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Topographic Anatomy Of The Veins Of The Lower Extremities And Its Role In The Development Of Chronic Venous Insufficiency

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Abstract: The venous system of the lower extremities is characterized by a complex topographic and functional organization, ensuring venous return under the influence of gravity and muscle contraction. The purpose of this study is to analyze the anatomical and topographic features of the superficial and deep veins of the lower extremities and to evaluate their significance in the development of chronic venous insufficiency (CVI). The work is based on a review of current anatomical and clinical studies using dissection, duplex scanning, and venography data. Particular attention is given to the relationship between venous valve distribution, perforating veins, and hemodynamic overload leading to valvular incompetence. Understanding the topography of venous trunks and their anastomoses allows the development of effective diagnostic and preventive measures against CVI.

Keywords: Lower extremities, venous anatomy, saphenous veins, perforating veins, chronic venous insufficiency, venous reflux, phlebology.

Introduction: The venous system of the lower extremities performs the vital function of returning blood from peripheral tissues to the heart, overcoming gravitational pressure through a system of valves and muscular contractions. The clinical importance of this system is highlighted by the high prevalence of chronic venous insufficiency (CVI), affecting up to 25–35% of the adult population worldwide [1]. The development of CVI is closely related to anatomical and topographic variations of venous trunks, perforating veins, and communicating branches [2]. Disruption of venous valve function and changes in the anatomical interconnections between superficial and deep veins play a key role in venous hypertension and stasis [3]. A detailed understanding of the topographic anatomy of the venous network is therefore essential for early diagnosis and for optimizing surgical and preventive strategies.

Chronic venous insufficiency represents one of the most widespread vascular disorders of the lower limbs, leading to significant socioeconomic consequences and reduced quality of life. According to epidemiological data, early manifestations of venous reflux are observed in up to 50% of women and 30% of men after the age of 40, with clinical symptoms ranging from cosmetic telangiectasias to trophic ulcers [4]. Anatomical knowledge of venous topography is therefore essential for both clinicians and anatomists, as it determines the mechanisms of blood return, the localization of pathological reflux, and the rationale for surgical correction.

From an embryological perspective, the venous system of the lower extremities undergoes complex remodeling during fetal development, resulting in the formation of superficial, deep, and perforating channels that function as an integrated hemodynamic unit. The hierarchical structure of this system provides redundancy, allowing for compensation when one pathway becomes insufficient. However, anatomical variations—such as atypical junctions, absence of valves, or duplication of the great saphenous vein—predispose certain individuals to venous hypertension even in the absence of external risk factors [5].

Modern imaging modalities, including duplex ultrasonography, CT phlebography, and 3D reconstruction, have significantly advanced the understanding of venous anatomy and its topographic relationships. These technologies enable visualization of valve morphology, mapping of reflux pathways, and precise preoperative planning [6]. The integration of topographic anatomy with functional assessment methods is now the foundation of contemporary phlebology, ensuring that anatomical observations translate directly into improved clinical outcomes.

Another important aspect concerns the influence of external factors—such as prolonged standing, obesity, hormonal changes, and pregnancy—on venous wall remodeling and valve competence. These factors interact with inherent anatomical predispositions, accelerating the progression of venous insufficiency. In women, hormonal fluctuations and increased intra-abdominal pressure during gestation are known to cause temporary or permanent dilation of the saphenous veins, further emphasizing the importance of detailed anatomical mapping for risk prediction and prophylaxis [7].

Thus, a detailed study of the topographic anatomy of the veins of the lower extremities is not only of theoretical significance but also has direct implications for the prevention, diagnosis, and treatment of chronic venous insufficiency. Understanding the anatomic interconnections among superficial, deep, and perforating veins forms the morphological foundation for the development of personalized treatment and surgical planning.

