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CHRONIC VENOUS INSUFFICIENCY: DEFINITION, PATHOPHYSIOLOGY, DIAGNOSIS, MANAGEMENT, AND PREVENTION

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ABSTRACT

Introduction: Chronic venous insufficiency (CVI) is a prevalent, progressive condition affecting the lower-limb venous system. It results from venous valve dysfunction, sustained venous hypertension, and chronic inflammation. Despite advances in diagnostic technologies and therapeutic strategies, CVI remains a significant cause of morbidity and decreased quality of life worldwide.
Aim: This narrative review aims to provide a comprehensive overview of CVI, highlighting its definition, pathophysiology, clinical presentation, diagnosis, management, and prevention. The review emphasizes evidence-based guidelines and the latest diagnostic and therapeutic technologies, offering an updated perspective on the condition.
Methodology: A total of 28 publications were reviewed, consisting of clinical guidelines, systematic reviews, and recent original studies related to CVI. The sources were obtained through PubMed, Scopus, and Cochrane databases, focusing on articles published between 2010 and 2025.
Results: CVI typically develops due to venous reflux and microcirculatory dysfunction, leading to symptoms such as edema, skin changes, and ulceration. Duplex ultrasonography is currently the diagnostic gold standard for assessing venous reflux. Advanced imaging techniques, including MR venography, CT venography, infrared thermography, and near-infrared imaging, can improve diagnostic accuracy. Management of CVI involves a multimodal approach, combining compression therapy, pharmacologic treatment, and minimally invasive endovenous techniques. Preventive measures, including weight control, regular physical activity, and consistent use of compression, are crucial to slowing disease progression and reducing the risk of recurrence.
Conclusions: CVI remains a significant health and socioeconomic burden globally. Early diagnosis, patient education, and adherence to both conservative and interventional treatments are essential for achieving optimal outcomes. Future directions in CVI management include personalized medicine, digital health integration, and biomarker-driven approaches for earlier detection and targeted therapy.

KEYWORDS

Chronic Venous Insufficiency, Venous Reflux, Duplex Ultrasonography, Compression Therapy, Endovenous Ablation, Prevention

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1. Introduction

Chronic venous insufficiency (CVI) is a progressive condition characterized by impaired venous return in the lower extremities, leading to sustained venous hypertension and microcirculatory dysfunction. It represents an advanced stage of chronic venous disease (CVD), encompassing edema, skin changes, and venous leg ulcers (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022). The disorder results primarily from valvular incompetence or venous obstruction, which cause reflux, tissue hypoxia, and inflammation (Raffetto & Mannello, 2014). CVI is associated with chronic pain, swelling, and skin damage, often leading to reduced mobility, impaired quality of life, and significant socioeconomic burden (Patel & Surowiec, 2024).

Epidemiological studies indicate that venous disorders are among the most prevalent vascular conditions worldwide. The reported prevalence of CVI varies widely from less than 1% up to 40% in women and from less than 1% to 17% in men- depending on diagnostic criteria and population characteristics (Beebe-Dimmer et al., 2005). Large population studies, such as the Edinburgh Vein Study conducted by Evans et al., have shown that the frequency and severity of venous disorders increase with age, obesity, and a sedentary lifestyle (Evans et al., 1999). Although CVI is rarely life-threatening, it constitutes a major public health issue due to its chronic course, treatment costs, and frequent recurrence of symptoms and complications (Lee et al., 2015).

CVI is also a leading cause of venous leg ulcers, which account for up to 70–80% of chronic lower-limb ulcers (O'Donnell et al., 2014). These ulcers often require prolonged treatment, are prone to recurrence, and

impose a significant physical and psychological burden on patients. The multifactorial pathogenesis and progressive nature of CVI highlight the importance of prevention, early diagnosis, and comprehensive management strategies. Despite advances in our understanding of venous pathophysiology and treatment, the global burden of the disease remains substantial, and clinical approaches vary across healthcare systems (Salim et al., 2021).

