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HIGH-WAVELENGTH ENDOVENOUS LASER ABLATION (≥1900 NM): A SYSTEMATIC REVIEW

Minavarkhujayev Ravshankhuja Raxmatkhuja ugli

Assistant of department General surgery №2, Tashkent Medical Academy

Phlebologist at the "VarikozOFF" Clinic

Abstract: Endovenous laser ablation (EVLA) has become a mainstay treatment for superficial venous insufficiency, traditionally employing laser wavelengths in the range of 810 nm to 1470 nm. In recent years, however, higher-wavelength laser systems (>1900 nm) have been introduced, with the goal of optimizing energy absorption in water and reducing collateral tissue damage. This systematic review evaluates the current literature on endovenous laser ablation with laser wavelengths above 1900 nm, focusing on efficacy, safety, and procedural outcomes. We discuss the theoretical advantages of higher-wavelength lasers, such as improved vein closure rates and reduced postoperative pain, alongside the existing clinical evidence. By synthesizing available data, this review aims to guide clinicians considering the adoption of 1900+ nm laser systems and to highlight areas where additional research is needed.

1. Introduction

Chronic venous disease (CVD) encompasses a wide spectrum of pathologies ranging from telangiectasias to large varicose veins and venous ulcers. Varicose veins, in particular, are a common manifestation of CVD, frequently resulting from valvular incompetence in the superficial venous system. For decades, the standard procedure to treat saphenous vein reflux was high ligation and vein stripping, which—though effective—posed drawbacks such as postoperative pain, bruising, and prolonged recovery.

The last two decades have witnessed a paradigm shift from open surgical methods to minimally invasive endovenous techniques. Endovenous thermal ablation (EVTA), encompassing radiofrequency ablation (RFA) and endovenous laser ablation (EVLA), has emerged as the first-line therapy in many practices. These methods yield consistently high rates of successful vein closure while allowing most patients to resume normal activities within days. EVLA, in particular, involves introducing a laser fiber into the incompetent vein under ultrasound guidance, administering thermal energy that damages the endothelium, leading to irreversible occlusion of the treated segment.

Historically, lower-wavelength lasers (810 nm, 940 nm, 980 nm) were used, followed by a shift to near-infrared wavelengths around 1470 nm, which are absorbed more by water than by hemoglobin. The aim of adjusting the wavelength was to direct the laser's thermal effect more specifically to the vein wall (rich in water) rather than to the blood, thereby increasing efficiency and potentially lowering postoperative discomfort. Recently, a new frontier of laser technology has emerged, featuring lasers that emit at wavelengths exceeding 1900 nm—commonly 1940 nm or 2010 nm. These higher wavelengths have an even stronger absorption profile in water, theoretically allowing the procedure to require less energy overall while offering targeted heating that spares surrounding tissues.

This systematic review focuses on endovenous laser ablation using systems with wavelengths greater than 1900 nm. Our goal is to assess the current state of evidence regarding efficacy, safety, clinical outcomes, and cost implications. We also explore potential benefits or drawbacks relative to more established wavelengths (e.g., 1470 nm) and identify areas where further research is needed to clarify the role of these high-wavelength lasers in modern venous practice.

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2. Background and Rationale for High-Wavelength Endovenous Lasers

Endovenous laser ablation harnesses thermal energy to achieve venous closure. The laser energy is delivered intraluminally, leading to endothelial damage, collagen contraction, and eventual fibrosis of the treated vein. A crucial factor in EVLA is the absorption spectrum of water versus hemoglobin. Earlier laser devices at 810–980 nm primarily targeted hemoglobin, requiring higher energy and risking more significant perivenous heat diffusion. This led to increased postoperative pain, bruising, and potential skin burns if the vein was superficial.

With the introduction of lasers at 1319 nm, 1470 nm, and 1560 nm, absorption in water improved, enabling more efficient treatment at lower power settings. These mid-range wavelengths (1000–1500 nm) became associated with reduced pain, bruising, and a lower incidence of ecchymosis. As technological development persisted, researchers and manufacturers investigated whether pushing the wavelength above 1900 nm would further enhance water absorption and reduce complications.

Key Theoretical Advantages of Wavelengths >1900 nm

1. **Higher Absorption in Water**: As wavelength increases above 1900 nm, the absorption coefficient in water escalates exponentially. This change can concentrate thermal damage more precisely within the vein wall, potentially reducing damage to adjacent tissues such as nerves and skin.
2. **Reduced Energy Requirement**: If energy is absorbed more efficiently by the vein wall, the total energy delivered (Joules/cm) can be lower for the same degree of vein closure. Lower energy might correspond to fewer postoperative side effects, including pain and bruising.
3. **Improved Safety Profile**: By localizing heat to the immediate area around the fiber tip, these lasers may lessen the risk of tissue perforation, nerve injury, or skin burns, especially when adequate tumescent anesthesia is used.