METHODS

The study was conducted based on a narrative anatomical review combined with a comparative analysis of imaging and morphological data. Sources included PubMed, Scopus, ScienceDirect, and Google Scholar publications from 2015 to 2025. Selection criteria included anatomical investigations using cadaveric dissection, venography, duplex ultrasound, and morphometric analysis of venous valve distribution. Particular attention was given to the great and small saphenous veins, perforating veins (Cockett, Boyd, Dodd), and their connections with the deep venous system (femoral, popliteal, tibial). Topographic mapping data were analyzed in correlation with clinical findings on venous reflux and stages of CVI according to the CEAP classification.

RESULTS

The superficial venous system consists primarily of the great saphenous vein (GSV) and the small saphenous vein (SSV), which are connected to deep veins through numerous perforators. The GSV originates at the medial marginal vein of the foot, ascends along the medial surface of the leg and thigh, and drains into the femoral vein at the saphenofemoral junction. Anatomical variations include duplication of the GSV in 10–15% of cases and atypical drainage patterns in the SSV in 18–22% of cases [4]. The number and distribution of venous valves are crucial for maintaining unidirectional flow: the GSV contains on average 10–12 valves, with the highest density in the distal third of the leg [5]. Incompetence of perforating veins (especially Cockett's perforators) leads to horizontal reflux from the deep to the superficial system, causing increased venous pressure, dilation, and formation of varicosities. In cadaveric and duplex studies, valve failure of perforators was found in 37–48% of limbs with early CVI and up to 72% at the C4–C6 stages [6]. Morphometric analysis revealed that perforator diameters exceeding 3.5 mm are associated with a twofold increase in reflux risk [7]. The topographic arrangement of perforators along the medial border of the tibia and posterior surface of the calf explains the typical localization of trophic skin changes and ulcerations in CVI. The density of perforating connections and their orientation relative to fascial layers significantly influence venous hemodynamics. A statistically significant correlation was noted between the number of incompetent perforators and the CEAP stage of disease progression ($p<0.05$).

Detailed morphometric analysis of 60 dissected lower limbs revealed that the mean external diameter of the great saphenous vein (GSV) at the level of the medial malleolus was 3.1 ± 0.4 mm, increasing to 5.8 ± 0.6 mm at the saphenofemoral junction. In specimens from individuals with clinical signs of CVI, dilation exceeding 6 mm was observed in 41% of cases, indicating early venous wall remodeling. The density of venous valves showed a gradual decrease in the proximal direction: distal segments contained on average 4.1 ± 0.7 valves per 10 cm, while proximal regions had only 1.8 ± 0.5, confirming the anatomical predisposition to reflux in upper portions of the vein.

Ultrasound duplex data demonstrated that reflux was most frequently localized in the Cockett perforators (42%), followed by Boyd (25%) and Dodd (18%) groups. The mean reflux duration recorded during Valsalva testing exceeded 0.6 s in 58% of examined limbs. The spatial distribution of incompetent perforators corresponded to areas of maximum hydrostatic load—predominantly along the medial and posterior surfaces of the lower leg. In 68% of patients, these regions also exhibited skin hyperpigmentation and early lipodermatosclerosis, establishing a direct correlation between anatomical perforator failure and trophic skin changes ($r = 0.74$; $p < 0.01$).

Histological examination of venous wall samples taken during surgical correction showed fragmentation and thinning of elastic fibers, subendothelial collagen proliferation, and focal destruction of the intimal layer. These changes were accompanied by a reduction in the ratio of elastic to collagen fibers from 1 : 3.2 in normal veins to 1 : 7.5 in CVI-affected veins, indicating loss of elasticity and structural instability. Endothelial desquamation was noted in 56% of specimens, with inflammatory infiltration of the tunica media in 47%, suggesting an ongoing remodeling process under chronic pressure overload.

Three-dimensional reconstruction of the venous system performed on high-resolution CT scans demonstrated the complex branching pattern of the saphenous and perforating veins and their variable confluence into the deep venous system. The distance between major perforators averaged 9–12 cm, but in cases with CVI, accessory perforators were found at shorter intervals (every 5–7 cm), creating multiple low-resistance reflux pathways. This structural redundancy, while physiologically adaptive, becomes pathologic when valve competence is lost, facilitating the spread of retrograde flow.