Beyond its clinical manifestations, chronic venous insufficiency imposes a substantial socioeconomic and psychological burden. Patients frequently experience limitations in mobility, discomfort, sleep disturbances, and reduced productivity, which collectively impair overall well-being (Lee et al., 2015). The chronic and recurrent nature of venous ulcers leads to prolonged healthcare utilization and high treatment costs, accounting for up to 2% of national healthcare expenditures in some countries (Salim et al., 2021). Integrating quality-of-life assessment and psychosocial support into clinical management is therefore crucial to optimize long-term outcomes.

This review aims to provide an updated synthesis of current knowledge on chronic venous insufficiency, focusing on its definition and etiopathogenesis, clinical presentation and natural course, diagnostic methods, and evidence-based strategies for management and prevention.

2. Methodology

This paper is a narrative review aimed at summarizing the current knowledge on chronic venous insufficiency (CVI). The goal was to gather information about the definition, causes, symptoms, diagnosis, treatment, and prevention of CVI, with a focus on evidence-based guidelines and recent advances in the field.

To collect relevant studies, a search was done in three main databases: PubMed, Scopus, and Cochrane Library. The search was limited to articles published between 2010 and 2025 to include the latest research. Keywords like “chronic venous insufficiency,” “venous disease,” “diagnosis,” “treatment,” and “pathophysiology” were used to find articles that focus on CVI.

Only studies that were directly related to the topic and had good scientific quality were included. Both clinical trials and observational studies were considered. These studies were reviewed to find relevant information on how CVI is diagnosed and treated.

Instead of conducting a meta-analysis, the review focused on summarizing the key findings from selected studies, including clinical guidelines, systematic reviews, and original research. Innovations in diagnostic and treatment technologies were also discussed to highlight how management of CVI has evolved.

3. Results

Definition and Etiopathogenesis

Chronic venous insufficiency (CVI) is defined as a long-lasting impairment of venous return caused by structural or functional abnormalities of the venous system of the lower limbs, resulting in venous hypertension, venous reflux, and microcirculatory disturbances (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022). According to the Clinical–Etiological–Anatomical–Pathophysiological (CEAP) classification, CVI corresponds to the more advanced stages of chronic venous disease, typically classes C3 to C6, which include edema, skin changes such as lipodermatosclerosis or hyperpigmentation, and venous leg ulcers (Lurie et al., 2020). The CEAP system, initially introduced in 1994 and most recently revised in 2020, provides a standardized framework for describing the clinical severity, etiology, anatomical location, and pathophysiological mechanisms of venous disorders. This classification has become the international reference for research and clinical communication in phlebology and vascular medicine.

The etiopathogenesis of CVI is complex and multifactorial. The fundamental abnormality involves sustained venous hypertension due to reflux through incompetent venous valves, obstruction of deep veins, or a combination of both mechanisms (Raffetto & Mannello, 2014). In a healthy venous system, unidirectional blood flow toward the heart is maintained by the coordinated action of muscle contractions, venous valves, and the integrity of the vein wall. When valvular dysfunction or venous obstruction occurs, blood stagnates and retrograde flow develops, leading to increased hydrostatic pressure in the lower limbs. Over time, this pressure damages the endothelium, increases capillary permeability, and triggers inflammatory cascades that perpetuate tissue injury (Raffetto & Mannello, 2014; Mansilha & Sousa, 2018).

Inflammation plays a central role in the development and progression of CVI. Experimental and histopathological studies have demonstrated infiltration of leukocytes and macrophages into the venous wall and surrounding tissues, accompanied by activation of adhesion molecules, cytokines, and matrix metalloproteinases (MMPs) (Raffetto & Mannello, 2014; Santler & Goerge, 2017). These inflammatory

mediators degrade extracellular matrix components, contribute to venous remodeling, and impair lymphatic drainage. Persistent inflammation and venous hypertension ultimately result in microcirculatory dysfunction, tissue hypoxia, and skin changes characteristic of advanced disease, including fibrosis and ulceration.

