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Review

Anatomy and Pathophysiology of Varicose Veins: A Comprehensive Review of Venous Structure, Reflux Mechanisms and Clinical Implications

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Abstract

Varicose veins are dilated and tortuous superficial veins most commonly affecting the lower limbs. They arise due to venous valve failure, venous wall weakness, and abnormal blood flow leading to venous hypertension. Although often considered cosmetic, varicose veins can progress to serious complications such as edema, skin changes, thrombophlebitis, and venous ulcers. The disease is influenced by genetic, hormonal, occupational, and lifestyle factors. Advances in diagnostic imaging have improved understanding of venous reflux patterns. Treatment has shifted from traditional surgery to minimally invasive endovenous methods. This review discusses the background, history, current status, mechanisms, principles, classification, applications, advantages, and comparison of modern therapies for varicose veins.

Keywords: Varicose veins; Venous reflux; Venous hypertension; Chronic venous disease; Endovenous therapy; Hemodynamics

INTRODUCTION

Varicose veins are permanently dilated, elongated, and tortuous superficial veins, usually seen in the lower extremities. They develop when venous valves fail, allowing blood to flow backward and pool in the veins, leading to increased venous pressure and progressive dilation. The prevalence of varicose veins ranges between 20–40% in adults, with higher rates in women and elderly individuals. Genetic predisposition plays a major role, and studies show that people with a family history have significantly higher risk [1]. Along with genetics, factors such as pregnancy, obesity, prolonged standing, and sedentary lifestyle increase venous pressure and accelerate disease development [2].

The venous system of the lower limb is designed to return blood against gravity using venous valves and the calf muscle pump. When these mechanisms fail, venous reflux develops, causing ambulatory venous hypertension. This sustained pressure damages the venous wall, alters collagen and elastin content, and worsens valve dysfunction [3]. Over time, microcirculatory damage occurs, leading to skin pigmentation, eczema, fibrosis, and ulceration.

Varicose veins are important not only because of physical symptoms but also due to psychosocial effects. Visible veins and skin discoloration affect body image and self-esteem. Chronic pain and ulceration reduce work ability and quality of life [4]. Economically, varicose veins impose heavy healthcare costs due to repeated treatments and long-term wound care.

IMPORTANCE OF THE REVIEW

Varicose veins are often underestimated as a cosmetic issue, but they represent a progressive vascular disease. Chronic venous hypertension leads to inflammation, capillary leakage, tissue hypoxia, and fibrosis, forming the basis of chronic venous insufficiency [5]. Advanced disease causes venous ulcers, which are difficult to heal and frequently recur.

Recent decades have seen major changes in diagnosis and management. Duplex ultrasound allows accurate mapping of reflux pathways, replacing blind surgical decisions [6]. Treatment has shifted from vein stripping to endovenous laser, radiofrequency ablation, foam sclerotherapy, mechanochemical ablation, and glue closure [7]. Understanding disease mechanisms is essential for selecting the right treatment and preventing recurrence.

AIM OF THE REVIEW

The aim of this review is to provide a clear and structured overview of varicose veins, including historical background, current status, mechanisms, principles, classification, applications, advantages of modern therapy, and comparison with conventional methods, to support academic learning and clinical practice.

HISTORY OF VARICOSE VEINS

Varicose veins have been recognized since ancient times. Early Egyptian medical writings described swollen and twisted leg veins and leg ulcers, but treatment was avoided because of severe bleeding and infection. In ancient Greece, Hippocrates used compression and puncture methods and observed that varicose veins often returned, showing early understanding of their chronic nature. Roman physicians, especially Galen, linked varicose veins with leg ulcers and attempted surgical removal, though without anesthesia or antisepsis these procedures were dangerous.

