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OPTIMIZATION OF LASER PARAMETERS IN AESTHETIC DERMATOLOGY: IMPACT OF FLUENCE, PULSE DURATION AND SPOT SIZE IN ND: YAG, IPL AND CUTERA SYSTEMS – A SYSTEMATIC REVIEW

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ABSTRACT

Laser-based therapies are widely used in aesthetic dermatology for the treatment of vascular lesions, pigmentation disorders and skin rejuvenation. Treatment outcomes and safety depend on appropriate selection of technical parameters, including fluence, pulse duration and spot size; however, standardized guidelines remain limited. This study systematically reviews the impact of key laser parameters on clinical efficacy and adverse events, with emphasis on vascular treatments using Nd:YAG, IPL and modern platforms, including Cutera systems.

A literature search in PubMed (2010–2025) identified clinical studies reporting specific laser settings. Fluence was the primary determinant of efficacy, with higher energy improving vascular clearance but increasing the risk of burns and post-inflammatory hyperpigmentation. Pulse duration influenced tissue selectivity, while spot size affected penetration depth and treatment outcomes.

Advanced systems demonstrated improved safety due to enhanced pulse modulation and cooling; however, complications remained linked to improper parameter selection. Optimization of laser parameters is essential for balancing efficacy and safety, and individualized treatment based on lesion characteristics and skin type remains crucial. Further research is needed to establish standardized protocols.

KEYWORDS

Fluence, Pulse Duration, Spot Size, Nd:YAG, IPL, Cutera, Laser Parameters

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1. Introduction

Laser-based technologies currently represent a cornerstone of aesthetic dermatology, offering minimally invasive treatment options for a wide range of conditions, including vascular lesions, pigmentation disorders and skin rejuvenation [15-19]. Among the most widely utilized systems are neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers and intense pulsed light (IPL) devices, both of which enable selective targeting of chromophores such as hemoglobin and melanin [5,6,22].

Recent technological advancements, including platforms developed by Cutera, have introduced enhanced pulse modulation, improved cooling systems and greater control over energy delivery. These innovations have contributed to improved safety profiles and expanded clinical indications [13,25,26]. However, despite these advancements, treatment outcomes remain highly dependent on appropriate parameter selection [18,20].

The principle of selective photothermolysis, originally described by Anderson and Parrish, explains how targeted thermal damage can be achieved by delivering energy at wavelengths preferentially absorbed by specific chromophores, using pulse durations shorter than or equal to the thermal relaxation time (TRT) of the target [1,2].

Among the key adjustable parameters, fluence, pulse duration and spot size play a central role in determining both treatment efficacy and safety [12,18]. Improper selection of these parameters may lead to insufficient clinical response or adverse events such as burns, blistering, scarring and post-inflammatory hyperpigmentation [20,27].

Despite the widespread clinical use of laser therapies, there is a lack of standardized guidelines for parameter optimization [10,18]. Existing studies often report heterogeneous treatment protocols, making it difficult to establish clear and universally applicable recommendations. Therefore, a comprehensive analysis of the relationship between laser parameters and clinical outcomes is essential.

The aim of this systematic review is to evaluate the impact of fluence, pulse duration and spot size on treatment efficacy and safety in aesthetic dermatology, with particular emphasis on vascular treatments using Nd:YAG, IPL and modern laser platforms.

2. Methodology:

A systematic literature search was conducted using the PubMed/MEDLINE, EMBASE and Google Scholar databases covering publications from January 2010 to March 2025. Search terms included combinations of the following keywords and Medical Subject Headings (MeSH): „ photothermolysis", „laser parameters", „fluence", „pulse duration", „spot size", „Nd:YAG", „IPL", „Cutera systems" and „aesthetic dermatology". Inclusion criteria comprised clinical trials and prospective studies reporting laser parameters in dermatologic applications involving human subjects. Exclusion criteria included animal and in vitro studies, small uncontrolled series, non-English publications, and studies lacking parameter data. Only original studies were included; review articles were excluded. Data were extracted into structured tables including laser type, parameters and outcomes.

3. Results

3.1 Fluence

Fluence, defined as energy delivered per unit area (J/cm²), was identified as the primary determinant of treatment efficacy [12,18]. Across multiple studies, higher fluence levels were associated with improved clearance of vascular lesions [3,14,20]. However, excessive energy delivery significantly increased the risk of adverse events, including epidermal damage, blistering and post-inflammatory hyperpigmentation [20,27]. Optimal fluence ranges varied depending on laser type and clinical indication. Nd:YAG lasers typically required higher fluence values compared to IPL systems due to deeper penetration characteristics [20,21], whereas IPL systems operated at lower fluence levels and utilized pulse sequencing to maintain safety [6,22].

