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Varicose Veins: Artificial Intelligence, 3d Magnetic Resonance Fingerprinting, Epidemiology, Etiology, Pathophysiology, Next-Generation Venous Diagnostics, Spider Veins, DVT, Microvascular Reflux, Macrovascular Remodeling, and Endovenous Ablation Therapy

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Abstract:

Chronic venous disease (CVD) is one of the most common presentations of this condition and is responsible for morbidity, significant health-care costs and poor quality of life in millions of people across the world who suffer from it, and in particular in those suffering from varicose veins. The disease is associated with venous valve incompetence, venous hypertension, vascular remodeling and progressive venous insufficiency. With the advent of new technologies in Artificial Intelligence (AI), machine learning, and 3D Magnetic Resonance Fingerprinting (MRF), the diagnosis and management of venous disorders have been transformed by improved imaging, predictive analysis and personalized treatment planning. This review outlines the current knowledge about the epidemiology, etiology, pathophysiology, clinical stages and complications of varicella. Special focus is on spider veins, deep venous thrombosis (DVT), microvascular reflux, macrovascular remodeling, next generation venous diagnostics, and minimally invasive endo venous ablation therapies. Research indicates that AI-powered imaging and sophisticated vascular mapping techniques can lead to more precise diagnoses and better treatments. The review emphasizes the existing knowledge gaps, new trends, and future directions in precision venous medicine.

Keywords: Varicose Veins, Artificial Intelligence, 3D Magnetic Resonance Fingerprinting, Chronic Venous Disease, Deep Vein Thrombosis, Venous Reflux, Endo venous Ablation.

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1. INTRODUCTION

Varicose veins can be considered the most common vascular disease in the world and comprise an important part of chronic venous disease (CVD). The venous disease is defined as a dilatation of the superficial veins which become elongated and tortuous in lower extremities; it affects millions of patients and is known to negatively impact physical well-being, patient life quality, and overall healthcare costs[1]. Despite the fact that varicose veins are commonly viewed as a cosmetical issue, it should be mentioned that nowadays venous disease is acknowledged as the progressive one characterized by venous hypertension, venous valves incompetence, chronic inflammation, tissue remodeling, and even serious complications like venous ulcers or deep vein thrombosis (DVT). In recent years, significant progress in vascular imaging, artificial intelligence (AI), and non-invasive treatments has changed the approach to the problem allowing diagnosing venous diseases at the early stages and implementing effective treatment plans for them. The current paper aims at presenting the aspects of the venous disease with a special focus on AI technology, MRF, microvascular reflux, macrovascular remodeling, and endovenous ablation treatments.

1.1. Background and Context

Varicose veins arise due to valve incompetence, leading to backflow of blood, with subsequent venous reflux and increased venous pressure. The hemodynamic derangements eventually cause changes in the venous wall structure, which include venous dilatation, tortuosity, and decreased elasticity. The condition is common in up to 15–35% of the adult population worldwide, with the higher risk found among women, older people, pregnant women, obese individuals, and those who perform standing and sitting occupations[2].

The manifestations of chronic venous insufficiency vary from asymptomatic spider veins and milder forms of varicosis to serious complications, which involve edema, skin discoloration, lip dermatosclerosis, and ulceration. Recent studies suggest that venous disease is not only a problem of the local vessel but a complex disorder, which involves multiple pathogenic factors, such as genetic predisposition, inflammation, endothelial dysfunction, changes in the extracellular matrix, and vascular remodeling. Thus, it is important to understand the complicated disease mechanisms.

1.2.Objectives of the Review

The present review aims to:

1. To examine the epidemiology, risk factors, etiology, and pathophysiological mechanisms underlying the development and progression of varicose veins.

2. To evaluate the role of microvascular reflux, macrovascular remodeling, spider veins, and deep vein thrombosis (DVT) in chronic venous disease and its clinical manifestations.
3. To critically assess emerging diagnostic technologies, including Artificial Intelligence (AI), machine learning, 3D Magnetic Resonance Fingerprinting (MRF), and next-generation venous imaging modalities for improved diagnosis and risk stratification.
4. To review current therapeutic approaches, particularly endovenous ablation techniques, and discuss future directions for precision medicine in the management of varicose veins and chronic venous disorders.

1.3. Importance of the Topic

Varicose veins represent a heavy burden on global public health because of their widespread incidence, chronicity, relapsing character, and effect on patients' welfare. Varicose veins cause high medical expenses, lost workdays, and decreased quality of life due to pain, cosmetic issues, and complications. Despite considerable progress in the treatment of varicose veins, a frequent relapse of the disease represents one of the most critical problems[3].