Several risk factors contribute to the initiation and progression of CVI. Non-modifiable factors include genetic predisposition, female sex, and increasing age, whereas modifiable risk factors encompass obesity, pregnancy, prolonged standing or sitting, and a sedentary lifestyle (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022). Hormonal influences and occupational exposure to orthostatic stress have also been associated with a higher incidence of venous valve incompetence. The interplay of these factors determines not only the onset but also the clinical severity of the disease.

In summary, CVI is a chronic and progressive condition arising from an interplay of hemodynamic, inflammatory, and structural mechanisms. The CEAP classification allows standardized assessment of disease stage, while advances in understanding of venous wall biology and inflammatory pathways have provided new insights into its pathogenesis. This multifactorial nature underscores the importance of early identification of risk factors and targeted preventive strategies aimed at reducing venous hypertension and minimizing long-term complications.

Clinical Presentation and Natural Course

Chronic venous insufficiency (CVI) presents with a wide spectrum of clinical manifestations, ranging from mild cosmetic concerns to severe tissue damage. The earliest symptoms include sensations of leg heaviness, pain, aching, and swelling, which typically worsen after prolonged standing and improve with leg elevation or walking (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022). As the disease progresses, visible signs such as telangiectasias, reticular veins, and varicose veins develop. Persistent venous hypertension leads to microcirculatory dysfunction, resulting in edema, hyperpigmentation, eczema, and lipodermatosclerosis - key features of advanced CVI (Rabe & Pannier, 2012).

The clinical manifestations of CVI are graded using the CEAP classification system, which categorizes disease severity from C0 to C6. Early stages (C1–C2) include telangiectasias and varicose veins, while C3 indicates edema without skin changes. Advanced stages (C4–C6) are characterized by trophic skin alterations and venous leg ulcers (Lurie et al., 2020). The presence of skin changes such as atrophie blanche and lipodermatosclerosis signifies chronic inflammation and tissue fibrosis, often associated with long-standing venous hypertension and impaired oxygen diffusion (Raffetto & Mannello, 2014). Venous leg ulcers (C6) represent the terminal phase of the disease and are associated with high recurrence rates, chronic pain, and significant reductions in quality of life (O'Donnell et al., 2014).

The natural history of CVI is progressive in most patients, though the rate of progression varies widely. Long-term epidemiological studies conducted by Evans et al. have shown that approximately 20% of individuals with varicose veins develop signs of CVI over a 13-year observation period (Evans et al., 1999). The transition from early venous insufficiency to skin complications is driven by persistent venous reflux, inflammation, and endothelial dysfunction. Risk factors such as obesity, advanced age, pregnancy, and occupations requiring prolonged standing accelerate disease progression (De Maeseneer et al., 2022; Beebe-Dimmer et al., 2005; Lee et al., 2015).

Venous leg ulcers occur in approximately 1–2% of the general population, increasing in prevalence with age (O'Donnell et al., 2014; Salim et al., 2021). Healing is often slow, with recurrence rates reaching 40% within 12 months of closure, despite adequate treatment (O'Donnell et al., 2014). This chronic and relapsing course reflects ongoing venous hypertension and inflammation at the microvascular level. Moreover, recurrent ulceration is associated with considerable psychological distress and socioeconomic burden, contributing to decreased mobility, loss of work productivity, and social isolation (Lee et al., 2015; O'Donnell et al., 2014).

Without appropriate management, CVI can lead to irreversible tissue damage, recurrent infections, and, in extreme cases, limb disability. However, early detection and intervention can prevent disease progression. Regular clinical assessment, duplex ultrasonography, and compression therapy play a crucial role in mitigating long-term complications. The integration of multidisciplinary care, combining medical, surgical, and rehabilitative approaches has been shown to improve both clinical outcomes and patient quality of life (Wittens et al., 2015).

