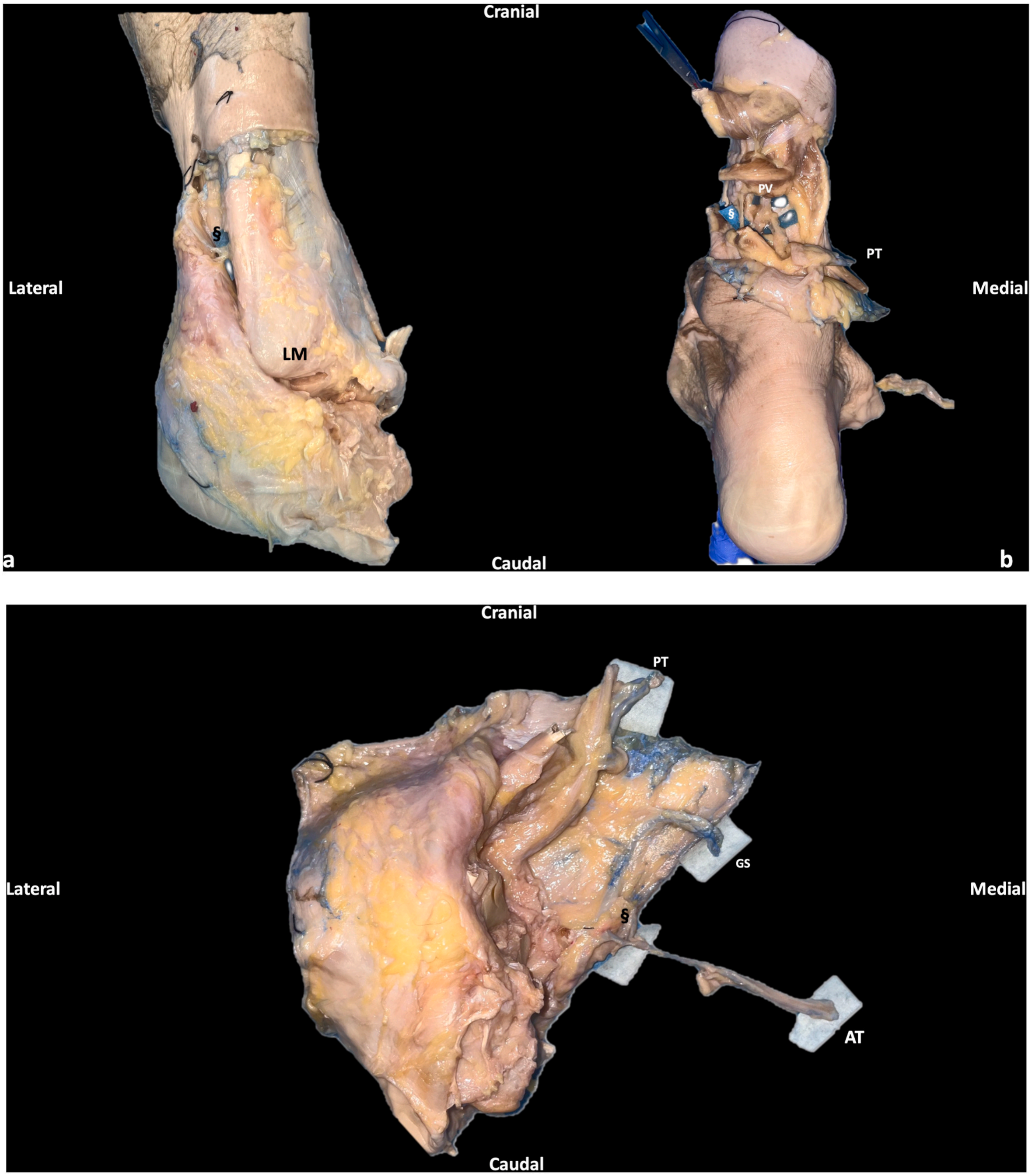

Fig. 4. a) During dissection, a perforating vein (§) to the peroneal vessels was identified posterior to the lateral malleolus (LM). b) Connections between the superficial lateral skin (§) and the posterior tibial veins merging with the peroneal veins (PV) posterior to the sectioned Achilles tendon. c) Connection between the medial superficial system and the anterior tibial system (§). Abbreviations: PT = posterior tibial artery; AT = anterior tibial artery; GS = great saphenous vein.

disrupted during flushing, resulting in filling of both the deep and superficial medial venous systems. Connections were observed between the superficial dorsal medial system and the anterior tibial circulation, as noted in specimens S. Moreover, a connection was seen between the lateral skin through a perforating vein and the peroneal veins that were subsequently connected to the posterior tibial veins behind the Achille's tendon. In Fig. 4 these connections are highlighted. Also, in this specimen It is clearly evident the blue dying of the anterior and posterior tibial vessels and a connection between great saphenous vein and anterior tibial vessels (Fig. 4c).

