

ENDOVENOUS LASER ABLATION: AN IN-DEPTH OVERVIEW

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Abstract: Endovenous laser ablation (EVLA) has revolutionized the management of varicose veins by offering a minimally invasive alternative to traditional surgical stripping. As a mainstay treatment for superficial venous insufficiency, EVLA provides high success rates, faster recovery, and improved patient satisfaction. This comprehensive review presents an in-depth analysis of EVLA, covering its historical evolution, technical principles, patient selection, procedural steps, outcomes, complications, comparative effectiveness, and future directions. While endovenous laser therapy is widely accepted as a first-line option in many clinical settings, understanding its intricacies—from device specifics to post-procedural care—is critical for optimizing results and minimizing risks.

1. Introduction

Varicose veins, a manifestation of chronic venous disease (CVD), affect a significant portion of the adult population worldwide. Characterized by dilated, tortuous, and visible superficial veins, they result from valvular incompetence and venous hypertension. Although traditionally regarded as a cosmetic concern, varicose veins can lead to substantial morbidity, including lower-extremity pain, edema, skin changes, and ulcerations in more advanced disease.

Prior to the introduction of minimally invasive procedures, the mainstay of therapy was surgical stripping of the incompetent saphenous vein. While effective, surgical stripping carried several disadvantages such as significant postoperative pain, extensive bruising, potential nerve injury, and prolonged recovery. In the past two decades, endovenous techniques—most notably endovenous laser ablation (EVLA) and radiofrequency ablation (RFA)—have dramatically altered the therapeutic landscape, offering high efficacy rates with fewer complications and shorter downtime.

Endovenous laser ablation (EVLA) employs laser energy delivered into a target vein via a fiber, causing irreversible thermal damage to the venous endothelium and subsequent vein closure. Since its introduction in the early 2000s, it has been refined to maximize vein closure rates while minimizing adverse effects. Growing clinical experience, improved device technology, and a robust evidence base have established EVLA as a cornerstone treatment for saphenous vein incompetence.

This review provides a comprehensive examination of EVLA, beginning with its historical context and the pathophysiological foundation that supports its use. Subsequent sections discuss patient selection, preoperative evaluation, technical considerations, outcome data, potential complications, comparisons with other treatments, and future innovations in endovenous laser therapy. By synthesizing the current body of knowledge, this article aims to guide healthcare professionals toward best practices and optimal patient outcomes.

2. Historical Overview

Historically, the standard approach for eliminating varicose veins was surgical ligation and stripping, initially popularized in the early 20th century. Although proven effective for treating great saphenous vein (GSV) reflux, surgical methods came with inherent drawbacks: anesthesia risks, incisional pain, nerve damage, and postoperative complications including hematomas and lengthy convalescence.

Two pivotal events shifted this paradigm:

1. Introduction of Ultrasound Imaging: Duplex ultrasound, combining B-mode imaging with Doppler flow evaluation, enabled precise mapping of venous anatomy and reflux segments. This advancement allowed for targeted treatment, reducing the need for extensive dissection and improving outcomes.

2. Development of Endovenous Techniques: In the late 1990s and early 2000s, technological innovations led to the adaptation of thermal ablation methods—first radiofrequency ablation (RFA) and, shortly thereafter, endovenous laser ablation (EVLA). Early feasibility studies demonstrated that local thermal damage to the incompetent vein could achieve results comparable (or superior) to surgery.

In 2001, the U.S. Food and Drug Administration (FDA) approved the first endovenous laser ablation system for treating saphenous vein reflux. Over the next decade, continuous refinements in laser wavelengths (810 nm, 940 nm, 980 nm, 1,320 nm, 1,470 nm, 1,940 nm, etc.), fiber designs (bare-tip fibers to radial fibers), and procedural techniques improved efficacy and safety. Today, EVLA is one of the most widely performed procedures for lower extremity varicose veins, often combined with adjunctive therapies such as foam sclerotherapy or microphlebectomy to address tributaries and residual varicosities.

3. Pathophysiology and Rationale for EVLA

Chronic venous disease arises from incompetent venous valves leading to blood reflux and increased venous pressures in the superficial system. Over time, venous hypertension causes dilation of superficial veins, ultimately forming varicose veins that can progress to edema, skin changes, and ulcerations.