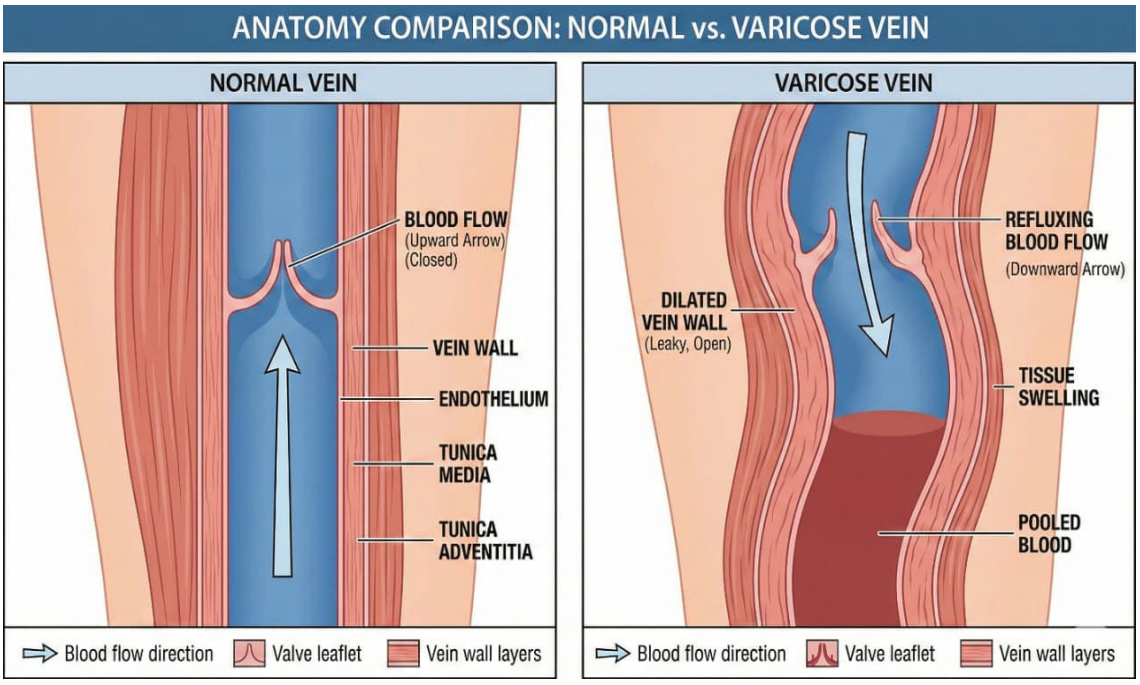

FIGURE:1 Anatomy Comparison : Normal vs Varicose Vein

During the Middle Ages, treatment relied on cauterization, tight bandaging, herbal remedies, and bloodletting. There was little understanding of the real cause of the disease, and therapy mainly aimed to reduce visible veins or pain. Varicose veins were common in people doing heavy work or standing for long hours and were often considered unavoidable with aging.

A major change came in the seventeenth century when William Harvey described blood circulation. Later, venous valves were discovered and their role in preventing backflow was understood. This explained why valve failure could lead to blood pooling and vein dilation.

The late twentieth century introduced ultrasound imaging, allowing doctors to see venous flow and identify faulty veins accurately. In the twenty-first century, minimally invasive treatments replaced surgery, closing veins from inside with heat, chemicals, or glue. These methods are safer, less painful, and allow faster recovery.Thus, the history of varicose veins shows progress from ancient recognition and risky treatment to modern, precise, and minimally invasive therapy.

CURRENT STATUS OF VARICOSE VEIN MANAGEMENT

Today, varicose veins are understood as a hemodynamic disorder rather than a simple structural problem. The main pathology is venous reflux due to valve incompetence, leading to ambulatory venous hypertension [8]. Duplex ultrasonography is now the gold standard for diagnosis, allowing visualization of superficial, deep, and perforator veins and measurement of reflux duration [9].