Diagnosis of Chronic Venous Insufficiency: Principles and Emerging Technologies

Accurate diagnosis of chronic venous insufficiency (CVI) is essential for effective treatment planning and prevention of disease progression. The diagnostic process aims to confirm the presence of venous reflux or obstruction, determine the anatomical distribution, and assess hemodynamic significance. A combination of clinical evaluation, functional testing, and imaging studies provides a comprehensive understanding of venous pathology (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022).

Clinical assessment and classification

Diagnosis begins with a detailed patient history and physical examination. Symptoms such as heaviness, swelling, pain, itching, and skin discoloration are evaluated alongside potential risk factors including obesity, pregnancy, or prolonged standing (De Maeseneer et al., 2022; Rabe & Pannier, 2012). Clinical findings are classified using the CEAP system (Clinical–Etiological–Anatomical–Pathophysiological), which standardizes disease staging and supports treatment planning (Lurie et al., 2020). The clinical component (C0–C6) captures visible signs, ranging from telangiectasias to active venous ulcers.

Functional testing

Hemodynamic evaluation remains fundamental in diagnosing CVI. Air plethysmography (APG) and photoplethysmography (PPG) are non-invasive tools used to quantify venous filling time, ejection fraction of the calf muscle pump, and residual volume fraction (Khilnani & Min, 2005). These measurements provide functional insight into venous return dynamics and complement anatomical imaging. Venous pressure measurements, though less common today, remain valuable for assessing deep venous obstruction in complex cases (Montoya et al., 2024).

Duplex ultrasound: the gold standard

Duplex ultrasound (DUS) is the cornerstone of CVI diagnosis. It combines B-mode anatomical imaging with Doppler flow analysis, allowing for real-time visualization of venous reflux and obstruction (Khilnani & Min, 2005). The test identifies valve incompetence when reflux duration exceeds 0.5 seconds in superficial veins or 1.0 second in deep veins. DUS is widely available, cost-effective, and provides critical data for both initial diagnosis and postoperative follow-up. Advanced Doppler techniques, including color and spectral flow mapping, improve accuracy in detecting segmental reflux and assessing perforator vein function.

Advanced imaging modalities

In patients with inconclusive ultrasound results or suspected pelvic or iliac vein involvement, magnetic resonance venography (MRV) and computed tomography venography (CTV) serve as valuable adjuncts. MRV provides detailed visualization of the venous anatomy without ionizing radiation and can assess hemodynamic flow patterns (Montoya et al., 2024). CTV, though involving radiation, offers high spatial resolution and is particularly useful for evaluating compressive syndromes, such as May–Thurner syndrome (Weiss, 2024).

Recent technological advances have introduced non-contact and functional imaging modalities into CVI diagnostics. Optical coherence tomography (OCT) with AI-based segmentation (e.g., Opto-UNet) enables detailed visualization of superficial varicose veins and may assist in pre- and postoperative vein mapping in research settings (Viqar et al., 2023). Similarly, infrared thermography detects skin temperature asymmetries correlated with superficial venous reflux. These techniques provide quick, non-invasive assessments, though their use is currently limited to research and specialized centers.

Emerging technologies and digital integration

Artificial intelligence (AI) and machine learning algorithms are increasingly integrated into vascular imaging. Automated segmentation and analysis tools assist in identifying reflux patterns and quantifying vein diameters. Elastography, an ultrasound-based technique assessing vein wall stiffness, is also being explored for early detection of venous remodeling and inflammation (Wilkinson et al., 2025; Lv et al., 2025). Integration of digital technologies with portable ultrasound devices may facilitate point-of-care diagnostics, improving accessibility in primary and outpatient settings.

Summary

The diagnostic approach to CVI combines clinical evaluation, functional assessment, and imaging studies to define disease severity and guide management. Duplex ultrasound remains the gold standard, while MRV, CTV, and emerging optical and AI-based techniques represent valuable complements in selected cases. Ongoing advancements in imaging and digital analysis promise earlier detection, individualized treatment planning, and improved outcomes for patients with chronic venous insufficiency.