The emergence of innovative techniques related to the application of Artificial Intelligence, advanced vascular imaging, and novel diagnostic technologies opens the new age of precision medicine in venous healthcare. Artificial intelligence in image recognition, prediction, and 3D Magnetic Resonance Fingerprinting will allow obtaining higher levels of diagnostic accuracy and individualization in risk stratification and therapy planning. At the same time, the appearance of new endovenous ablation methods represents safer and more effective solutions than surgical intervention. It becomes evident that a literature review of these developments is needed for clinicians, researchers, and policy makers in venous healthcare.

2. EPIDEMIOLOGY OF VARICOSE VEINS

Varicose veins are among the most common conditions related to chronic venous disease (CVD) and present a serious health problem globally. The disease is equally prevalent in different ethnic groups and geographic locations, although prevalence rates differ with respect to age, sex, genetics, environmental factors, and methods of diagnosis in epidemiological research. Based on current literature, around 15–35% of adults suffer from varicose veins, with the prevalence rate being particularly high in older patients. Generally, females are more vulnerable than males to the disease as a result of hormonal differences, vascular changes during pregnancy, and varying composition of connective tissues.

Several epidemiological studies have revealed a range of risk factors contributing to varicose veins' development and progression. Genetic predisposition is known as one of the strongest predictors of the disease since people with family history of varicose veins have much higher risk of contracting the disease. Other contributing risk factors include obesity, prolonged standing or sedentary activities, pregnancy, aging, inactivity, and prior venous disease. High rates of obesity and inactive lifestyles around the world have also increased the number of cases of the disease. Recurrent venous disease is another problem in the field.

Table 1: Global Epidemiology and Risk Factors of Varicose Veins[4]

Parameter	Findings
Global Prevalence	15–35% of adults
Female Prevalence	Higher than males
Common Age Group	>40 years
Genetic Predisposition	40–60%
Obesity Association	Strong correlation
Occupational Risk	Prolonged standing occupations
Pregnancy Impact	Increased venous pressure and hormonal changes
Recurrence Rate	20–30%

There exist distinct differences in the incidence rates of varicose veins. According to research studies, the prevalence rate rises gradually with age because of valve dysfunction of the vein, loss of elasticity of veins, and hemodynamic strain. In addition, pregnancy is also a predisposing factor because the increase in blood volume, hormonal changes, and high intra-abdominal pressure lead to enlargement of veins and malfunctioning of valves. Obese individuals have increased pressure on their veins of the lower extremities.

Population-based studies conducted recently have also stressed the socio-economic burden of the chronic venous disease. There are major expenses incurred by patients suffering from varicose veins due to diagnostic procedures, treatment costs, recurrent attacks, as well as complications like venous ulcers. In addition, there is reduced physical activity, pain, work disability, and poor quality of life experienced by those affected. With increasing aging populations around the world, the burden of varicose veins is likely to rise in the future, making preventive measures and proper treatments essential[5].

It is clear that there is an urgent need for better disease surveillance as well as novel diagnostic and management techniques due to increasing number of cases and the socio-economic burden of varicose veins. Future technologies like AI-assisted risk prediction models and vascular imaging techniques could assist in better patient selection and prevention of disease in the future.

3. ETIOLOGY AND PATHOPHYSIOLOGY

Varicose veins result from a combination of various factors that affect the venous system such as genetic predisposition, hormones, environment, inflammation, and hemodynamics. This leads to incompetent venous valves, venous hypertension, vascular remodeling, and venous insufficiency.

While there is no standard pattern of disease development, it has been determined that structural weaknesses in the venous wall and incompetent venous valves serve as key precipitating factors.

a) Genetic Factors

Genetic susceptibility is one of the important causes of varicose veins. The people who have a familial background of chronic venous disease are more susceptible to have venous insufficiency because of the genetic mutations which result in alterations in collagen formation, elastic fiber formation, extracellular matrix changes, and venous valve formation. Changes in MMPs and connective tissue proteins also contribute to venous wall weakness and venous dilation[6].

b) Hormonal Influences

The presence of hormonal causes is responsible for the predominance of varicose veins in females. Estrogen and progesterone decrease the tone of venous wall and decrease vascular resistance. Increased venous volume, hormonal changes, and intra-abdominal pressure in pregnancy cause venous hypertension and valve dysfunction.