Modern guidelines recommend minimally invasive endovenous procedures as first-line therapy. Endovenous laser ablation and radiofrequency ablation show closure rates above 90% with low recurrence [10]. Foam sclerotherapy is widely used for tortuous and recurrent veins [11]. Newer techniques such as mechanochemical ablation and cyanoacrylate glue closure avoid thermal injury and do not require tumescent anesthesia [12].

Compression therapy remains important for symptom relief and prevention of complications. Pharmacological agents such as flavonoids and horse chestnut extract reduce edema and inflammation but do not correct reflux [13]. Management now focuses on correcting reflux pathways, preventing progression, and improving quality of life.

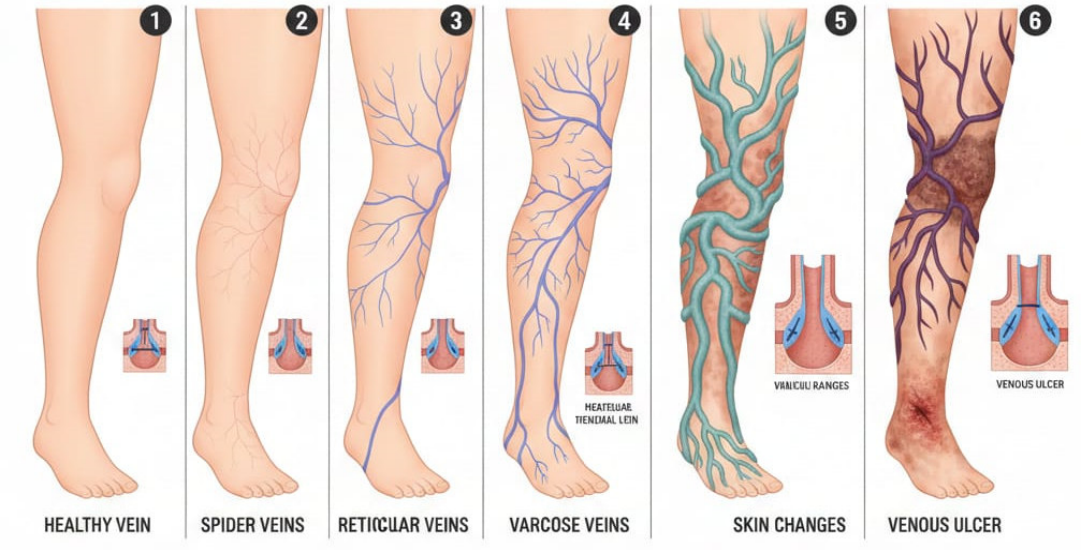

FIGURE:2 Stages of Varicose Vein

MECHANISM OF VARICOSE VEINS

Varicose veins develop due to interaction between structural weakness of the vein wall, valve failure, and abnormal hemodynamics. Genetic factors influence collagen and elastin composition of the venous wall, making veins more prone to dilation [14]. When veins dilate, valve cusps cannot close properly, leading to reflux.

Venous reflux causes retrograde blood flow, increasing pressure in superficial veins. During standing, ankle venous pressure may reach 80–100 mmHg, and in healthy individuals this pressure falls during walking due to calf muscle pump action. In varicose veins, pressure fails to fall during walking, a condition called ambulatory venous hypertension [15].

High pressure damages the venous wall by increasing collagen deposition and reducing elastin, making veins stiff and dilated [16]. Smooth muscle cells lose contractility and shift to a synthetic type, producing excess collagen [17]. Inflammation plays a major role; leukocytes release cytokines and proteolytic enzymes that damage valves and vein wall [18].

Microcirculatory changes occur when high venous pressure is transmitted to capillaries. Capillary leakage leads to edema, red blood cell breakdown, and hemosiderin deposition, causing pigmentation [19]. Chronic inflammation and hypoxia lead to fibrosis and ulceration.