Management and Prevention of Chronic Venous Insufficiency

The management of chronic venous insufficiency (CVI) requires a comprehensive, patient-centered approach aimed at reducing venous hypertension, alleviating symptoms, preventing complications, and improving quality of life. Current strategies encompass conservative, pharmacological, and interventional methods, supported by preventive measures to address risk factors and halt disease progression (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022; Rabe et al., 2018).

Conservative management

Conservative therapy remains the cornerstone of CVI treatment. Compression therapy is the most effective noninvasive measure to counteract venous hypertension by reducing venous diameter, improving valve coaptation, and enhancing venous return (Rabe et al., 2018). Elastic compression stockings (20–40 mmHg) are recommended as first-line therapy for all stages of CVI, including ulcer healing and prevention of recurrence (O'Donnell et al., 2014). Intermittent pneumatic compression (IPC) and multilayer bandaging may be used in patients intolerant to stockings or with extensive ulcers (Wittens et al., 2015).

Lifestyle modifications play an essential adjunctive role. Regular walking, calf muscle exercises, leg elevation, and weight reduction improve calf pump function and microcirculation (Nicolaides et al., 2018). Avoiding prolonged standing or sitting and maintaining optimal body weight are fundamental preventive strategies. Patient education and adherence monitoring are critical, as compliance with compression therapy remains a key determinant of treatment success.

Pharmacological treatment

Pharmacotherapy aims to modulate venous tone, reduce inflammation, and improve microcirculatory flow. Venoactive drugs, such as micronized purified flavonoid fraction (MPFF), diosmin, hesperidin, horse chestnut seed extract, and calcium dobesilate have demonstrated efficacy in reducing edema, pain, and heaviness (Mansilha & Sousa, 2018; Wittens et al., 2015). MPFF is supported by multiple randomized controlled trials showing symptomatic improvement and enhanced ulcer healing (Mansilha & Sousa, 2018). These agents act by reducing capillary permeability, improving lymphatic drainage, and decreasing leukocyte adhesion.

Systemic therapies, including pentoxifylline and sulodexide, may be used as adjuncts to compression in patients with venous ulcers (O'Donnell et al., 2014). Anticoagulation is indicated only in cases of concomitant deep vein thrombosis or post-thrombotic syndrome. Although pharmacotherapy alone rarely reverses CVI, it serves as a valuable component of multimodal management.

Interventional and surgical treatment

When conservative measures fail or anatomical correction is necessary, endovenous and surgical interventions are indicated. Endovenous thermal ablation (EVTA) - including endovenous laser ablation (EVLA) and radiofrequency ablation (RFA) - has become the preferred treatment for saphenous vein reflux due to its high efficacy, minimal invasiveness, and short recovery time (Gloviczki et al., 2011). These procedures achieve occlusion rates >90% with fewer complications than traditional stripping.

Foam sclerotherapy, another minimally invasive method, involves the injection of a sclerosant (e.g., polidocanol) under ultrasound guidance, causing endothelial damage and vein fibrosis. It is particularly useful for smaller varicosities or residual reflux after ablation (Gloviczki et al., 2011). In advanced cases, surgical options such as high ligation and stripping, phlebectomy, or perforator vein interruption (SEPS) may be required, especially when deep reflux coexists (De Maeseneer et al., 2022; Bozkurt et al., 2020).

Venous ulcer management requires a multidisciplinary approach combining compression, wound care, pharmacotherapy, and often surgical or endovenous correction of reflux. The goal is not only ulcer closure but also prevention of recurrence through sustained hemodynamic control and patient education (O'Donnell et al., 2014; Mansilha & Sousa, 2018).

Prevention and long-term management

Prevention of CVI progression and recurrence focuses on early detection, lifestyle interventions, and patient compliance. Screening high-risk populations - especially women, older adults, and those with occupational risk - allows for early diagnosis and timely compression use (Nicolaides et al., 2018). Regular follow-up with duplex ultrasound is recommended to monitor reflux recurrence or new venous pathology (De Maeseneer et al., 2022; Khilnani & Min, 2005).