c) Environmental and Lifestyle Factors

Various lifestyle-related factors can cause diseases. The condition of obesity exerts greater pressure on veins that are located in the lower limbs. At the same time, constant standing or sitting is connected to venous stasis and impairment of the calf muscle pump function. Aging, smoking, sedentary behavior, and occupation also have negative effects on venous blood flow.

d) Venous Hypertension and Reflux

Venous hypertension is the key hemodynamic disorder in the development of varicose veins. The dysfunction of valves allows the reverse direction of blood flow (venous reflux). As a result, there is an elevation of venous pressure. Such processes are associated with endothelial damage, inflammation, dilation of vessels, and valve incompetence.

e) Inflammation, Microvascular Reflux, and Vascular Remodeling

Chronic inflammation is very important in the development of chronic venous diseases. Increased inflammatory cytokines and oxidative stress lead to endothelial dysfunction and destruction of the extracellular matrix[7]. Microvascular reflux causes tissue hypoxia, edema, and cutaneous changes, while macrovascular remodeling leads to thickening of the venous wall, collagen deposition, lack of elasticity, and dilation of the vein. These factors together cause the advanced stage of chronic venous disease, such as venous ulcers.

The pathophysiology of the formation of varicose veins is represented in Fig. 2.

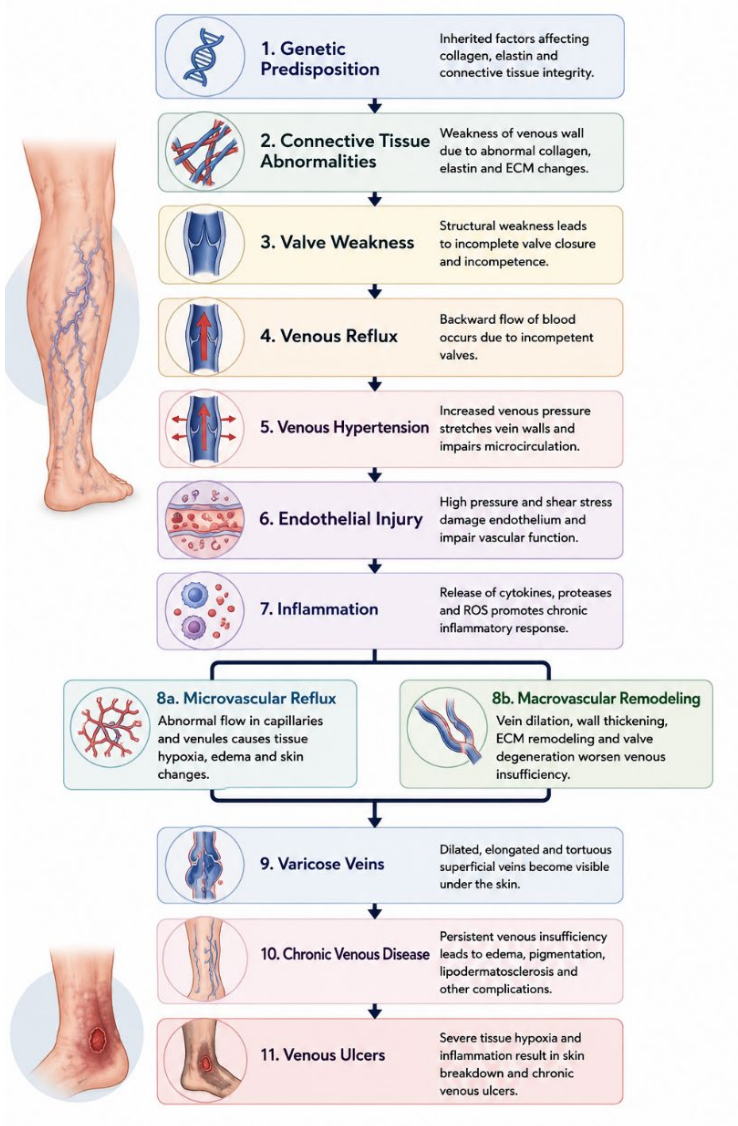

Figure 1: Pathophysiological Mechanism of Varicose Veins[8]

In general, the pathophysiology of varicose veins results from the interactions of genetic predisposition, hormones, mechanical forces, chronic inflammation, and vascular remodeling. Knowledge of these mechanisms is critical for the design of diagnostic and treatment approaches to inhibit disease progression and recurrence.

4. CLINICAL STAGES AND ASSOCIATED VENOUS DISORDERS

Varicose veins include a wide array of clinical presentations that range from asymptomatic telangiectasia to the severe condition of chronic venous insufficiency with ulceration. It is important to stage the disease properly for the purpose of making the diagnosis, choosing the treatment options, and predicting the patient's future prognosis. The CEAP classification system is globally acknowledged as the standardized method for classifying chronic venous disease based on its clinical presentation and pathophysiology.

