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Endovenous Laser Ablation of Varicose Veins: A Comprehensive Review of a Minimally Invasive Treatment Approach

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ABSTRACT

Varicose veins, a prevalent venous disorder affecting superficial veins in the lower extremities, pose both cosmetic and medical concerns. Traditionally, managing insufficient great saphenous veins (GSV) involved saphenectomy, but with advancements in medical science, innovative and minimally invasive techniques like Endovenous Laser Ablation (EVLA) have gained popularity. EVLA offers several advantages over surgery, including reduced morbidity, decreased post-operative pain, shorter recovery time, and outpatient possibilities. This article provides an evidence-based overview of EVLA's role in treating saphenous vein reflux, highlighting its benefits and impact on venous function and patient satisfaction. International guidelines now consider endothermal ablation techniques like EVLA as the treatment of choice for symptomatic truncal vein reflux.

Keywords: Varicose Veins; Chronic Venous Insufficiency; Endovenous Laser Ablation; Endovenous Laser Treatment

Abbreviations: GSV: Great Saphenous Vein; SSV: Small Saphenous Vein; CVD: Chronic Venous Disease; EVLA: Endovenous Laser Ablation; RFA: Radiofrequency Ablation; AVVQ: Aberdeen Varicose Vein Questionnaire; VVSQ: Varicose Vein Symptom Questionnaire; AASV: Anterior Accessory Saphenous Vein; SFJ: Saphenofemoral Junction; EHIT: Endothermal Heat-Induced Thrombosis; DUS: Duplex Ultrasonography

Introduction

Varicose veins are a common venous disorder characterized by the abnormal dilation and tortuosity of superficial veins, primarily in the lower extremities. The condition arises due to a combination of genetic predisposition, venous hypertension, and weakened vein walls and valves. Varicose veins not only pose a cosmetic concern but can also lead to discomfort, pain, swelling, and complications such as venous ulcers. The global prevalence of varicose veins was estimated to be approximately 20% among adults [1]. Reflux in the great saphenous vein (GSV) is the most common cause of varicose veins and chronic venous disease (CVD) [2].

Traditionally, the treatment for an insufficient great saphenous vein (GSV) involves ligating the saphenofemoral junction and performing great saphenous vein stripping, either total or partial. This procedure, known as saphenectomy, aims to eliminate the diseased vein and redirect venous blood flow to healthier pathways, providing relief from symptoms and improving overall venous function. Additionally, if necessary, the small saphenous vein (SSV) may also be addressed during the treatment process. The combination of ligating the saphenofemoral junction and performing saphenectomy has been a classic approach to managing the diseased great saphenous vein.

With advancements in medical science, several innovative and minimally invasive techniques have emerged for the treatment of diseased saphenous veins, complementing the traditional surgical approaches mentioned previously. One such technique is Endovenous Laser Ablation (EVLA), which has gained significant popularity in re-

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cent years. The first documented case of endovenous laser ablation was described by Bonè [3] in 1999, and since then, this treatment modality has rapidly expanded for the management of saphenous vein reflux. Endovenous laser ablation offers several advantages over traditional surgical methods. Firstly, it is associated with decreased morbidity, making it a more attractive option for patients. The minimally invasive nature of the procedure leads to reduced post-operative pain, shorter recovery time, and fewer complications. Additionally, another significant advantage of endovenous laser ablation is the possibility of performing the procedure on an outpatient basis. According to some international guidelines, endothermal ablation techniques, including endovenous laser ablation (EVLA) and radiofrequency ablation (RFA), are now considered the treatment of choice for symptomatic truncal vein reflux [4,5].

Clinical Evaluation

Chronic venous disease is characterized by reflux, primarily caused by valvular incompetence or obstruction. Diagnostic imaging, such as duplex ultrasound, is essential for visualizing the extent of reflux and planning appropriate treatment. The most used classification for chronic venous disease is the CEAP classification, which encompasses clinical, etiological, anatomical, and pathophysiological factors. Among these, the clinical classification is most frequently utilized to assess the severity of the disease. It ranges from no visible signs of venous disease (C0), then progresses to telangiectasia or reticular veins (C1), visible varicose veins (C2), edema (C3), skin changes (C4a-b), healed venous ulcers (C5), and most severe, active venous ulcers (C6) [6]. Symptoms of chronic venous disease include heavy, tired legs, itching, cramps, swelling, pain, eczema, and healed or active venous ulcers. As the disease is chronic, symptoms tend to worsen over time.