Mechanism of Action

Endovenous laser ablation addresses the root cause of varicose veins (i.e., valvular insufficiency and reflux) by thermally injuring the vessel from within:

1. Tumescant Anesthesia: Before energy delivery, perivenous tumescant anesthesia (a dilute anesthetic solution) is injected around the target vein. This technique compresses the vein, creates a heat sink protecting surrounding tissues (nerve, skin, muscle), and provides analgesia.

2. **Laser Energy:** A laser fiber is threaded into the incompetent segment under ultrasound guidance. When activated, the laser produces thermal energy absorbed by blood and the vein wall, reaching temperatures that denature proteins and induce wall collapse.

3. **Vein Closure:** The immediate response is endothelial damage, followed by fibrotic occlusion of the treated vein. The incompetent vein is thus removed from systemic circulation, rerouting blood flow into healthy deep and superficial veins.

4. **Clinical Effects:** Symptom relief often occurs rapidly as venous hypertension diminishes. Over time, the body resorbs the occluded vein. Aesthetically, patients may notice a reduction in bulging varicose veins.

Why Laser?

Endovenous laser ablation has a few proposed advantages over surgical stripping and other minimally invasive techniques:

- **Minimally Invasive:** Performed percutaneously with ultrasound guidance, reducing incision size, postoperative pain, and healing time.
- **Local Anesthesia:** The procedure typically uses local anesthesia, allowing patients to avoid general anesthesia risks.
- **High Success Rates:** Published data consistently show closure rates above 90% in short- and mid-term follow-up. Long-term studies also support its efficacy.
- **Rapid Recovery:** Patients frequently resume normal activities within days, reducing time off work and improving quality of life.

Thus, EVLA represents a targeted, patient-friendly treatment that addresses the fundamental pathophysiology of venous reflux.

4. Patient Selection and Indications

Primary Indication

The most common indication for endovenous laser ablation is symptomatic great saphenous vein (GSV) insufficiency. Other superficial veins, such as the small saphenous vein (SSV) or anterior accessory saphenous vein (AASV), are also frequently treated if they demonstrate significant reflux and symptomatic or cosmetic concerns.

Clinical Spectrum

Patients may present with a broad range of symptoms:

- Aching, heaviness, or throbbing in the legs
- Swelling around the ankles
- Night cramps
- Skin changes, hyperpigmentation, or eczema
- Venous ulcers in advanced cases (C5 or C6 in CEAP classification)
- Cosmetic dissatisfaction with visible varicose veins

Contraindications

While EVLA is well-tolerated, there are scenarios where it may be contraindicated or require caution:

- **Extensive Deep Vein Thrombosis (DVT):** Active DVT or severe post-thrombotic changes may preclude safe catheter placement and ablation.
- **Severe Peripheral Arterial Disease (PAD):** In rare situations, if arterial supply is compromised, addressing venous outflow may need careful evaluation.
- **Tortuous Vein Anatomy:** Extremely tortuous veins sometimes cannot accommodate laser fibers safely.
- **Superficial Veins Close to the Skin:** Ablation can risk thermal injury to the skin if the vein is within 5–10 mm of the surface and there is insufficient tumescent infiltration or protective tissue.
- **Inability to Ambulate:** Patients who cannot walk post-procedure or wear compression may face higher risk of thrombotic events.

In daily practice, the majority of patients with superficial venous reflux are candidates for EVLA, provided their venous anatomy and overall health permit the safe and effective use of this technique.

5. Preoperative Evaluation

Successful endovenous laser ablation relies on thorough planning and evaluation:

1. Comprehensive Clinical Assessment

- **Medical History:** Identify symptoms, risk factors (e.g., family history, multiple pregnancies, obesity, prolonged standing), and prior venous procedures.
- **Physical Examination:** Inspect the lower limbs for visible varicosities, skin changes, edema, and potential complications (e.g., stasis ulcers).

2. Duplex Ultrasound

- This is the gold standard diagnostic modality for mapping venous insufficiency.
- Evaluate saphenous vein diameters, reflux duration, saphenofemoral junction competency, and deep venous patency.
- Confirm that venous segments are amenable to ablation (i.e., accessible and not severely tortuous).

3. CEAP Classification

- Assign a clinical stage (C1–C6), etiology (primary vs. secondary), anatomical involvement (superficial, deep, perforating), and pathophysiology (reflux, obstruction).
- This classification helps assess disease severity and guides management.

4. Laboratory Tests

- Generally minimal. If sedation is planned, or if significant comorbidities exist, basic labs (complete blood count, coagulation profile) may be necessary.
- Evaluate for thrombophilia if the patient has a history of thrombotic events.