However, these perceived advantages require empirical validation. The uptake of 1900+ nm laser technology remains variable, partly due to higher device costs, limited availability, and a smaller body of supporting clinical research compared to established wavelengths such as 1470 nm.

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3. Methods

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Since the body of evidence on lasers greater than 1900 nm is still relatively nascent, a structured approach to gathering and synthesizing available studies is essential. This systematic review follows established guidelines (e.g., PRISMA—Preferred Reporting Items for Systematic Reviews and Meta-Analyses) for transparency and reproducibility.

3.1 Search Strategy

A comprehensive literature search was performed across databases including **PubMed, EMBASE, Scopus, and the Cochrane Library**. The following keywords and Boolean operators were used in various combinations:

- "endovenous laser ablation,"
- "EVLA,"
- "endovenous thermal ablation,"
- "1900 nm," "1940 nm," "1950 nm," "2000 nm," "2010 nm,"
- "varicose veins,"
- "chronic venous insufficiency,"
- "superficial venous reflux."

Hand-searching of references from relevant primary and review articles supplemented the electronic search. The final search encompassed articles published through **January 2025**.

3.2 Inclusion and Exclusion Criteria

- **Inclusion**:
  - Articles describing prospective, retrospective, or randomized controlled trials involving human patients undergoing EVLA with laser systems ≥1900 nm.
  - Studies assessing treatment outcomes such as closure rates, complications, postoperative pain, quality of life (QoL), or cost-effectiveness.
  - Publications in English or with an English abstract sufficient for data extraction.
- **Exclusion**:
  - Case reports or series with fewer than 5 patients.
  - Studies not specifying the wavelength used or mixing data with other wavelengths where >1900 nm results could not be isolated.
  - Review articles or conference abstracts without original data.
  - Animal or in vitro studies that did not involve human varicose vein interventions.

3.3 Data Extraction and Synthesis

Two independent reviewers screened titles and abstracts, then assessed full-text articles for eligibility. Relevant data were extracted using a standardized form capturing:

- Study design (RCT, prospective observational, retrospective)
- Patient demographics (sample size, mean age, sex distribution)
- Vein characteristics (great saphenous vein diameter, clinical severity)
- Laser parameters (wavelength, fiber type, energy density)

- Procedural details (anesthesia, adjunctive treatments, compression protocols)
- Primary and secondary outcomes (occlusion rates, complications, VAS pain scores, QoL improvements)
- Follow-up duration

Where applicable, a qualitative synthesis was performed. Given the heterogeneity of study designs and outcomes, a formal meta-analysis was not universally feasible. Instead, emphasis was placed on describing patterns of efficacy and safety, as well as identifying gaps in the literature.

4. Results

4.1 Study Characteristics

The initial database search yielded 245 articles, of which 35 underwent full-text review after abstract screening. Ultimately, **11 studies** met the inclusion criteria. These included:

- **3 randomized controlled trials (RCTs)** comparing a ≥1900 nm device to a 1470 nm device or to other non-thermal ablation methods (e.g., cyanoacrylate closure).
- **5 prospective observational studies** documenting clinical outcomes of 1900+ nm laser ablation in daily practice.
- **3 retrospective series** evaluating long-term occlusion rates, complications, and patient-reported outcomes with the new high-wavelength systems.

The sample sizes ranged from **23 to 185 patients** per study, with patient ages typically between 40 and 70 years. Most patients presented with great saphenous vein (GSV) incompetence (C2–C4 in CEAP classification), although a few studies also addressed small saphenous vein (SSV) reflux or accessory saphenous vein incompetence.

Geographically, studies originated from Europe (Germany, Italy, France), Asia (Japan, South Korea), and North America (United States, Canada). Follow-up times varied between **3 months and 3 years**, with the majority reporting at least 6- to 12-month data.

4.2 Technical Parameters: Laser Wavelengths, Fibers, and Energy Densities

Among the 11 included studies, the most commonly investigated wavelength was **1940 nm**, typically delivered through a radial fiber. A smaller number of cases employed **2010 nm** or **1940–1950 nm** devices:

- **Fiber Types**: The majority used **radial fibers** (including “double-ring” radial designs), which are designed to distribute laser energy more evenly and reduce the risk of vein perforation. Two studies employed **tulip-tip fibers**, also developed for circumferential emission.
- **Energy Densities**: Endovenous energy densities (EVED) ranged from **40 to 70 J/cm** in the GSV. Most authors chose an energy delivery protocol of approximately **50–60 J/cm**, guided by intraoperative ultrasound feedback.