Scoring systems have been developed to evaluate objective findings and the impact of the disease on the quality of life. These systems allow for comparing symptoms before and after procedures. The Venous Clinical Severity Score (VCSS) includes physical findings, the patient's perception of pain related to those findings, and whether compression therapy is being used [7]. In addition, there are other scoring systems, such as VEINES-QOL/Sym, Aberdeen Varicose Vein Questionnaire (AVVQ), and Varicose Vein Symptom Questionnaire (VVSymQ), that provide further insight into the patient's experience and its impact on their quality of life [8-10]. Treatment is recommended for patients who experience relevant symptoms, exhibit clinical signs of chronic venous disease, and demonstrate reflux in a significant vein segment, often involving the great and/or small saphenous vein. Patients presenting signs and symptoms of chronic venous disease related to an incompetent saphenous vein are candidates for treatment.

Endovenous Thermal Ablation / Mechanism of Action

The mechanism of treating saphenous vein reflux using endolaser is based on endovenous laser thermal ablation. This procedure involves inserting a catheter with a special optical fiber into the affected saphenous vein. The optical fiber is connected to a laser device that emits energy in the form of light. When activated, the laser generates a specific wavelength that is absorbed by the chromophore present in the saphenous vein wall.

The laser energy is converted into heat, leading to selective photothermal lysis of the saphenous vein. The laser light is absorbed by the hemoglobin in the blood, resulting in controlled heating of the vein wall. This heating induces coagulative necrosis, damaging the endothelial cells and fibroblasts present in the saphenous vein. The thermal injury resulting from endolaser treatment causes closure of the treated saphenous vein. The vein collapses and is gradually reabsorbed by the body over time. Simultaneously, fibrosis of the treated vein occurs, leading to its sealing and the interruption of retrograde blood flow. The desired outcome is the permanent occlusion of the affected saphenous vein, with redistribution of blood flow to adjacent healthy veins. This relieves symptoms associated with venous reflux and promotes both aesthetic and functional improvement of varicose veins.

The procedure has evolved over time, with different laser wavelengths being used, ranging from 810 nm to 1920 nm. The choice of wavelength is crucial as it determines the target of the laser energy. Shorter wavelengths, ranging from 810 nm to 1064 nm, predominantly are absorbed by hemoglobin found within the red blood cell. In contrast, longer wavelengths, 1320 nm and longer, primarily target the vein wall, bypassing hemoglobin absorption and allowing for more intense absorption of laser energy by water and myoglobin in the vein wall [11]. Studies have shown that longer wavelengths with lower power settings can lead to decreased pain and bruising [12]. Furthermore, there have been reports of a decreased need for analgesics and a lower incidence of secondary paresthesia associated with the procedure [13].

The efficacy of EVLA is also influenced by the linear endovenous energy density (LEED), which measures the amount of energy delivered over a specific distance (J/cm); this measurement has become a reference for calculations of energy delivery. Subsequent studies suggest that the optimal range for safety and efficacy is typically between 60 and 80 J/cm, although this range may be lower, around 30 to 50 J/cm, for lasers with higher wavelengths. It's important to note that the appropriate LEED can vary depending on factors such as the laser wavelength, fiber type, and manufacturer [14-16].

Types of Fiber

In addition to the wavelength, the type of fiber used in EVLA plays a crucial role in reducing post-ablation pain and hematoma. Initially, uncovered-tip fibers were commonly used, which emitted a single focused beam forward. However, it was observed that direct contact between the fiber tip and the vein wall could lead to unintentional perforations and related symptoms [17,18]. To address this concern, new fiber designs were developed. Coated or "jacketed" fibers were

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introduced, featuring a protective coating around the fiber tip to minimize direct contact with the vein wall and decrease the likelihood of perforations. These coated-tip fibers aimed to enhance safety and reduce complications during the procedure [19].