5. Patient Counseling

- Discuss the rationale for EVLA, procedural steps, potential risks, alternatives (compression-only therapy, radiofrequency ablation, foam sclerotherapy, or surgery), and expected outcomes.

- Patients should understand the need for compression stockings and follow-up ultrasounds.

6. Marking and Mapping

- On the day of the procedure, the interventionalist or surgeon may use ultrasound to mark the skin over varicose tributaries and confirm access points for vein cannulation.

Preoperative planning is paramount to achieving high technical success rates and minimizing complications, ensuring that the target veins are suitable for endovenous laser therapy.

6. Technical Aspects and Procedure Steps

Endovenous laser ablation usually takes place in an outpatient setting, often under local or tumescent anesthesia with mild sedation if needed.

1. Room Setup and Patient Positioning

- The patient is typically placed supine for GSV ablation. For small saphenous vein ablation, prone or lateral decubitus positioning may be used.

- Ultrasound equipment is placed on the contralateral side of the operator for convenience.

2. Ultrasound-Guided Vein Access

- Under sterile conditions and real-time ultrasound, the target vein is punctured, commonly below or at the knee for GSV.

- A guidewire is inserted, followed by an introducer sheath to facilitate fiber placement.

3. Fiber Placement and Confirmation

- The laser fiber is advanced to the desired tip position, usually 1–2 cm distal to the saphenofemoral junction (or saphenopopliteal junction for SSV).

- Ultrasound confirms precise positioning. The location is critical to avoid ablating near the deep system junction, which could increase the risk of deep vein thrombosis or saphenous nerve injury.

4. Tumescent Anesthesia

- A dilute solution of lidocaine, saline, and epinephrine is carefully infiltrated around the vein using ultrasound guidance.

- Goals:

- Compress the vein around the laser fiber.
- Provide a buffer zone to protect perivenous structures.
- Ensure local analgesia and reduce post-procedural pain.

5. Laser Parameters

- EVLA devices differ by wavelength (e.g., 810 nm, 940 nm, 980 nm, 1,320 nm, 1,470 nm, 1,940 nm) and fiber design (bare-tip vs. radial).

- Each wavelength has unique absorption characteristics in water vs. hemoglobin. Modern radial fibers distribute energy circumferentially, potentially lowering the risk of vein perforation.

- The operator selects the pullback speed and energy density (measured in Joules/cm or Joules/cm²) based on vein diameter and manufacturer recommendations.

6. Energy Delivery and Pullback

- Laser ablation is typically performed while slowly pulling back the fiber at a constant speed.
- The goal is to deliver sufficient thermal energy to irreversibly damage the endothelium without excessive heat that could injure adjacent tissue.
- The vein should demonstrate an immediate, clear closure under ultrasound (the “striping” or “coaptation” sign), though incomplete closure can still progress to full occlusion over time.

7. Completion and Immediate Assessment

- Upon finishing the laser ablation, ultrasound is used to evaluate the treated segment for any reflux or incomplete closure.
- Manual compression of the puncture site and application of a sterile dressing follow.

8. Application of Compression

- The patient is promptly fitted with compression stockings or bandages to reduce bruising, thrombosis risk, and discomfort.
- Most practitioners recommend wearing compression for at least 1–2 weeks post-procedure, although protocols vary.

The procedure duration typically ranges from 30 minutes to an hour, depending on the length of vein treated and the complexity of the anatomy.

7. Outcomes and Efficacy

Numerous studies and meta-analyses have documented the efficacy of endovenous laser ablation in eliminating saphenous reflux and improving clinical symptoms:

1. Vein Closure Rates

- Modern EVLA techniques consistently achieve >90% immediate closure rates for the GSV. At 1-year follow-up, closure rates typically remain high (85–95%).
- Long-term studies (5+ years) still demonstrate durable closure rates in the 80–90% range, although a small fraction of veins may recanalize over time.

2. Clinical Improvements

- Most patients report rapid relief of aching, heaviness, and swelling. Quality-of-life assessments show substantial improvement in validated measures (e.g., CIVIQ or AVVQ questionnaires).
- Complete resolution of visible varicose veins depends on whether concurrent procedures (microphlebectomy or sclerotherapy) are performed for tributaries.

3. Recurrence

- Recurrence can occur from neovascularization or recanalization, albeit at lower rates than post-surgical stripping.
- Maintaining follow-up ultrasound scans helps detect early recurrences that might be amenable to secondary interventions (additional sclerotherapy or repeated ablation).