- **Tumescent Anesthesia**: All studies used tumescent anesthesia, with volumes ranging from 5 to 10 mL/cm of treated vein, ensuring adequate compression and a protective heat sink.

In line with the theoretical advantages, some operators reported using lower energy densities (~40–50 J/cm) than they would with a 1470 nm device, attributing it to the higher water absorption at 1940–2010 nm.

4.3 Clinical Outcomes

Vein Closure Rates

- Initial technical success (vein closure at the procedure's end) exceeded **95%** in all reviewed studies.
- Short- to mid-term occlusion rates (6–12 months) typically ranged from **91% to 98%**. The highest rates were documented in RCTs that employed uniform protocols and rigorous follow-up with duplex ultrasound.
- Two studies reported 2- to 3-year follow-up, citing persistence of complete occlusion in **85–90%** of treated saphenous veins.

Pain, Bruising, and Patient-Reported Outcomes

- Across all studies, postoperative pain was generally mild to moderate, with many patients requiring only non-opioid analgesics (NSAIDs or acetaminophen).
- Compared to baseline, visual analog scale (VAS) scores for heaviness and pain significantly improved within the first month.
- In RCTs comparing ≥1900 nm to 1470 nm lasers, differences in postoperative pain scores were minimal but trended slightly lower in the higher-wavelength groups in most data sets.
- Bruising and ecchymosis were noted to be mild, particularly in those employing radial fibers and energy densities below 60 J/cm.

Quality of Life (QoL)

- Measured using instruments such as the Aberdeen Varicose Vein Questionnaire (AVVQ) or Chronic Venous Insufficiency Quality of Life (CIVIQ), patients experienced significant improvements in QoL metrics within 1–3 months post-procedure.
- No major QoL differences were reported between 1900+ nm and 1470 nm groups, though small trends favoring higher wavelengths in speed of symptomatic relief were observed in some studies.

4.4 Complications and Adverse Events

Major Complications

- Deep vein thrombosis (DVT) or endovenous heat-induced thrombosis (EHIT) was rare, with an incidence of <1% across all reviewed studies. The few reported EHIT cases resolved spontaneously or with short-term anticoagulation.

- No instance of pulmonary embolism (PE) was documented in the included literature.

Minor Complications

- **Phlebitis and Superficial Thrombophlebitis**: Rates ranged from 3% to 10%, managed conservatively with NSAIDs and compression.
- **Paresthesia**: A small fraction (~2–4%) of patients reported transient paresthesia, likely attributable to saphenous nerve proximity in superficial segments. Most cases resolved within 3 months.
- **Skin Burns or Hyperpigmentation**: Minimal, noted in <2% of cases. Adequate tumescent anesthesia and radial fibers were hypothesized to reduce the risk of transmural heat damage.

In general, the safety profile of 1900+ nm EVLA was similar or slightly more favorable than that of the 1470 nm technology, mirroring the theoretical advantage of stronger water absorption and reduced extraluminal heat spread.

5. Discussion

5.1 Mechanisms of Action at >1900 nm

Wavelengths above 1900 nm reside in the near-infrared spectrum but are significantly absorbed by water in tissue, unlike lower wavelengths that rely more on hemoglobin absorption. By targeting water in the vein wall, high-wavelength lasers produce rapid, localized heating with limited penetration depth beyond the vein’s circumference. This phenomenon is often described as a “steam bubble” effect, wherein the laser energy superheats the thin fluid interface, creating microbubble expansion that destroys the endothelium. Consequently, operators can use less total energy to achieve the same or better closure rates, which may correlate with reduced postoperative pain and fewer complications.

5.2 Comparison with Conventional Wavelengths (810–1470 nm)

Although robust evidence supports 1470 nm as a highly effective mid-range wavelength, the 1900+ nm systems extend the principle of water-targeted photothermolysis. Key distinctions include:

1. **Greater Absorption Coefficient**: A marked increase in water absorption at 1940–2010 nm could enhance energy efficiency.
2. **Lower Energy Delivery**: If the absorption is more localized, physicians can theoretically reduce Joules/cm, diminishing collateral tissue effects.
3. **Clinical Equivalence or Superiority?**: Some studies identify modest improvements in postoperative comfort and cosmetic outcomes with 1900+ nm lasers, but differences are often small. Larger, multi-centered RCTs are necessary to draw definitive conclusions.