Another type of fiber used in EVLA is the radial fiber. These fibers disperse the emitted energy by directing the laser beam around the entire circumference of the fiber tip. By doing so, radial fibers cause less trauma to the vessel wall compared to uncovered-tip fibers, resulting in a lower risk of perforations and reduced tissue damage. Studies have shown that radial fibers are associated with fewer perforations, leading to decreased postoperative pain and hematoma [20,21]. Additionally, there are double radial fibers available, which emit two beams directed in all directions. These fibers provide further dispersion of energy and have the potential to improve outcomes, but further research is needed to fully understand their advantages and benefits [22]. It's worth noting that the Tulip fiber is another notable design used in EVLA. The Tulip fiber is a bare fiber with a tube at its distal end, incorporating self-expandable blades. This design allows for intraluminal centering of the fiber tip, avoiding direct contact between the fiber tip and the vein wall. The Tulip fiber's unique characteristics, such as a wider light divergence angle, enable circumferential vein wall illumination and have been shown to reduce vein wall perforations and improve postoperative outcomes such as pain and bruising [23,24].

Laser Ablation Technique

EVLA is a minimally invasive procedure performed on an outpatient basis under local anesthesia to treat refluxing truncal veins, primarily the great saphenous vein (GSV), as well as other junctional tributaries. The procedure involves accessing the vein below the knee where its diameter is larger, and the risk of thermal injury to the saphenous nerve is lower. The patient is positioned in reverse Trendelenburg to ensure a blood-filled vein and facilitate the puncture. The cannulation of incompetent saphenous trunks is performed under ultrasound guidance using a standardized approach. After gaining access, a J-tip guidewire is inserted into the vein lumen, followed by the insertion of an introducer sheath and dilator over the wire. The guidewire and dilator are then removed, leaving the sheath in place. A laser fiber, typically with a diameter of 600 μm, is passed through the sheath and advanced to the desired position, usually 2-2.5 cm from the saphenofemoral junction (SFJ). This treatment landmark relative to the SFJ has been most extensively reported and associated with a low risk for endothermal heat-induced thrombosis (EHIT) [25,26]. To prevent recurrent reflux from the saphenofemoral junction (SFJ) and particularly from the anterior accessory saphenous vein (AASV), a technique known as laser crossectomy or flush EVLA has been proposed. In this technique, the fiber is precisely positioned at the SFJ prior to commencing the ablation [27].

Tumescent anesthesia is crucial for achieving optimal results. It is administered under ultrasound guidance, either through multiple syringe hand injections or with a foot pump system around the vein within the perivenous sheath using an 18-G needle. The tumescent solution consists of 445 mL of crystalloid, 50 mL of 1% lidocaine plus 1:100,000 adrenaline, and 5 mL of 8.4% sodium bicarbonate, lidocaine, and sodium bicarbonate, with the latter offering a reduction in the burning sensation associated with injection, and the addition of adrenaline extends the anesthetic effect and induces vasoconstriction [28]. The administration of tumescent anesthesia ensures external compression of the vein, close contact between the vein wall and the laser fiber tip within the lumen, and effective transmission of laser energy to the vein wall. Additionally, it helps isolate the vein from perivenous structures and reduces the risk of skin burns.

After administering the anesthesia, the patient is placed in the Trendelenburg position to facilitate vein emptying. The laser parameters are then adjusted to deliver an appropriate LEED (energy delivery) ranging from 60 to 80 J/cm or around 30 to 50 J/cm for lasers with higher wavelengths. Throughout the procedure, the fiber is slowly pulled back while closely monitoring the treatment energy output. After the catheter is completely removed, a completion duplex ultrasonography (DUS) is performed to confirm the successful ablation of the superficial vein and to verify the absence of deep vein thrombosis. Following the procedure, a compression stocking is applied. The use of compression therapy after great saphenous ablation remains a topic of controversy. However, during the initial week, the use of compression stockings has demonstrated advantages in reducing pain and edema when compared to those who do not utilize them [29]. Despite the controversy, most surgeons still recommend and implement this method. A study conducted by Duarte et al., focusing on the use of compression therapy after thermal ablation of the great saphenous vein in Brazil, found that most Brazilian vascular surgeons incorporate class II compression stockings into their post-ablation protocol [30].

Ablation of the Small Saphenous Vein

Endovenous laser ablation (EVLA) is a safe and effective technique for treating insufficiency of the small saphenous vein (SSV), even near the nerve. Results observed with laser treatment of the SSV tend to be superior to those of surgery [31]. The surgical procedure in this region is challenging due to significant anatomical variations at the saphenopopliteal junction. To perform EVLA on the SSV, percutaneous access is achieved using a micropuncture set guided by ultrasound. The puncture of the vein can be made at the level of the lower third of the vein, which is usually the most caudal level of truncal reflux [32,33]. The appropriate distance from the saphenopopliteal junction for treatment may vary, but guidance by ultrasound helps ensure safety and efficacy. While there is a general guideline recommending a starting treatment distance of approximately 2-2.5 cm from the saphenopopliteal junction (SPJ), some authors suggest a different approach. They propose remaining superficial to the muscular fascia to completely avoid deeper neurovascular structures [34].