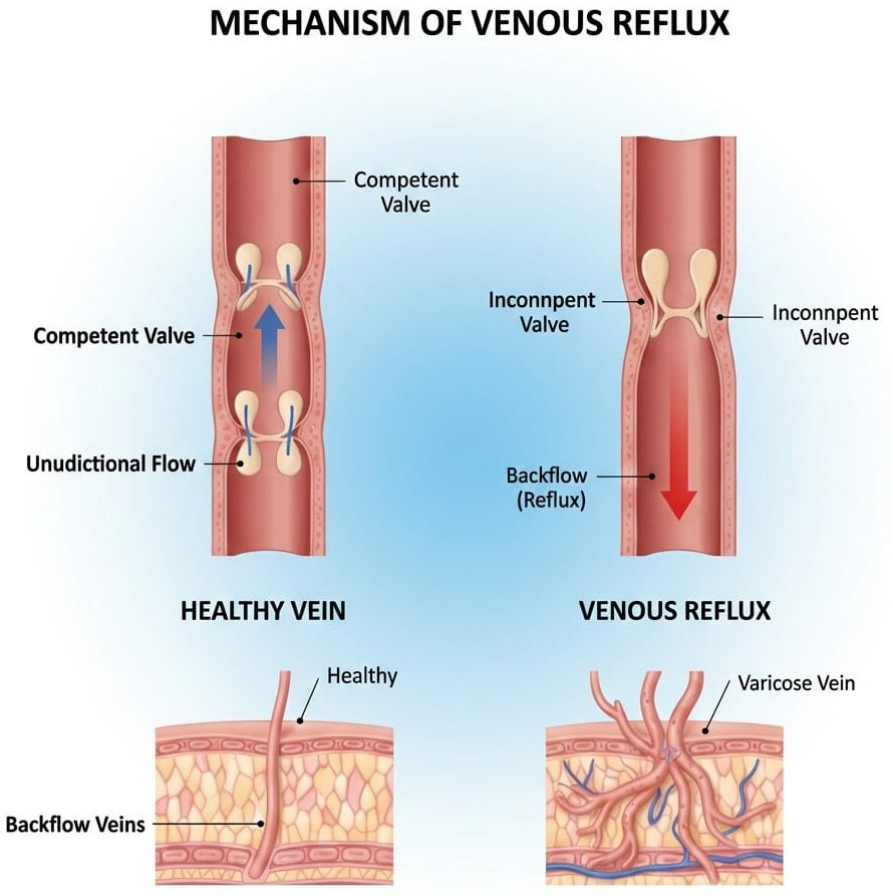

FIGURE:3 Mechanism of Vericose Vein

PRINCIPLE OF VARICOSE VEIN DEVELOPMENT

The basic principle behind varicose vein disease is failure of unidirectional blood flow. Normal venous return depends on competent valves, calf muscle pump, and elastic venous walls. When any of these fail, blood flows backward, increasing venous pressure.

This pressure causes progressive dilation, which further worsens valve incompetence, forming a vicious cycle. Persistent venous hypertension leads to structural remodeling, inflammation, and microvascular damage [20]. Treatment principles therefore focus on:

- Eliminating reflux
- Reducing venous pressure
- Improving calf pump function
- Preventing complications

Modern treatments aim to close incompetent veins so that blood is redirected through healthy deep veins, restoring normal hemodynamics [21].

CLASSIFICATION AND TYPES OF VARICOSE VEINS

BASED ON ANATOMY

Varicose veins can be classified according to the part of the venous system involved. This anatomical classification is important because the choice of treatment depends largely on which veins are incompetent.