Table 2: CEAP Classification of Chronic Venous Disease[9]

CEAP Stage	Clinical Features	Severity
C0	No visible or palpable signs of venous disease	Minimal
C1	Spider veins (telangiectasia) and reticular veins	Mild
C2	Visible varicose veins	Moderate
C3	Edema without skin changes	Moderate
C4	Skin pigmentation, eczema, lip dermatosclerosis	Severe
C5	Healed venous ulcer	Very Severe
C6	Active venous ulcer	Advanced

✓ **Spider Veins (Telangiectasia)**

Spider veins mark the initial visible appearance of chronic venous disease and are defined as the development of dilated blood vessels underneath the skin with an appearance of branching vessels in the form of red, blue or purple colors. While usually seen as only a cosmetic issue, spider veins can also suggest a problem of venous reflux and require a proper examination of the patient's condition.

✓ **Varicose Veins**

At the C2 stage, superficial veins get widened, elongated, and twisted due to the failure of venous valves and elevated venous pressure. The symptoms include heavy feeling, aching pain, tiredness, itching, burning, and night-time cramps. If left untreated, the disease will progress to chronic venous insufficiency and other complications.

✓ **Edema and Skin Changes**

Due to chronic venous hypertension, the fluids start leaking from the veins to the tissues around, causing lower limbs' edema. Further progressing of the disease causes changes in skin pigmentation, venous eczema, fibrosis, and lip dermatosclerosis[10].

✓ **Venous Ulcers**

Venous ulcers are the most severe form of chronic venous disease, which is associated with venous hypertension, microcirculatory dysfunction, and poor wound healing. Venous ulcers are typically located at the medial malleolus, and they are usually chronic, recurring, and hard to treat. Venous ulcers have a very negative impact on the quality of life, and they account for enormous expenses related to health care.

5. MICROVASCULAR REFLUX AND MACROVASCULAR REMODELING

Microvascular reflux and macrovascular remodeling have been found to be essential pathological mechanisms involved in the development and progression of chronic venous disease (CVD).

Whereas classical researches tended to concentrate mainly on incompetent valves and dilation of superficial veins, new findings showed that microcirculatory dysfunction and large vessels' remodeling played an important role in predicting the severity of the disease, its presentation, and response to therapy. Interaction of both processes leads to venous hypertension, tissue injury, chronic inflammation, and development of advanced complications, including skin alterations and venous ulcers[11].

1) Microvascular Reflux

The phenomenon of microvascular reflux involves a pathological process of reverse blood circulation in the capillaries, venules, and smaller veins of the lower limbs. The pathogenesis of chronic venous insufficiency involving the incompetent valves leads to a rise in hydrostatic pressure within the microcirculation, followed by dilatation of the capillaries, endothelial dysfunction, and poor perfusion of tissues.

These abnormalities result in disturbances in oxygen and nutrient delivery to the nearby tissues, thus causing chronic hypoxia and inflammation. Microvascular reflux affects not only the function of blood circulation but also the vessel's permeability to proteins and inflammatory molecules, thus causing edema and tissue fibrosis. Other manifestations of microcirculatory dysfunction include skin hyperpigmentation, venous eczema, lip dermatosclerosis, and impaired wound healing. In the worst cases, tissue hypoxia and inflammation can lead to venous ulcerations, which represent the most disabling complication of chronic venous insufficiency.

2) Macrovascular Remodeling

Macrovascular remodeling can be defined as the morphological changes that take place in the large veins due to chronic venous hypertension and inflammation[12]. This includes venous dilatation, thickening of venous wall, extracellular matrix remodeling, deposition of collagen, loss of elasticity in the venous walls, degradation of elastin fibers, and deterioration of venous valves. All these factors cause weakening of the venous wall and further loss of valve functionality, worsening the venous reflux.

The histological findings of altered type I and type III collagen ratio, increased matrix metalloproteinase enzyme activity, dysfunction of smooth muscle cells, and presence of inflammatory cells have been seen in varicose veins. These structural abnormalities lead to the tortuous and dilated nature of varicose veins. Also, macrovascular remodeling has been found to play an important role in the recurrence of disease after the treatment.