- **Fillet flap DS**:

Simultaneous injection of the deep plantar lateral (blue) and dorsal medial (pink) veins. Mixed deep and superficial circulation was observed, with a connection to the anterior tibial artery circulation. Fig. 5 shows the results of injection. To note the purple latex in the deep tibial veins representing the merging of the two colors. In particular it means that blue dye goes from the lateral plantar vein and reach the posterior tibial artery. No coloration of the lateral portion of the flap was detected, suggesting that the superficial lateral system is independent from the medial dorsal skin.

Unlike in the DS specimen, the superficial lateral component was injected, as latex was introduced through the dorsal lateral vein, with drainage detected toward both the anterior tibial and peroneal veins.

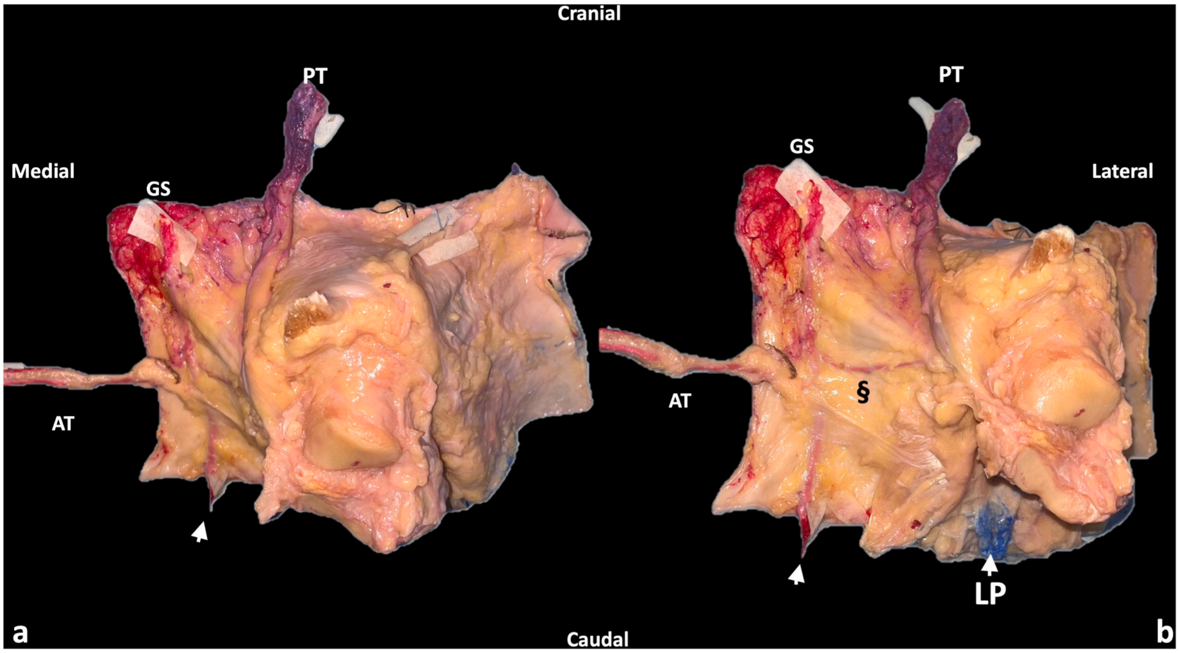

Fig. 5. a) Both systems injected, with the superficial system filled only through the dorsomedial vein. Note that the dorsolateral skin is not perfused. The posterior tibial artery (PT) appears purple due to mixing of dyes. Arrow tips indicates injection point. b) Clear connection (§) between the great saphenous vein (GS) and the anterior tibial veins (AT). The lateral plantar vein is shown in blue. Arrow tips indicates injection point.

4. Discussion

The calcaneal fillet flap has been proposed since 1996[9] as a strategy to avoid above-knee amputation. This approach is part of the "spare parts" concept, which enables preservation of bone length and knee function while providing durable, sensate soft-tissue coverage without additional donor-site morbidity.[11]

Both pedicled[6–12] and free versions of the flap[6–9] have been described. In all cases, adequate vascularization is essential for flap survival. Arterial inflow through the posterior tibial artery is usually sufficient, but venous drainage often proves inadequate. Pedicle flaps sometimes require additional venous anastomoses,[7] and free flaps are particularly prone to venous congestion and subsequent failure.

Wu[8] reported 11 successful cases without venous congestion, relying solely on anastomosis of the great saphenous vein. Similarly, Chiang and Ghali[6–13] reported favorable outcomes, particularly when both anterior and posterior tibial vessels were preserved in continuity. However, Tos[7] observed venous complications in 3 of 8 patients, ranging from minor skin loss to extensive necrosis, despite supplementary venous anastomoses.

Taken together, these case reports and small series suggest that venous complications represent the most frequent vascular problem. However, clear risk factors are difficult to identify due to the heterogeneity of flap dimensions, designs, and reported techniques. Few studies describe flap size in detail, and systematic analyses of venous drainage are lacking.