- Superficial varicosities – Great saphenous vein, small saphenous vein, accessory veins
- Perforator incompetence – Cockett, Boyd, Dodd perforators
- Deep venous disease – post-thrombotic changes

Superficial varicosities involve the superficial venous system, mainly the great saphenous vein, small saphenous vein, and their accessory branches. Incompetence in the great saphenous vein is the most common cause of varicose veins, leading to dilated veins along the medial side of the leg and thigh. Small saphenous vein reflux usually produces varicosities in the posterior calf region. Accessory saphenous veins act as important tributaries, and reflux in these veins is a frequent cause of recurrent varicose veins after treatment. Because superficial veins are located in subcutaneous tissue with limited support, they dilate easily when exposed to high venous pressure .Perforator incompetence occurs when veins connecting the superficial and deep systems lose their valve function. Important perforators include the Cockett perforators in the lower calf, Boyd perforator in the upper calf, and Dodd perforator in the thigh. Normally, these veins allow blood to flow from superficial to deep veins only. When incompetent, blood flows backward into superficial veins, increasing pressure and producing localized or segmental varicosities. Incompetent perforators play a major role in advanced chronic venous disease and venous ulcer formation . Deep venous disease refers to involvement of the deep venous system, often due to previous deep vein thrombosis. Post-thrombotic changes cause obstruction, valve destruction, and chronic venous hypertension. This leads to secondary varicose veins, edema, and severe skin changes. Unlike superficial disease, deep venous disease is more difficult to treat and often requires long-term compression and supportive therapy [22].

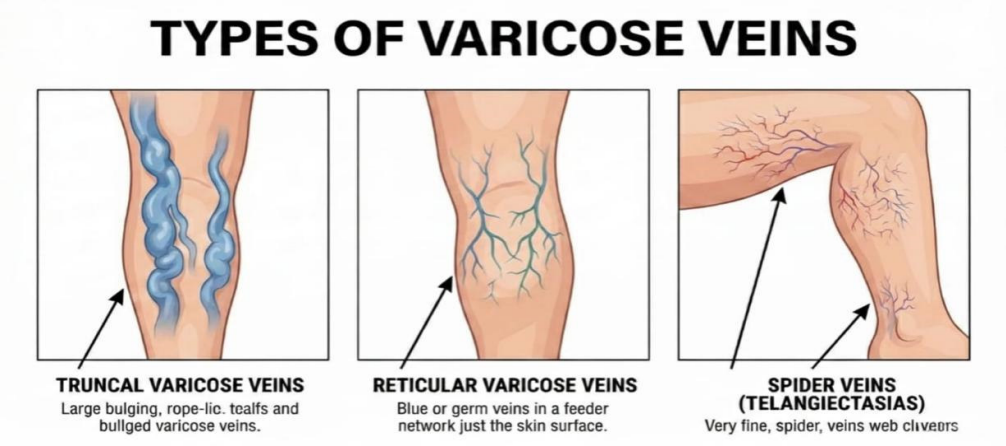

FIGURE: 4Types of Varicose Veins

BASED ON ETIOLOGY

Etiological classification divides varicose veins according to their cause.

- Primary varicose veins – due to congenital weakness of vein wall or valves
- Secondary varicose veins – due to deep vein thrombosis, pelvic tumors, pregnancy-related obstruction
- Congenital – rare malformations such as Klippel-Trenaunay syndrome.

Primary varicose veins develop due to congenital or inherited weakness of the venous wall or venous valves. In these patients, there is no previous history of deep vein thrombosis or external obstruction. Genetic factors affect collagen and elastin content, making veins more distensible and valves more prone to failure. Primary varicosities account for the majority of cases seen in clinical practice.

Secondary varicose veins occur due to obstruction or damage to the deep venous system. Common causes include deep vein thrombosis, pelvic tumors, pregnancy-related venous compression, and trauma.

When deep veins are obstructed, blood is diverted into superficial veins, increasing pressure and causing them to dilate. These varicose veins are usually associated with severe symptoms and skin changes and are more difficult to manage than primary varicosities.

Congenital varicose veins are rare and occur due to developmental malformations of the venous system. Conditions such as Klippel–Trenaunay syndrome are characterized by abnormal veins, limb hypertrophy, and vascular malformations. These patients often present in childhood and require specialized management[23].