Table 3: Comparison Between Microvascular Reflux and Macrovascular Remodeling[13]

Parameter	Microvascular Reflux	Macrovascular Remodeling
Primary Location	Capillaries and small venules	Superficial and deep veins
Main Cause	Increased venous pressure	Chronic venous hypertension
Pathological	Endothelial dysfunction, capillary	Wall thickening, valve

Changes	leakage	degeneration
Clinical Effects	Edema, pigmentation, ulcers	Varicosities, venous insufficiency
Disease Role	Tissue-level damage	Structural vascular damage
Diagnostic Methods	Capillaroscopy, advanced imaging	Duplex ultrasound, MR venography
Impact on Recurrence	Indirect	Strong association

The pathological connection between microvascular reflux and macrovascular remodeling is depicted in Fig 4 below. It shows how valve incompetence in veins leads to venous reflux and hypertension, leading to microcirculatory disorders and venous remodeling. Both conditions play a significant role in chronic venous disease and cause advanced complications such as venous ulcers.

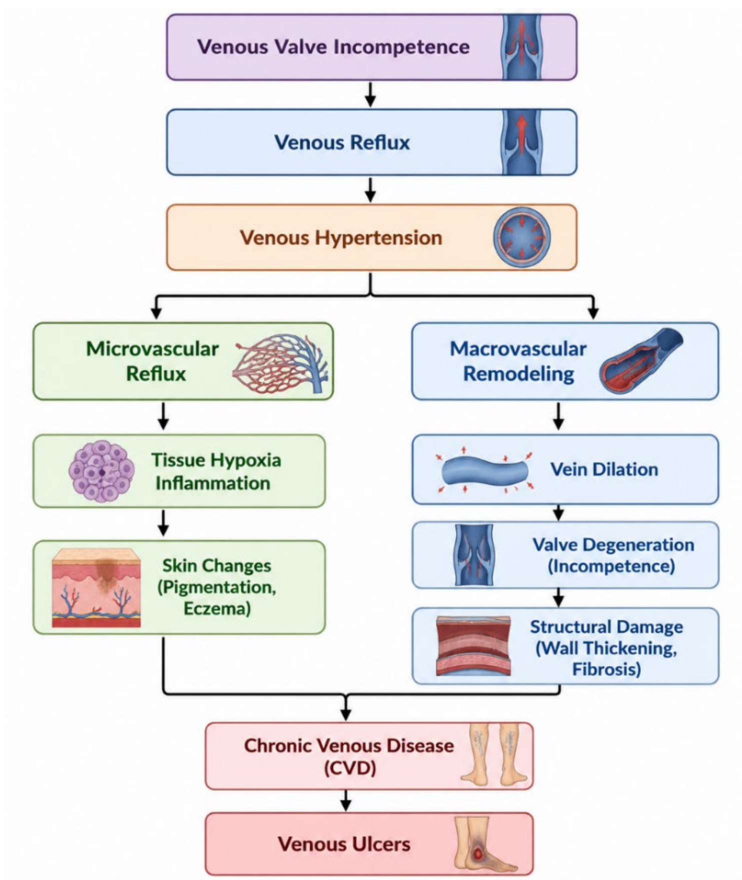

Figure 2: Relationship Between Microvascular Reflux and Macrovascular Remodeling[14]

3) Clinical Significance

The combination of microvascular reflux and macrovascular remodeling offers a more thorough understanding of the development of chronic venous disease than any single process. The current scientific literature demonstrates the need for an evaluation of both microcirculation problems and changes in large vessel structure in order to successfully treat varicose veins. New technologies in diagnostics such as high-resolution duplex ultrasound, artificial intelligence imaging, and three-dimensional magnetic resonance fingerprinting provide new means of examining the intertwined pathological processes[15].

The combination of microvascular and macrovascular assessments is expected to lead to a more effective stratification of patients, choice of treatment methods, prevention of disease recurrence, and success of therapy in the future. Thus, future strategies for venous disease management will be associated with multimodal imaging and precision medicine.

6. ARTIFICIAL INTELLIGENCE IN VENOUS MEDICINE

Artificial Intelligence (AI) is another revolutionary technology applied in contemporary healthcare, which is able to change the approaches to diagnosing, monitoring and treating vascular disorders. In venous medicine, AI technology uses machine learning, deep learning, computer vision and predictive analytics in order to analyze different datasets in terms of their complexity, fastness and accuracy. There is an increase in the number of patients who suffer from chronic venous disease and varicose veins[16]. Thus, there is a necessity to introduce more innovative diagnostics in order to improve early detection, risk assessment and personalized treatment planning. AI technologies are increasingly used in vascular imaging and clinic, which opens new opportunities to improve the results of treatment.