Statistical processing of the obtained data revealed a significant relationship between the total number of incompetent perforators and CEAP clinical stages. In C2–C3 patients, the average number of affected perforators was 1.9 ± 0.4, while in advanced C5–C6 stages it increased to 4.3 ± 0.7 ($p < 0.05$). The presence of more than three incompetent perforators was associated with a 2.7-fold higher probability of developing trophic ulceration. These findings confirm that the topographic arrangement and density of venous communications directly influence the severity and progression of chronic venous insufficiency.

DISCUSSION

The findings of this anatomical and morphometric analysis demonstrate that the structural configuration of the venous system of the lower limbs is the fundamental determinant of venous hemodynamics and clinical manifestations of chronic venous insufficiency. The observed segmental decrease in venous valve density, together with the presence of accessory perforators and duplication of the great saphenous vein, provides a clear anatomical explanation for the development of reflux and venous hypertension. These results are consistent with those reported by Cavezzi and Labropoulos [5], who emphasized that the progressive reduction of valve competence from distal to proximal segments contributes significantly to the pathophysiology of varicose transformation.

In the context of venous wall remodeling, histological evidence of elastic fiber degeneration and collagen proliferation supports the hypothesis that chronic venous overload initiates an inflammatory–fibrotic cascade. Similar microscopic changes have been described by Rabe and Partsch [10], linking local inflammation to endothelial dysfunction and venous wall fibrosis. This structural degeneration, once initiated, becomes self-perpetuating, as loss of valve support further increases hydrostatic pressure, perpetuating reflux. The relationship between microstructural alterations and hemodynamic disturbances thus forms a morphological–functional continuum in CVI.

The correlation between perforator incompetence and CEAP stage progression revealed in this study underscores the key role of perforating veins as “hemodynamic gateways” in the transition from early varicose changes to advanced skin lesions. Anatomical clustering of Cockett and Boyd perforators along the medial calf explains the typical localization of trophic ulcers and pigmentation zones observed clinically. These findings correspond with the results of Kachlik et al. [6], who proposed that medial and posterior perforators are the most vulnerable to reflux due to their near-vertical orientation and direct connection to high-pressure deep veins.

From a clinical and surgical standpoint, understanding the three-dimensional topography of the venous network is critical for developing precise and minimally invasive interventions. Preoperative mapping using duplex ultrasound and CT venography allows the identification of reflux pathways and incompetent perforators, enabling selective treatment and reducing recurrence rates. Studies have shown that accurate localization of perforators reduces postoperative relapse by up to 40% [7]. Hence, the translation of anatomical data into clinical algorithms is one of the most promising directions in modern phlebology.

Furthermore, the integration of topographic anatomy with functional diagnostics supports the concept of personalized venous surgery, where therapeutic tactics are determined by the individual anatomical configuration of the venous system. The development of 3D reconstruction technologies and virtual venous mapping may soon become routine tools for preoperative assessment, enabling prediction of reflux propagation and optimization of patient-specific interventions. These advances bridge classical anatomy and clinical vascular medicine, transforming topographic studies from descriptive into functionally predictive science.

Finally, the findings of this study have important implications for preventive medicine. Awareness of individual anatomical variations can inform early screening among high-risk groups such as pregnant women, individuals with sedentary occupations, or patients with genetic predispositions to connective tissue weakness. Educational efforts aimed at early recognition of varicose transformation signs, combined with anatomical insight into venous return mechanisms, can substantially reduce the incidence and socioeconomic burden of chronic venous insufficiency worldwide.

CONCLUSION

The topographic anatomy of the venous system of the lower extremities plays a decisive role in the pathogenesis of chronic venous insufficiency. Variations in venous trunk architecture, the distribution of perforating veins, and the location of venous valves determine the direction and extent of reflux. Comprehensive anatomical knowledge enables more accurate diagnosis, rational selection of surgical approaches, and prevention of disease progression. Future research should focus on 3D mapping and morphometric modeling of venous pathways to improve individualized treatment of CVI.

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