CEAP Classification

The CEAP classification system (Clinical, Etiological, Anatomical, Pathophysiological) is an internationally accepted system used to standardize diagnosis, treatment planning, and research reporting.

The clinical component grades disease severity as:

C0 – No visible or palpable venous signs
C1 – Telangiectasia or reticular veins
C2 – Varicose veins
C3 – Edema
C4 – Skin changes such as pigmentation or eczema
C5 – Healed venous ulcer
C6 – Active venous ulcer

Each clinical class may be described as symptomatic or asymptomatic. Higher classes indicate advanced disease and greater risk of complications.

The etiological component identifies whether disease is primary, secondary (post-thrombotic), congenital, or of unknown cause. The anatomical component specifies whether superficial, deep, or perforator veins are involved. The pathophysiological component describes whether disease is due to reflux, obstruction, or both. This combined system allows precise description of venous disease and guides treatment choice [24].

Based on Clinical Appearance

- Trunk varicosities
- Reticular veins
- Spider veins
- Segmental varicosities

Varicose veins can also be classified by their visible pattern.

Trunk varicosities are large, elongated, and tortuous veins arising from reflux in the main saphenous trunks. These are often symptomatic and usually require endovenous ablation or surgery.

Reticular veins are bluish, dilated veins less than 3 mm in diameter, commonly seen around the knee and thigh. They are often treated for cosmetic reasons using sclerotherapy.

Spider veins (telangiectasia) are very small red or purple veins less than 1 mm in diameter. They rarely cause symptoms but are treated for cosmetic improvement.

Segmental varicosities are localized dilated veins due to reflux in a specific segment or perforator. These can often be treated with targeted sclerotherapy or phlebectomy.

Different clinical types require different treatment strategies, and correct classification ensures appropriate and effective management [25].

APPLICATIONS OF VARICOSE VEIN MANAGEMENT

SYMPTOM RELIEF AND FUNCTIONAL IMPROVEMENT

Management of varicose veins has wide clinical application ranging from cosmetic correction to treatment of severe chronic venous disease. In early-stage disease, treatment is mainly aimed at relieving symptoms such as heaviness, pain, swelling, and night cramps. Many patients seek treatment because these symptoms interfere with daily activities and work performance, and correction of superficial venous reflux significantly improves functional capacity and quality of life [26]. Even in patients with mild disease, early management helps prevent progression to more advanced stages.

CONSERVATIVE AND PREVENTIVE APPLICATIONS

Conservative management is commonly applied in patients with early varicose veins, elderly individuals, pregnant women, and those unfit for invasive procedures. Compression therapy is widely used to reduce vein diameter and improve venous return, which decreases venous pressure and edema. By increasing flow velocity and reducing venous stasis,

compression stockings reduce pain, swelling, and risk of skin changes [27]. These methods are especially useful in occupational groups that require prolonged standing or sitting.

ENDOVENOUS TREATMENT FOR TRUNCAL REFLUX

Endovenous therapies are mainly applied in patients with symptomatic reflux in the great or small saphenous veins. Endovenous laser ablation and radiofrequency ablation are widely used because they directly eliminate refluxing trunks and redirect blood flow into healthy deep veins, resulting in rapid symptom relief and high long-term success rates [28]. These techniques are applied in working adults because they allow early return to normal activity with minimal hospital stay.

TREATMENT OF TORTUOUS AND RECURRENT VEINS

Ultrasound-guided foam sclerotherapy is especially useful in patients with tortuous veins, recurrent varicosities, and residual tributaries after surgery or ablation. Because foam can fill irregular and twisted veins, it is highly suitable for treating veins that cannot be accessed easily by catheters [29]. It is also applied in elderly patients and those with multiple medical conditions where surgery is risky.