The first area of AI usage in venous medicine is automated image interpretation. Conventional venous imaging methods, especially duplex ultrasonography, depend on the experience of the operator and are associated with significant variability among different operators. However, AI-based algorithms are able to analyze different images (ultrasound, Doppler, CT and MRI) in order to detect venous reflux, valve incompetence, thrombotic lesions and other pathological changes in the venous system. Deep learning models have an ability to recognize the smallest patterns, which can be hardly noticed by the human eye.

Additionally, AI shows its advantages in disease prediction and risk assessment. Using demographic information, medical history, genetic factors, imaging and laboratory biomarkers, artificial intelligence models are able to predict the probability of disease progression, recidivism after treatment, complications such as chronic venous insufficiency, venous ulcers and DVT. These predictive capabilities support proactive patient management and enable clinicians to identify high-risk individuals who may benefit from closer monitoring and early therapeutic intervention.

Table 4: Selected Studies on Artificial Intelligence Applications in Venous Medicine

Author(s)	Study Focus	AI Application	Key Findings

Velasco et al. (2022)[17]	Cardiac Magnetic Resonance Fingerprinting	AI-assisted image acquisition and analysis	AI improved quantitative MRI interpretation, image reconstruction, and automated tissue characterization, demonstrating the potential of AI-integrated fingerprinting technologies in vascular imaging.
Atreyapurapu et al. (2022)[18]	Advanced Chronic Venous Insufficiency	Machine learning-based anatomical assessment	AI techniques successfully identified anatomical changes associated with advanced venous disease and supported improved disease characterization and treatment planning.
Gil et al. (2024)[19]	Venous Thromboembolism	Machine learning prediction models	AI enhanced risk stratification, thromboembolism prediction, and clinical decision-making through analysis of large-scale patient datasets.
Pugalenthi et al. (2025)[20]	Varicose Veins Management	AI-driven diagnosis and predictive analytics	AI improved diagnostic accuracy, predicted disease progression, and guided personalized management strategies for patients with varicose veins.
Wilkinson et al. (2025)[21]	Chronic Venous Insufficiency	Review of AI applications in venous medicine	Highlighted the growing role of AI in imaging interpretation, disease prediction, patient monitoring, and clinical decision-support systems while emphasizing the need for further validation.

As illustrated in Table 4, the researches discussed here provide evidence for growing utilization of Artificial Intelligence in various areas of venous medicine. Current knowledge about AI proves that AI has applications in imaging analysis, disease prediction, anatomical identification, thromboembolism evaluation, and decision-making. Such developments have a potential for shifting from traditional diagnostic approaches to the use of more individualized methods of diagnosis.

AI is also widely used in clinical decision-making as part of AI-based Clinical Decision Support Systems (CDSS). Such systems process clinical and imaging information specific to patients in order to provide evidence-based suggestions concerning the diagnosis, choice of treatment and follow-up actions. With AI-supported decision-making, clinicians may choose an optimal approach to treatment, whether conservative, compression, endovenous ablation or surgery. This is one of the key features of precision medicine.

7. 3D MAGNETIC RESONANCE FINGERPRINTING (MRF)

3D magnetic resonance fingerprinting (MRF) is one of the promising quantitative imaging technologies which have become increasingly popular in the field of vascular medicine in recent years due to its capability to provide simultaneous measurement of multiple tissue characteristics during a single imaging session[22]. Contrary to the conventional magnetic resonance imaging (MRI), MRF creates unique signal signatures that can be compared with a reference database to obtain quantitative maps of tissue characteristics. Thus, this method allows performing an objective assessment of tissue composition and pathology and can be applied for evaluation of chronic venous disease and varicose veins.

There are several advantages that venous medicine may receive from the implementation of 3D MRF imaging. First, this technology allows receiving high resolution images of venous anatomy and measuring tissue parameters including T1 and T2 relaxation times, proton density, and vascular tissue composition at the same time. Therefore, MRF allows assessing venous wall pathology, inflammatory changes, thrombotic lesions, and vascular remodeling.

Quantitative tissue mapping provided by MRF may contribute to the improvement of treatment planning, disease management, and evaluation of treatment effects. One of the main areas of application of 3D MRF is assessment of microvascular and macrovascular remodeling. The technology allows assessing structural changes including fibrosis, collagen deposition, endothelial dysfunction, and inflammatory infiltration of venous walls. Besides, MRF was proven to have diagnostic potential to detect and characterize deep vein thrombosis (DVT) and evaluate its composition[23].