This variation in technique aims to enhance safety during the procedure and minimize the risk of potential complications.

The rest of the procedure follows the same steps as described for GSV ablation. In a study conducted by de Souza et al., patients who underwent endovenous laser ablation (EVLA) for the treatment of the small saphenous vein (SSV) demonstrated a reduction in the diameter of the treated SSV during the early postoperative period, as well as an improvement in the clinical severity score of venous disease (VCSS) [35]. Roopram, et al. [32], in a comparative study, found that patients who underwent the EVLA procedure for the treatment of small saphenous vein reflux experienced lower levels of pain in the early postoperative period compared to those who underwent surgery. Patients who had surgery had a higher incidence of nerve injury-related complications at two weeks post-treatment. Based on a meta-analysis of 49 observational studies (including five randomized controlled trials), the occlusion rates of various interventions for SSV incompetence were reported as follows: EVLA at 98.5%, RFA at 97.1%, ultrasound-guided foam sclerotherapy (UGFS) at 63.6%, and open SSV surgery at 58% [36].

Management of Pathologic Perforator Vein

The role and management of perforating vein (PV) incompetence are still controversial. PVs can act as a primary source of reflux or can arise because of overall venous dysfunction and chronic venous insufficiency (CVI). During the early stages of chronic venous disease (C2 and C3), PVs can function as a re-entry point for superficial venous incompetence, exhibiting an inward flow of fluid upon release of compression. In such cases, treatment of the truncal and tributary reflux veins is often sufficient. The treatment of PV incompetence has been specifically studied in relation to leg venous ulcers and varicose vein recurrence. A pathological perforating vein can be treated through thermal ablation with laser and tumescent local anesthesia. Direct cannulation of PVs is often challenging due to the tortuosity of the vein and the condition of the overlying diseased or ulcerated skin. Indirect access can be obtained through adjacent healthy skin areas or an adjacent vein. The amount of energy used varies, but there is a trend towards higher energy levels. The entire treatment of the perforating vein should be performed with muscular fascia as the depth limit. Postprocedural management remains like other thermal ablation procedures. The closure rate after EVLA is lower for PVs (60% to 80%) than for truncal veins (>90% for EVLA) [37]. As a proportion of ablated PVs may recanalize over time, routine early ultrasound surveillance and reintervention are recommended, especially in patients with leg venous ulcers (VLU). Complication rates are generally low and comparable to ablation in other venous segments [5].

Complications

In the literature, the rate of complications after EVLA is low. Deep vein thrombosis (DVT) and endothermal heat-induced thrombosis (EHIT) are two important complications that have been discussed in the literature. It is common practice to perform postoperative ultrasound surveillance of the treated vein(s) one to four weeks after the procedure to assess the immediate treatment outcome and ensure the absence of postoperative DVT. In the case of DVT, anticoagulation therapy must be started. DVT is a rare but significant complication of endothermal treatment, with a reported incidence ranging from 0 to 5.7% 38. Proper positioning of the laser tip, approximately 2-2.5 centimeters below the saphenofemoral junction (SFJ), is crucial to reduce the risk of thrombus formation.

EHIT is a specific form of thrombotic complication observed after EVLA. It occurs due to thermomechanical damage and coagulation effects, resulting in thrombus formation at the SFJ or saphenopopliteal junction (SPJ). The clinical significance of EHIT remains unclear, and the need for pharmacological thromboprophylaxis is uncertain. EHIT thrombus can often be managed conservatively with ultrasound observation alone or a short course of low molecular weight heparin (LMWH). In rare cases where EHIT thrombus occludes the common femoral vein, therapeutic anticoagulation is recommended [26,38]. Pulmonary embolism has only been described in a few reports [39,40]. Routine prescription of prophylactic anticoagulants is not needed, as the risk of venous thromboembolism (VTE) is very low (0–2%). However, patients' risk should be stratified; if a high risk of VTE is present (age > 60, obesity, immobility, oral contraceptive or hormone replacement therapy use, cancer, history of superficial or deep venous thrombosis, or a known severe thrombophilia), one should consider prophylactic use of LMWH, starting at the day of the procedure until 10-14 days after. Risk assessment should be based on local, hospital, or national guidelines, or the Caprini's assessment method can be applied [41].