NON-THERMAL AND NON-TUMESCENT TECHNIQUES

Mechanochemical ablation and cyanoacrylate glue closure are applied when thermal methods are not preferred. These techniques are useful in patients with veins close to nerves or skin, where heat may cause injury. Because they do not require tumescent anesthesia, they are comfortable for patients and allow faster procedures [30]. These methods are also useful in patients who fear injections or have difficulty tolerating long procedures.

MANAGEMENT OF ADVANCED DISEASE AND ULCERS

In advanced disease with skin changes and ulcers, management has both therapeutic and limb-saving applications. Correction of superficial venous reflux using endovenous ablation significantly improves healing of venous ulcers when combined with compression therapy, showing that treatment is not only cosmetic but also essential for tissue healing [31]. In patients with severe perforator incompetence contributing to ulcers, surgical methods such as subfascial endoscopic perforator surgery are applied to reduce venous pressure in the ulcer area and prevent recurrence [32].

QUALITY OF LIFE AND LONG-TERM CARE

Thus, applications of varicose vein management extend from symptom relief and cosmetic improvement to prevention of complications, healing of chronic ulcers, improvement of mobility, and restoration of quality of life through long-term care and follow-up.

ADVANTAGES OF MODERN TREATMENT METHODS

Modern management of varicose veins has shifted from invasive surgery to minimally invasive endovenous procedures. These newer methods offer multiple advantages over traditional techniques.

One of the major advantages is reduced invasiveness. Endovenous laser and radiofrequency ablation close veins from inside without removing them, avoiding large incisions and tissue trauma [33]. This leads to less postoperative pain, bruising, and bleeding compared to stripping surgery.

Another major advantage is faster recovery. Most endovenous procedures are performed under local anesthesia on an outpatient basis. Patients can walk immediately after the procedure and usually return to work within 1–3 days, whereas surgical stripping often requires hospital stay and longer rest [34].

Cosmetic outcome is also better with modern techniques. Because there are no large scars, cosmetic satisfaction is higher. Foam sclerotherapy and glue closure leave minimal marks on the skin [35].

Safety profile is improved. Complications such as wound infection, nerve injury, and hematoma are much less frequent with endovenous therapy than with surgery [36]. Newer techniques such as mechanochemical ablation and glue closure avoid thermal damage and therefore reduce the risk of nerve burns and skin injury [37].

Effectiveness is comparable or superior to surgery. Long-term studies show closure rates of more than 90% with laser and radiofrequency ablation, similar to or better than stripping [38]. Patient satisfaction and quality-of-life scores improve significantly after endovenous treatment.

Another advantage is repeatability. If recurrence occurs, endovenous techniques can be easily repeated or combined with sclerotherapy, whereas repeated surgery is more complex and risky [39].

COMPARISON WITH EXISTING (TRADITIONAL) METHODS

Surgical Stripping Versus Endovenous Techniques

Traditional treatment of varicose veins mainly consisted of high ligation and stripping of the great saphenous vein. This procedure involved surgical exposure at the groin, ligation of the saphenofemoral junction, and physical removal of the vein. Although it reduced visible varicosities, it caused significant postoperative pain, bruising, hematoma formation, and nerve injury, particularly involving the saphenous and sural nerves. Many patients required hospital admission and prolonged rest before returning to work, indicating high physical and economic burden [40].

In contrast, endovenous laser and radiofrequency ablation close veins internally without removal. These techniques cause minimal tissue trauma, require only local anesthesia, and allow patients to walk immediately after the procedure. Studies comparing stripping with endovenous methods showed faster recovery and less postoperative pain with endovenous therapy, while long-term success rates were similar or better [43].

Recurrence After Surgery Versus Image-Guided Therapy

One major limitation of traditional surgery is recurrence of varicose veins. After stripping, new abnormal vessels often develop near the ligated junction, a process called neovascularization, which leads to recurrent disease. Long-term follow-up studies demonstrated high recurrence rates after surgery due to neovascularization and missed refluxing tributaries[41].