However, there are several factors that currently limit the use of MRF for venous disease evaluation. First, high equipment cost and special requirements for computations limit the access to the technology. Besides, there are no standardized imaging protocols and there is a need for large-scale clinical research for validation of diagnostic performance of MRF.

8. NEXT-GENERATION VENOUS DIAGNOSTICS

There have been substantial changes in the diagnosis of varicose veins and chronic venous disease due to the development of advanced imaging techniques, data analytics, and digital health solutions[24]. Despite the continued use of physical examination and duplex ultrasonography for evaluation of the venous system, new diagnostic modalities are giving a more detailed insight into the anatomy of the veins, their physiology, pathophysiology, and the nature of diseases of the venous system. This technology allows for early identification of venous disease, improves diagnostics and supports personalized treatment plans.

Table 5: Emerging Diagnostic Technologies for Varicose Veins[25]

Technology	Advantages	Limitations
Duplex Ultrasound	Gold standard	Operator dependent
AI-Based Imaging	High diagnostic accuracy	Requires large datasets
MR Venography	Detailed anatomy	High cost
3D MR Fingerprinting	Quantitative assessment	Limited availability
Wearable Sensors	Continuous monitoring	Experimental stage

The duplex ultrasonography is the most frequently used technique for evaluation of venous reflux, valve incompetence, the diameter of veins, and changes caused by the formation of thrombus. The real-time imaging and the ability to conduct examination without any invasion make this modality absolutely essential in clinical practice. Nevertheless, the results depend greatly on the skills and interpretation of the operator, which means that standardization of the evaluation procedure would be required. Artificial Intelligence (AI)-based imaging systems represent a promising solution to this problem. Machine learning and deep learning algorithms are able to automatically detect the presence of abnormalities in the veins, evaluate the patterns of venous reflux, quantitatively assess the disease severity and help physicians to make their diagnoses more objective.

In addition to traditional ultrasound, Magnetic Resonance Venography (MRV) and 3D Magnetic Resonance Fingerprinting (MRF) can provide additional valuable information about vascular abnormalities[26]. With its high-resolution anatomical mapping of both superficial and deep veins, MRV is especially effective in complicated cases and in identification of deep vein obstructions. At the same time, 3D MRF allows simultaneously analyzing a number of different properties of tissues, which makes it suitable for evaluation of venous wall integrity, thrombotic lesions and vascular remodeling.

The other promising approach is the use of wearable sensors and digital monitoring technologies. These tools allow conducting the assessment of physiological parameters, such as venous pressure, blood flow dynamics, tissue oxygenation, limb activity. Even though currently these systems are mainly experimental, they may prove useful for remote monitoring of patients and long-term evaluation of their disease course and response to treatment. Combined with the AI-based analytical algorithms, wearable technology can provide valuable information for patient-specific risk assessment and treatment.

9. ENDOVENOUS ABLATION THERAPY

Endovenous ablation therapy has dramatically changed the management of varicose veins by offering a less-invasive way to perform a surgery that removes venous reflux from the body through closing incompetent veins to ensure normal flow in veins[27]. Compared to surgical procedures, endovenous treatments are characterized by a number of benefits, such as lesser pain after the surgery, fewer scars, faster recovery process, fewer complications, and high patient satisfaction. Therefore, endovenous ablation therapy is considered an ideal therapy option for varicose veins treatment.

Table 6: Comparison of Endovenous Treatment Modalities[28]

Treatment	Success Rate (%)	Recovery
EVLA	90–98	1–3 days
RFA	92–97	1–2 days
MOCA	85–95	1–2 days
Cyanoacrylate Closure	90–97	Same day
Surgical Stripping	80–90	1–2 weeks

Currently used treatment methods include Endovenous Laser Ablation (EVLA) and Radiofrequency Ablation (RFA), which are the two most popular methods of thermal ablation. These procedures use thermal energy to destroy endothelium and cause vein wall contraction and permanent occlusion. Many clinical studies confirmed high effectiveness of these procedures, durable outcomes, and symptomatic relief after these procedures. RFA usually causes slightly fewer post-procedural pain and bruises, while EVLA has similar efficiency and continues to be used thanks to its proven clinical experience.

Another two methods, which are more novel and don't require thermal energy, are called Mechanochemical Ablation (MOCA) and Cyanoacrylate Closure[29]. They don't require any anesthetic, because MOCA disrupts venous endothelium mechanically, applying a sclerosant, while Cyanoacrylate Closure occludes the vein using medical glue. These procedures provide quick treatment, fast recovery, and good cosmetic outcomes without lowering vein occlusion rate and patient satisfaction.