4. Comparison with Surgery

- Randomized controlled trials have consistently shown that EVLA offers at least equivalent—often superior—efficacy compared to high ligation and stripping, with faster recovery, less pain, and fewer complications.

5. Comparison with Radiofrequency Ablation (RFA)

- EVLA and RFA share similarly high occlusion rates. Some evidence indicates that higher wavelengths and radial fibers in laser systems reduce postoperative pain, equating to or improving upon RFA outcomes.
- Operator preference and local availability often determine which method is employed.

Overall, endovenous laser ablation is regarded as a highly effective, durable treatment that has largely supplanted surgical stripping for saphenous reflux in many medical centers around the globe.

8. Complications and Their Management

Although EVLA is generally safe, no procedure is without risk. Familiarity with possible complications and their management is vital:

1. Periprocedural Pain

- The thermal effect and tumescent infiltration can cause discomfort, but most patients tolerate EVLA well under local anesthesia.
- Adequate tumescent anesthesia and judicious sedation minimize discomfort.

2. Bruising and Hematoma

- Bruising (ecchymosis) around the treated vein or puncture site is common, often mild, and resolves within 1–2 weeks.
- A localized hematoma can be managed conservatively with compression and heat; evacuation is rarely necessary.

3. Phlebitis

- Inflammation of treated or adjacent veins may present as redness, tenderness, and a palpable cord.
- Management includes NSAIDs, compression, and routine follow-up to exclude extension into deep veins.

4. Skin Burns or Nerve Injury

- Thermal injury to subcutaneous tissues or cutaneous nerves can result in numbness or painful dysesthesia.
- Proper tumescent injection and strict adherence to recommended energy parameters reduce this risk.

5. Deep Vein Thrombosis (DVT) and Pulmonary Embolism (PE)

- Although rare, extension of thrombus into the deep system is a serious concern. Risk factors include limited mobility, large vein diameters, or hypercoagulable states.
- Prophylactic measures (e.g., compression, early ambulation) and vigilant ultrasound follow-up can mitigate this complication.
- If DVT is detected, anticoagulation therapy is initiated according to established guidelines.

6. Recanalization

- The treated vein may reopen partially or completely. This typically occurs months to years post-procedure if energy delivery was insufficient or an underlying venous abnormality persists.
- Additional ablation or sclerotherapy is often effective for symptomatic recanalization.

7. Arteriovenous Fistula or Other Rare Events

○ Extremely rare occurrences include formation of an arteriovenous fistula or endovenous heat-induced thrombosis (EHIT) at the junction with deep veins. Thorough ultrasound monitoring post-procedure helps detect and address these promptly.

Overall, serious complications are infrequent. With proper technique, patient screening, and diligent follow-up, EVLA is a well-tolerated treatment with a favorable safety profile.

9. Comparison with Other Endovenous Techniques

While endovenous laser ablation stands as a primary option, other approaches offer alternative benefits or specific niche applications:

1. Radiofrequency Ablation (RFA)

- **Mechanism:** Radiofrequency energy heats the vein wall, similar in principle to EVLA.
- **Efficacy:** Comparable closure rates and long-term durability to EVLA.
- **Differences:** Some studies report slightly less post-procedural pain with RFA, whereas modern EVLA devices (radial fibers, 1,470 nm or 1,940 nm wavelengths) narrow that gap.
- **Availability:** RFA catheters can be more expensive; local institutional factors often influence technique selection.

2. Mechanochemical Ablation (MOCA)

- **Technique:** A rotating wire disrupts the endothelium while a sclerosant solution is injected, negating the need for thermal energy.
- **Advantages:** Often less painful, minimal tumescent anesthesia required.
- **Limitations:** Fewer long-term data are available; success rates can be slightly lower than thermal ablation.

3. Cyanoacrylate Closure

- **Procedure:** A proprietary medical “superglue” is delivered endovenously, sealing the vein segment without the need for tumescent anesthesia or external compression (in some protocols).
- **Advantages:** Potentially less post-procedural discomfort.
- **Challenges:** Higher material costs, possible foreign body reactions, limited long-term follow-up data.

4. Foam Sclerotherapy

- **Use:** Commonly used for smaller varicose veins, tributaries, or as an adjunct to EVLA or RFA.
- **Efficacy:** Lower closure rates for large-diameter saphenous veins, but highly effective for tributary veins or perforator incompetence.