With modern ultrasound-guided treatment, reflux pathways are accurately mapped before intervention, allowing targeted therapy. Image-guided procedures reduce the chance of leaving untreated refluxing segments and therefore decrease recurrence rates [42].

Pain, Trauma, and Recovery Time

Traditional surgery requires large incisions and vein removal, leading to greater tissue trauma. This results in significant postoperative pain, bruising, wound infection, and longer recovery periods. Many patients experience delayed return to work and daily activities [40].

Endovenous techniques require only needle punctures or small incisions. Patients usually resume normal activity within a few days. Comparative studies show significantly shorter recovery time and less postoperative discomfort with radiofrequency and laser ablation compared with surgery [43].

Foam Sclerotherapy Versus Surgical Removal

Foam sclerotherapy is less invasive and does not require incisions or anesthesia. However, studies have shown that recurrence rates are higher with foam therapy, especially in large-diameter veins, when compared with surgical removal [44]. Surgery removes the vein completely, giving more durable anatomical correction but with higher morbidity.

Therefore, foam therapy is mainly preferred in elderly patients, recurrent disease, and those unfit for surgery, while surgery or endovenous ablation is used for major refluxing trunks.

Non-Thermal Techniques Versus Surgery

Mechanochemical ablation avoids both surgery and thermal injury. Compared with surgical stripping, it causes less pain, avoids hospital admission, and allows rapid return to work. Clinical studies have shown good occlusion rates with fewer complications than surgery [45].

Similarly, cyanoacrylate glue closure seals veins without heat or surgery and avoids tumescent anesthesia. Compared with surgical stripping, glue closure results in less pain and quicker recovery[45].

Compression Therapy Versus Definitive Surgical Treatment

Compression stockings have traditionally been used to manage varicose veins conservatively. They reduce venous pressure and improve symptoms, but they do not eliminate reflux. When compression is stopped, symptoms and progression return. Studies show that compression controls symptoms but cannot cure varicose veins, unlike surgery which removes refluxing veins[46].

Drug Therapy Versus Surgical Correction

Venoactive drugs reduce swelling, inflammation, and

pain but do not correct valve failure or venous reflux. Therefore, they cannot provide permanent cure. Drug therapy is supportive, while surgery and endovenous methods provide definitive anatomical correction of disease [47].

OVERALL INTERPRETATION

Traditional surgery provides anatomical removal of veins but is associated with high trauma, pain, long recovery, and recurrence due to neovascularization [40,41]. Modern endovenous and non-thermal methods offer similar or better long-term success with fewer complications and faster recovery by using image-guided, targeted therapy [42–45]. Conservative methods such as compression and drugs provide symptom control but cannot correct the underlying disease [46,47].

CONCLUSION

Varicose veins are a common and progressive vascular disorder caused mainly by venous valve incompetence and venous hypertension. Although often regarded as a cosmetic problem, they can lead to serious complications such as edema, skin changes, thrombosis, bleeding, and venous ulcers, greatly affecting quality of life.

Understanding the anatomy, hemodynamics, and mechanisms of venous reflux is essential for accurate diagnosis and effective treatment. Advances in duplex ultrasound have transformed varicose vein management from blind surgical removal to targeted, image-guided therapy.

Modern treatment has shifted toward minimally invasive endovenous techniques such as laser ablation, radiofrequency ablation, foam sclerotherapy, mechanochemical ablation, and cyanoacrylate glue closure. These methods provide excellent clinical outcomes with fewer complications, faster recovery, and better cosmetic results than traditional surgery.

Lifestyle modification, compression therapy, and patient education remain important for prevention and long-term control. Early diagnosis and appropriate treatment can prevent progression to chronic venous insufficiency and improve both physical and psychological well-being. Overall, integrated use of modern diagnostic and therapeutic strategies offers the best approach for effective management of varicose vein disease.

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