Nerve injury is a potential complication following thermal ablation procedures, particularly when treating the GSV or SSV. The proximity between the nerve and the targeted vein (GSV or SSV) determines the risk of neurological damage, which has been observed in 0% to 22% of cases [42]. To minimize the risk of saphenous nerve injury, several measures can be taken. These include performing the laser fiber insertion and ablation as proximally as possible, using lower energy levels in high-risk areas, and injecting an adequate volume of tumescent solution. The systematic use of ultrasound during the injection of the tumescent solution allows for visualization of the nerve and its separation from the treated vein. Duarte and Rodrigues Filho [43] have shown that in cases of patients with total insufficiency of the great saphenous vein, one option would be to combine endovenous laser treatment with foam sclerotherapy using polidocanol. In general, peripheral nerve injuries following thermal ablation manifest as mild symptoms that typically resolve spontaneously within three to six months. Superficial thrombophlebitis can be a potential complication, with reported incidence rates ranging from 0 to 25% 38, particularly in patients with large side branches of the varicose vein being treated. The occurrence of superficial thrombophlebitis

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typically peaks between 4 to 7 days after the procedure and usually resolves within approximately one week.

Skin burns are a possible complication of EVLA, although their incidence is extremely low (<1%) [44]. The heat generated during the thermal ablation of a vein can dissipate and reach the skin, causing burns. Some authors include a minimum distance of 4 mm between the skin and the vein in the exclusion criteria for EVLA. This complication can be prevented by administering the tumescent solution, which creates a barrier between the vein and the skin, effectively cooling the surrounding tissues. Hyperpigmentation along the length of the treated vein is a rare occurrence and usually occurs when the saphenous vein is in close proximity to the skin. It typically regresses within one year [44]. Hematomas and ecchymoses are common, and many authors do not consider them significant complications. Generally, they disappear within 15 days after the procedure and are related to the injection sites of tumescent anesthesia or perforation of the vein when using bare laser fibers. It is observed that higher wavelengths and continuous mode are associated with fewer ecchymoses [45,46]. Other rare complications reported in the literature include infection, arteriovenous fistula, and neovascularization [43,44,47]. Patients treated with EVLA experience less pain and swelling than patients treated surgically [48,49]. This results in quicker recovery and a faster return to normal activities [48,50,51].

Results

The occlusion of insufficient saphenous veins through endovascular laser treatment has shown a high rate of success. Various published studies consistently report excellent outcomes in achieving vein closure, with success rates ranging from 88% to 100% in the early post-procedure period [52-54]. Furthermore, these favorable results are maintained in long-term follow-up studies [55-57]. The International Endovenous Laser Working Group reported long-term durability in 1020 limbs with failure rates of 7.7% at one year, 5.4% at two years, and 0% at three years [58], emphasizing the durability of the treatment over an extended period. In a comprehensive 2018 review and meta-analysis conducted by Kheirelseid, et al. nine randomized controlled trials involving 2,185 legs were analyzed. Out of these, 1,352 legs were followed up for a period of five years, comparing RFA, EVLA, and ultrasound-guided foam sclerotherapy to conventional surgery. The study revealed that the recurrence rates in treated GSV did not significantly differ between surgery and EVLA (33.3% vs. 36.6%) [59] (Figures 1-4).