Despite these alternatives, EVLA remains a mainstay in many practices for its proven track record, cost-effectiveness, and predictable outcomes.

10. Postoperative Care and Follow-Up

Effective postoperative management enhances clinical outcomes, patient comfort, and early detection of complications:

1. Compression Therapy

- Most practitioners advocate using graduated compression stockings (20–30 mmHg or higher) for 1–2 weeks post-procedure, although protocols vary.
- Compression mitigates bruising, reduces postoperative swelling, and promotes vein closure.

2. Ambulation

- Patients are typically encouraged to walk immediately after the procedure. Early ambulation lowers the risk of thrombotic events and aids circulation.
- Strenuous exercise can be postponed for a few days, but normal daily activities are usually resumed quickly.

3. Pain Management

- Mild analgesics such as NSAIDs or acetaminophen are sufficient for most patients.
- Tumescence anesthesia, if performed adequately, generally decreases the need for stronger medications.

4. Ultrasound Surveillance

- A follow-up duplex ultrasound is commonly done within a week to assess for closure and rule out EHIT (endovenous heat-induced thrombosis).
- Additional ultrasounds over the ensuing months track vein closure and identify any recanalization or new reflux.

5. Identification of Tributaries

- Residual bulging veins or incompetent tributaries may require adjunctive sclerotherapy or microphlebectomy. Staged treatments often yield the best cosmetic and symptomatic results.

6. Lifestyle and Preventive Measures

- Weight management, regular exercise, and leg elevation (when possible) aid long-term venous health.
- Patients with a family history or predisposition to venous disease might benefit from ongoing use of support stockings, especially during prolonged travel or standing.

By adhering to a structured post-ablation protocol, clinicians can significantly optimize patient satisfaction, reduce complication rates, and ensure durable vein closure.

11. Future Directions and Innovations

Endovenous laser ablation continues to evolve as manufacturers and clinicians refine the technology and technique:

1. Wavelength Advancements

- As laser fibers and generators improve, newer wavelengths (1,470 nm, 1,940 nm) are designed for better absorption by water in the vein wall, potentially allowing for more efficient ablation with less peri-venous damage.
- Future wavelengths may further minimize postoperative pain and bruising.

2. Fiber Design

○ Shift from bare-tip to radial or tulip-tip fibers has already improved energy distribution. Continuing innovations may reduce complications and further enhance vein closure rates.

3. Real-Time Feedback Systems

○ Some experimental systems incorporate intraluminal temperature or pressure sensors to guide energy delivery in a real-time closed-loop manner, optimizing ablation while preventing over-treatment.

4. Combination Therapies

○ Physicians increasingly employ a combination of EVLA with foam sclerotherapy or mechanochemical approaches for more comprehensive treatment of both truncal veins and secondary branches in a single session.

5. Artificial Intelligence in Ultrasound

○ Emerging AI-driven ultrasound software may automate vein mapping and ablation planning, improving accuracy and reducing operator variability.

6. Enhanced Patient Experience

○ Efforts to reduce patient discomfort, from improved tumescent anesthesia protocols to shorter procedure times, continue to be a focus of clinical research.

7. Cost-Effectiveness Studies

○ As new devices enter the market, further economic evaluations will be essential to determine the most cost-effective solutions for healthcare systems worldwide.

The underlying principle behind these innovations is consistent: to deliver safe, effective vein closure while reducing postoperative morbidity and enhancing patient convenience.

12. Conclusion

Endovenous laser ablation has emerged as a leading treatment modality for lower extremity varicose veins, driven by high closure rates, faster convalescence, and favorable long-term durability. It offers a minimally invasive alternative to conventional surgical stripping, substantially reducing patient discomfort and complication rates. Despite the technique's widespread adoption, success hinges on proper patient selection, meticulous ultrasonographic mapping, and a thorough understanding of laser physics and perivenous anesthesia techniques.

Current evidence consistently validates EVLA's efficacy, with closure rates exceeding 90% in most clinical series. The rare complications, such as thrombophlebitis or nerve injury, can be minimized through careful planning and protocol-based management. In the event of recanalization or incomplete closure, additional interventions—often less invasive—remain viable options.

Looking forward, advances in laser technology and procedural techniques promise to further improve patient outcomes. Higher wavelengths, innovative fiber designs, integrated imaging guidance, and combination therapies expand the treatment repertoire for chronic venous disease. As research continues, it is increasingly clear that endovenous laser ablation will remain central to varicose vein management, establishing itself as a gold standard for modern, patient-focused venous care.

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