Conventional surgical stripping, which used to be more common in the past but lost its popularity due to the rise of endovenous procedures, is still used occasionally in specific cases when endovenous therapy cannot be applied due to extensive disease or anatomical reasons[30].

Currently, the optimal treatment method is chosen depending on several factors, such as the degree of vein disease, anatomy, preferences of a patient, comorbidity, and clinical experience. In the future, it can be improved by incorporating advanced imaging technologies, AI-powered treatment planning, and precision medicine approaches. With the development of the field, the ablation procedures continue to be the main method of treating chronic venous disease.

10. DISCUSSION

The present review focuses on the multi-factorial characteristics of varicose veins and CVD, drawing attention to the intricate interactions between genes, hormones, environmental factors, venous hypertension, inflammation, and remodeling[31]. The evidence gathered suggests that varicose veins cannot be viewed as purely cosmetic problems anymore, being a progressive condition with high potential for developing serious morbidity, lowering the quality of people's lives, and imposing significant economic costs. Epidemiological evidence shows that this condition is quite common among the world's population, affecting especially women, elderly patients, pregnant women, and people involved in professions that require constant standing.

10.1. Interpretation and Analysis of the Findings

It should be noted that the reviewed articles confirm venous valve incompetence and venous hypertension to be the key drivers of the disease progression[32]. Nonetheless, some studies suggest a more complex picture of the pathology, where the development and progression of varicose veins can be attributed to the presence of an inflammatory response, endothelial injury, microvascular reflux, and macrovascular remodeling[33]. These interconnected pathological conditions play a role in deteriorating the structure and functions of veins, eventually resulting in chronic venous insufficiency, changes in the skin, and venous ulcers. Moreover, the findings provided by current literature suggest that microvascular reflux and macrovascular remodeling are not separate phenomena but rather two complementing pathological processes.

An important point revealed by this review is the increased use of novel technologies in venous medicine. Artificial Intelligence has proven itself to be effective in image analysis and interpretation, prediction of disease and risk stratification[34]. Also, 3D Magnetic Resonance Fingerprinting (MRF) represents a valuable innovation in vascular imaging and provides an opportunity to examine the state of venous wall, its pathology, presence of thrombosis, and vascular remodeling[35]. As a result, these new technologies can radically change traditional approaches to venous diagnostics through increased accuracy and precision of diagnosis, elimination of inter-observer variability, and personalization of treatments. Additionally, progress in endovenous ablation procedures (EVLA, RFA, MOCA, and cyanoacrylate vein closure) has resulted in the increase in efficacy and recovery speed of the procedures[36].

10.2. Implications and Significance

The discussed literature demonstrates an increasing medical and public health challenge related to chronic venous disease in the world[37]. Better knowledge of the disease mechanisms may help detect patients earlier and develop better treatment methods. In this regard, the combination of AI diagnostics, advanced imaging of veins, and precision medicine can positively impact the treatment by offering personalized treatment plans and reducing recurrences[38]. Moreover, new endovenous treatments are much safer and effective than surgeries; hence, improving quality of life and healthcare spending.

10.3. Research Gaps and Future Directions

Although there have been considerable advancements in chronic venous disease studies, there are still some knowledge gaps that need to be filled in the future[39]. Firstly, the molecular mechanisms of the development of venous wall damage should be explored. There is a need to conduct large randomized trials for validation of AI algorithm and standardization of 3D MRF technology and other imaging innovations[40]. Moreover, future research should also include the integration of AI, imaging modalities, wearables, and biomarkers into precision venous medicine.

11. CONCLUSION

Varicose veins are a multifactorial and progressive representation of chronic venous disease, characterized by venous valvular incompetence, venous hypertension, inflammation, micro venous reflux, and macrovascular remodeling. The review presents an analysis of the multifactorial pathogenesis, epidemiology, progression, and complications of chronic venous disease, including spider veins, chronic venous insufficiency, DVT, and venous ulceration. The results indicate that the latest advancements in Artificial Intelligence, 3D MRF, and novel venous diagnostics technologies have revolutionized the diagnostic and treatment process of venous diseases, allowing the accurate imaging, risk estimation, and personalized treatment planning. Moreover, the introduction of endovenous ablation techniques has improved patient satisfaction and the recovery period compared to traditional surgical techniques. Nevertheless, additional research will be needed in order to establish standardization of novel technologies, validation of AI-driven diagnostic models, and treatment approaches optimization. In conclusion, the implementation of advanced imaging and computational analytics technologies in combination with precision medicine approaches has a great potential for improving diagnosis, treatment, and care of varicose veins and chronic venous disease patients.

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