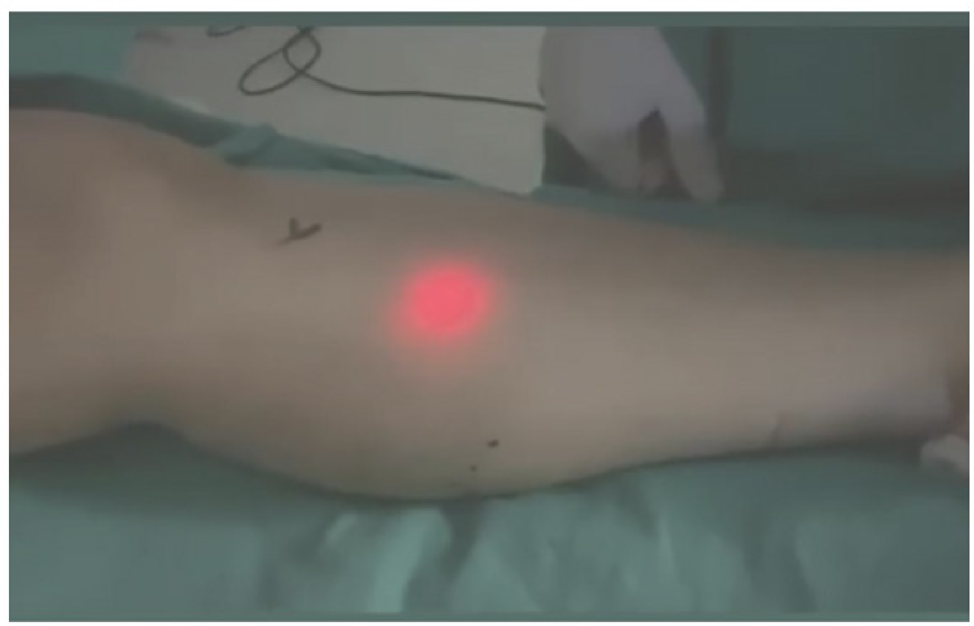

Figure 1: Endovenous Laser Ablation (EVLA). Laser fiber inside the great saphenous vein (GSV).

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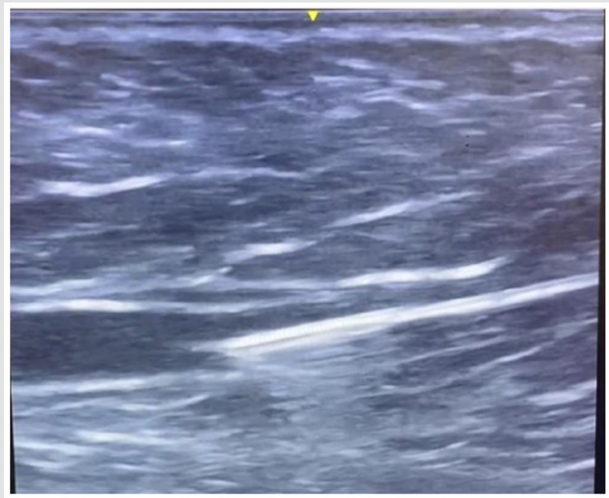

Figure 2: Duplex ultrasonography image of the laser fiber moving towards the saphenofemoral junction.

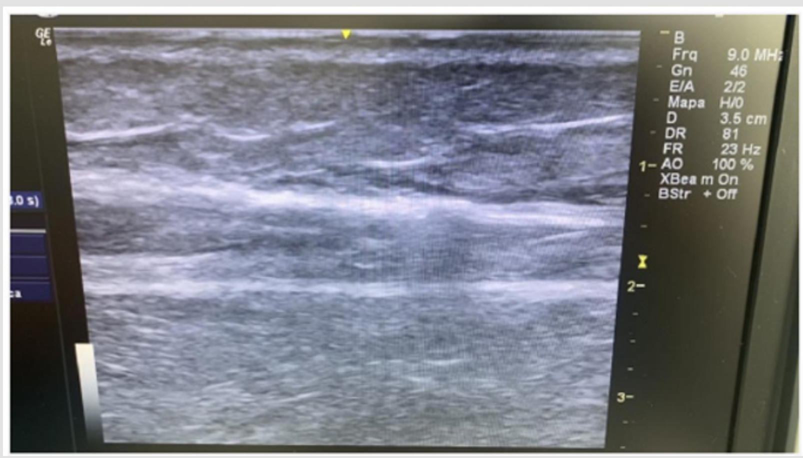

Figure 3: Image of the great saphenous vein immediately after laser ablation.

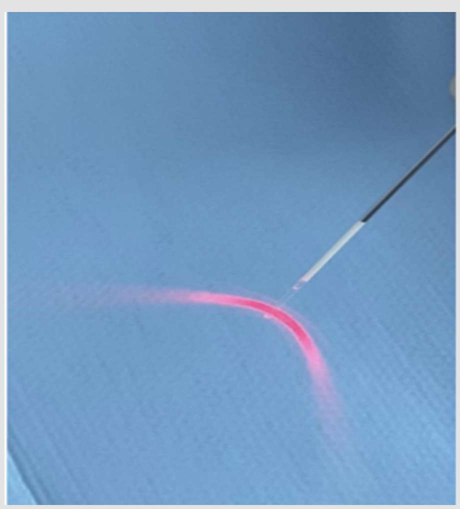

Figure 4: Radial Fiber.