The aim of the present study was to clarify venous outflow in the calcaneal fillet flap and suggest technical strategies to minimize complications. Our findings highlight the relative independence of the medial and lateral venous systems. In line with Wu's classification,[14] dye injection confirmed that the medial skin drains primarily through the great saphenous vein and deep tibial vessels, while the lateral component drains into the small saphenous vein. Additional connections between the SSV, peroneal veins, and posterior tibial comitantes were also identified. These pathways suggest that preserving peroneal–tibial continuity may reduce the need for SSV anastomosis, although this approach is technically demanding.

The discrepancy between Wu's complication-free series and our findings may be explained by differences in flap design. Wu's technique emphasized plantar and medial ankle skin—territories drained predominantly through the great saphenous vein—thus unifying venous outflow. In contrast, when larger lateral skin components are included, the SSV territory must also be addressed.

Both superficial venous systems communicate with the anterior tibial veins, as previously described by Uhl and Gillot.[15] This pathway could serve as an alternative outflow route, although anterior tibial dissection is technically challenging. Our study confirms these anatomical connections and provides the first evidence of their relevance to the calcaneal fillet flap.

For larger flaps incorporating lateral ankle skin, additional venous anastomoses may be required. Options include suturing the SSV in addition to the GSV or posterior tibial comitantes, or utilizing the anterior tibial system for comprehensive drainage. Chiang described a flap that included both dorsal and plantar skin, maintaining medial continuity and performing dual arterial and venous anastomoses, thereby ensuring broad venous outflow. Conversely, other authors have reported connections between lateral skin and the peroneal venous system. While these pathways exist anatomically, their clinical use is limited due to the difficulty of dissection. Only Holden[16] reported suturing the peroneal vessels, and even in that case continuity of the posterior tibial vessels was preserved by coiling them within the flap.

Our findings align with those of Uhl and Gillot,[15] who demonstrated the existence of two distinct dorsal venous systems (medial and lateral) draining into the great and small saphenous veins, respectively. These systems are interconnected through perforators that also link to deep veins. The GSV consistently communicates with the deep system through two major perforators and connects to the anterior tibial veins, while the lateral system drains into the peroneal system and continues with the SSV. Further cross-connections, as later described by Uhl and Lo Vuolo,[17] were confirmed in our dissections. We also identified a previously unreported connection between the dorsal lateral system and the anterior tibial veins.

With respect to the deep system, most drainage occurs through the lateral plantar veins, which collect blood from the calcaneal region via the calcaneal perforator and subsequently drain into the deep medial system. Although we did not dissect the plantar and calcaneal skin, this arrangement may explain why venous congestion is rarely observed clinically in those areas.

It is worth noting that, despite the anatomical connections between the dorsal venous system and the anterior tibial veins, Ghali[6] reported flap failure when relying solely on the anterior tibial system. This suggests that while the anterior tibial artery primarily supplies the dorsal skin, its venae comitantes—through their extensive interconnections—can theoretically drain the entire flap.

From a clinical standpoint, reliable venous drainage of large calcaneal fillet flaps may require multiple venous anastomoses. If only one vein is used, maintaining peroneal–posterior tibial continuity via the interosseous membrane could be a solution, though it is technically complex and time-consuming. Another possible strategy is to limit the lateral skin component or design the flap with a medial incision, thereby preserving the venous plexus and directing drainage preferentially into the great saphenous system.

Study limitations include variability in injection pressure (saline vs. latex) and the unknown vascular history of the cadaveric specimens. In addition, the sample size was small—only five specimens—which is insufficient to draw definitive anatomical conclusions. Moreover, this anatomical model does not replicate physiological conditions. As previously suggested,[18] flap elevation itself may open or modify venous connections, potentially explaining why some clinical cases achieve adequate drainage despite anastomosis of only a single venous system. Indeed, Januszkiewicz[9] reported a very large flap (30 × 40 cm) successfully drained by just two venous anastomoses, without congestion.

5. Conclusions

To ensure reliable venous drainage of large calcaneal fillet flaps—particularly when the lateral component is included—either anastomosis of the small saphenous vein (the simpler option) or preservation of the peroneal–posterior tibial venous connection through the interosseous membrane (the more complex option) is required. Relying on the great saphenous vein alone is unlikely to provide sufficient outflow in such extensive flaps. An alternative strategy is to use the anterior tibial comitantes, which receive drainage from both the medial and lateral dorsal systems and also communicate with the plantar system through perforators. However, dissection of the anterior tibial vessels may be technically challenging during flap harvesting.

From a design perspective, as proposed by Wu, it may be advantageous to preserve the plantar and medial ankle skin, which can be reliably drained by the great saphenous and posterior tibial veins, without reducing the available skin surface for coverage. Moreover, when designing this flap, veins from both the superficial and deep venous systems should be included whenever possible to reduce the risk of venous complications.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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