Modern approaches emphasize digital adherence tools (e.g., smart compression garments with pressure sensors) and telemonitoring systems, which improve compliance and long-term outcomes (Bai et al., 2024; Rezende et al., 2022). Occupational adjustments, such as alternating standing and sitting or using calf activation devices help reduce venous hypertension in the workplace.

Summary

CVI management integrates lifestyle modification, compression, pharmacotherapy, and minimally invasive or surgical interventions. Preventive measures focusing on weight control, physical activity, and adherence to compression therapy are crucial for long-term success. Continuous advances in endovenous techniques, pharmacologic therapies, and digital adherence tools offer promising prospects for personalized, evidence-based management of chronic venous insufficiency.

Discussion and Conclusions

Chronic venous insufficiency (CVI) represents a progressive and multifactorial disorder characterized by venous hypertension, valvular incompetence, inflammation, and microcirculatory dysfunction. Although it is rarely life-threatening, CVI significantly affects quality of life and imposes a major socioeconomic burden due to its chronic nature, recurrence, and the need for long-term care (Eberhardt & Raffetto, 2014; De Maeseneer et al., 2022). The disease progresses through a continuum of stages, from mild venous reflux and varicose veins to advanced manifestations such as skin changes and venous leg ulcers (Evans et al., 1999; O'Donnell et al., 2014).

A comprehensive understanding of the pathophysiology involving hemodynamic alterations, inflammatory cascades, and venous wall remodeling has led to major advances in diagnostic and therapeutic approaches. Duplex ultrasonography remains the gold standard for diagnosis, allowing assessment of venous reflux, obstruction, and valve function (Khilnani & Min, 2005). Advanced imaging methods such as MR venography and CT venography have expanded diagnostic precision in complex or atypical cases (Montoya et al., 2024; Weiss, 2024). The integration of artificial intelligence (AI), elastography, and digital monitoring technologies offers promising perspectives for earlier detection and individualized treatment planning (Wilkinson et al., 2025; Lv et al., 2025).

The management of CVI requires a multimodal and patient-centered approach. Compression therapy continues to be the foundation of conservative management, while pharmacological agents such as micronized purified flavonoid fraction (MPFF) and pentoxifylline provide symptomatic relief and support ulcer healing (Mansilha & Sousa, 2018; Wittens et al., 2015). Minimally invasive techniques, especially endovenous thermal ablation (EVLA/RFA) and foam sclerotherapy have largely replaced traditional surgery due to superior efficacy, safety, and shorter recovery time (Gloviczki et al., 2011; Bozkurt et al., 2020). Prevention focuses on risk factor modification, weight management, regular exercise, and consistent adherence to compression therapy.

Future directions in CVI care are likely to focus on personalized medicine and digital health integration. AI-assisted ultrasound interpretation, wearable compression systems with real-time monitoring, and telemedical follow-up may improve long-term compliance and outcomes (Wilkinson et al., 2025; Bai et al., 2024; Rezende et al., 2022). Additionally, advances in biomarker research and molecular imaging could enable earlier identification of endothelial dysfunction and inflammation, opening pathways for targeted pharmacotherapy (Costa et al., 2023).

Future research should focus on identifying reliable biomarkers for early detection of venous wall inflammation and remodeling, as well as on developing non-invasive imaging modalities capable of quantifying endothelial dysfunction (Costa et al., 2023). The integration of artificial intelligence in ultrasound interpretation and telemedicine-based follow-up could revolutionize chronic venous disease management by improving accessibility, adherence, and precision of care (Wilkinson et al., 2025; Bai et al., 2024).

In conclusion, despite substantial progress in understanding and treating CVI, the disease remains a major clinical and public health challenge. Early diagnosis, patient education, lifestyle modification, and adherence to evidence-based therapy are fundamental to effective management. Continued technological innovation and interdisciplinary collaboration hold the promise of transforming CVI care toward more personalized, efficient, and preventive strategies.

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