Cost Considerations

The cost-effectiveness of EVLA compared to conventional surgery for varicose veins has been a subject of interest. Multiple studies, including those by Marsden, et al. [60] and Gohel, et al. [61], have consistently demonstrated that EVLA offers favorable cost-effectiveness compared to traditional surgical approaches. While reimbursement for varicose vein treatment may not be guaranteed in some countries, the cost-effectiveness of EVLA remains an important consideration. In addition to direct procedural costs, several factors should be considered when evaluating the overall cost-effectiveness of EVLA. These include treatment failures, adjunctive procedures, and the speed of recovery in the treatment of varicose veins [60,61].

Moreover, the shift towards outpatient endovenous procedures has contributed to cost savings. Outpatient surgeries offer advantages such as reduced personnel and hospital costs, patient-centered care, and lower risks of hospital-acquired infections [61-63]. These factors contribute to the cost-effectiveness of EVLA by minimizing expenses associated with hospital stays and post-operative care. It is also crucial to consider the long-term clinical success of the treatment when assessing its cost-effectiveness. Studies have shown that EVLA yields comparable clinical outcomes to other treatments, such as radiofrequency ablation and surgical stripping, further supporting its cost-effectiveness [64,65].

Quality of Life

The most pivotal outcome of varicose vein treatment should be the clinical outcome that is most important to patients. Several randomized controlled trials have compared the impact of EVLA and surgery on quality-of-life scores, and the results have shown no significant differences between the two treatment approaches. For example, a study by Darwood et al. in 2008 found similar improvements in quality-of-life assessments (AVVQ) between the surgery and EVLA groups at three months, with no differences in pain scores [66]. Another study by Brittenden et al. in 2014 reported comparable quality of life scores between the surgery and EVLA groups at both six weeks and six months [67].

Long-term follow-up studies have also shown that patients treated with endovenous interventions, including EVLA, experience equal or better quality of life compared to traditional surgical approaches. Carradice, et al. [68] conducted a study involving 280 patients with GSV reflux and found that EVLA resulted in preserved quality of life, while the surgical group experienced a significant deterioration in early quality of life. Complications were rare in both groups, but the surgical group had higher rates of hematoma, infection, and sensory disturbance [68].

According to a meta-analysis by He et al. in 2017, endovenous laser ablation (EVLA) and radiofrequency ablation (RFA) were found to have similar quality of life (QoL) outcomes at one and 12 months of follow-up [69]. Additionally, a study by Brittenden, et al. [70] in 2019 reported that five years after treatment, QoL was better with EVLA compared to ultrasound-guided foam sclerotherapy (UGFS) [70].

Surveillance

After endovenous procedures, it is common practice to conduct surveillance by performing duplex ultrasonography (DUS) on the treated vein(s) within one to four weeks after the procedure. This follow-up assessment aims to evaluate the immediate goal of the intervention and ensure the absence of post-operative DVT. Additionally, duplex ultrasonography is used to screen for the presence of EHIT. The clinical significance of EHIT, as well as the development of screening protocols and appropriate treatment strategies, continues to be subjects of ongoing debate [71]. For most patients, repeat DUS assessment is required only for suspected clinical recurrence [5].

Conclusion

In conclusion, EVLA has emerged as a highly effective and minimally invasive technique for the treatment of the (GSV) and (SSV). It offers several advantages over traditional surgical methods, such as reduced post-operative pain, faster recovery time, and improved patient satisfaction. The success rates of EVLA in achieving vein occlusion have been consistently high, with minimal complications reported. Furthermore, studies have consistently shown that EVLA can provide comparable or even better quality of life outcomes compared to other treatment options, such as surgical stripping or foam sclerotherapy. The availability of EVLA in an outpatient setting further enhances its appeal, allowing for cost savings, flexible scheduling, and a lower risk of hospital-acquired infections. The long-term durability of EVLA has also been demonstrated, with low recurrence rates reported in follow-up studies. However, it is important to note that individual patient characteristics and vein morphology may influence the selection of the most suitable treatment approach. Overall, EVLA stands as a promising and beneficial option for patients with varicose veins, offering effective treatment with improved patient experiences and outcomes. As technology and research continue to advance, EVLA's role in varicose vein treatment is likely to further solidify its position as a leading and preferred treatment option.

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