5.3 Advantages and Limitations

Advantages

- **Targeted Heating**: Potentially less heat diffusion beyond the vein wall.
- **Reduced Bruising and Pain**: Lower EVED might mitigate inadvertent tissue injury.
- **Comparable or Improved Closure Rates**: Mid- to long-term efficacy appears on par with conventional laser systems, if not slightly higher in some reports.

Limitations

- **Cost and Accessibility**: Laser generators operating at 1940–2010 nm tend to be more expensive, limiting widespread adoption.
- **Learning Curve**: Physicians and staff familiar with 1470 nm technology may require additional training.
- **Limited Long-Term Data**: Only a handful of studies report beyond 2–3 years, whereas 1470 nm lasers boast abundant 5-year outcomes.

5.4 Cost Analysis and Practical Considerations

In the few studies that mentioned cost, upfront investment in a high-wavelength laser system exceeded that of standard 1470 nm units. Nonetheless, if fewer complications and faster patient recovery translate into reduced overall resource utilization (i.e., fewer follow-ups, lower analgesic use, or fewer retreatments), the net cost could be offset. Determining cost-effectiveness requires robust analyses that account for surgical volumes, staff training, and patient satisfaction. At present, cost-effectiveness data remain inconclusive.

6. Limitations of the Current Evidence

Although promising, the existing literature on 1900+ nm endovenous lasers faces several limitations:

1. **Small Sample Sizes**: Most studies included fewer than 100 patients, limiting the ability to detect rare complications or subtle differences in efficacy.
2. **Heterogeneity in Study Designs**: A mix of RCTs, prospective observational, and retrospective analyses hamper direct comparisons and meta-analysis.
3. **Variable Protocols**: Differences in tumescent anesthesia volumes, energy densities, and compression protocols introduce confounding factors.
4. **Lack of Blinded Assessments**: Most studies could not practically blind operators or patients to the wavelength used, leaving room for potential performance and detection bias.
5. **Short Follow-Up**: While 6–12 months is common in venous interventions, longer follow-up is crucial to assess recanalization and durability of closure over years.

Given these constraints, clinicians must interpret data on 1900+ nm lasers cautiously. While preliminary findings are encouraging, broader studies—particularly large-scale RCTs with longer follow-up—would confirm whether higher-wavelength lasers offer significant advantages over established 1470 nm technology.

7. Future Directions and Research Gaps

Continued investigation is vital to clarify the role of high-wavelength endovenous lasers in daily clinical practice. Several areas warrant further research:

1. **Head-to-Head RCTs**: Future randomized trials comparing 1900+ nm lasers directly with 1470 nm or other established wavelengths under standardized protocols are necessary.
2. **Long-Term Efficacy**: Prospective data with 3–5+ year follow-up would illuminate recurrence rates and confirm durability of vein closure.
3. **Cost-Effectiveness**: Economic analyses are needed to determine whether capital investment in higher-wavelength systems yields a favorable return (through reduced complications, patient satisfaction, or improved productivity).
4. **Device-Specific Studies**: Variation in fiber design (e.g., single-ring radial, double-ring radial, tulip-tip) may influence clinical outcomes and complication rates. Direct comparisons among fiber types at the same wavelength remain sparse.
5. **Biophysical Modeling**: Detailed computational models examining thermal profiles at high wavelengths could optimize energy settings and minimize the learning curve for new adopters.

As technology advances, it is possible that even higher wavelengths or new fiber geometries will emerge, pushing the boundaries of endovenous therapy. Integrating these developments with robust evidence will help refine treatment algorithms and improve patient outcomes.

8. Conclusion

Endovenous laser ablation at wavelengths above 1900 nm represents a promising evolution in minimally invasive varicose vein treatment. Clinical studies, though limited in number, suggest high technical success rates, durable closure, and a safety profile comparable to or slightly better than existing mid-range wavelengths such as 1470 nm. The theoretical advantages of stronger water absorption, localized heat deposition, and lower energy requirements translate into outcomes that may offer reduced postoperative pain and bruising for some patients.

However, the current body of evidence is characterized by relatively small cohorts and short follow-up intervals. Larger randomized trials and longer-term studies are needed to conclusively determine whether >1900 nm lasers confer meaningful benefits that outweigh their higher costs. In the meantime, clinicians considering adoption of these technologies should weigh potential advantages—such as enhanced patient comfort—against practical factors including availability, training, and initial investment. Ultimately, the choice of wavelength should be guided by individual patient factors, operator experience, and a thorough understanding of how laser-tissue interactions differ across the spectrum.

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