3.2 Pulse duration

Pulse duration plays a critical role in ensuring selective photothermolysis [1,2]. Matching pulse duration to the thermal relaxation time of the target structure is essential to minimize collateral tissue damage [4,12]. Short pulse durations allow for precise targeting but may increase the risk of vessel rupture and purpura. Longer pulse durations provide more gradual heating but may lead to non-selective thermal diffusion, increasing the risk of damage to surrounding tissues. Clinical studies demonstrated that improper pulse duration settings were strongly associated with increased complication rates, particularly in patients with darker skin phototypes [4,20,27].

3.3 Spot size

Spot size influences both the depth of penetration and the distribution of laser energy. Larger spot sizes allow for deeper penetration due to reduced scattering, making them particularly effective for treating deeper vascular lesions [3,12,18]. However, increased spot size also requires careful adjustment of fluence to avoid excessive energy delivery. Studies indicated that inappropriate combinations of large spot size and high fluence significantly increased the risk of burns [20,27].

Importantly, these parameters do not act independently but interact in a complex and interdependent manner. Their interaction determines the overall energy distribution and thermal response of tissues.

The values presented in Table 1 represent parameter ranges reported across the included studies.

Table 1. Reported ranges of laser parameters in included studies

Study	Laser type	Indication	Fluence (J/cm²)	Pulse duration (ms)	Spot size (mm)	Outcome	Adverse effects
Clark et al. [4]	Nd:YAG	Telangiectasia	100–180	10–30	3–6	High clearance	Erythema, burns
Sadick et al. [3]	Nd:YAG	Vascular lesions	120–160	15–40	3–5	Good efficacy	Post-inflammatory hyperpigmentation (PIH)
Taub et al. [7]	IPL	Rosacea	20–40	Multi-pulse	10–15	Reduced erythema	Transient erythema
Babilas et al. [5]	IPL	Vascular lesions	25–45	Variable	8–15	Moderate–high efficacy	Pigmentary changes
Bernstein et al. [13]	Cutera	Vascular lesions	80–140	10–20	5–10	High efficacy	Low complication rate

4. Discussion

The findings of this systematic review highlight the central role of laser parameter optimization in determining both the efficacy and safety of aesthetic dermatologic procedures. While technological advancements have significantly improved device performance, treatment outcomes remain highly dependent on the appropriate selection and combination of fluence, pulse duration and spot size. Importantly, these parameters do not act independently, but rather interact in a complex manner that influences energy distribution, tissue response and the risk of adverse events.

4.1 Parameter optimization

Optimization of laser parameters is essential to achieve selective photothermolysis while minimizing collateral tissue damage [1,12]. Fluence plays a key role in determining treatment efficacy, directly influencing the extent of thermal damage delivered to target structures. Higher fluence values are associated with improved clinical efficacy, particularly in vascular lesion clearance; however, they also significantly increase the risk of complications such as burns and post-inflammatory hyperpigmentation [20,27]. Pulse duration must be carefully adjusted in relation to the thermal relaxation time of the target chromophore. Short pulse durations enable precise targeting and confinement of thermal damage, whereas longer pulses may result in heat diffusion to surrounding tissues, reducing selectivity. In vascular treatments, matching pulse duration to vessel diameter is particularly critical, as inappropriate settings may lead to either insufficient coagulation or vessel rupture. Spot size plays a complementary role by affecting both penetration depth and energy distribution [12]. Larger spot sizes reduce scattering and allow deeper energy delivery, which is advantageous for treating deeper vascular structures. However, increased spot size requires proportional adjustment of fluence to prevent excessive thermal accumulation. Importantly, optimal parameter selection requires consideration of their interdependence. For example, increasing spot size may necessitate lowering fluence, while shorter pulse durations may require adjustments in energy levels [1,2]. Therefore, parameter optimization should be viewed as a dynamic process rather than a fixed set of values.

4.2 Safety considerations

Safety remains a critical concern in aesthetic laser treatments, with adverse events largely resulting from improper parameter selection rather than device limitations [20,27]. The most commonly reported complications include erythema, edema, blistering and post-inflammatory hyperpigmentation, while more severe outcomes such as scarring and persistent dyschromia are less frequent but clinically significant. Fluence is the most influential factor in the development of adverse events. Excessive energy delivery leads to rapid temperature elevation and unintended thermal injury [20], particularly in patients with higher Fitzpatrick skin phototypes. In such cases, melanin competes as a chromophore, increasing the risk of epidermal damage. Pulse duration also plays a significant role in safety. Pulses that are too short may cause rapid vessel rupture and purpura, while excessively long pulses promote non-selective heat diffusion [12]. Proper matching of pulse duration to target structures is therefore essential to balance efficacy and safety. The presence of advanced cooling systems, particularly in modern platforms such as those developed by Cutera, has improved epidermal protection and reduced the incidence of superficial burns. However, cooling alone cannot compensate for inappropriate parameter selection. Patient-related factors further influence safety outcomes. Skin phototype, recent sun exposure and individual sensitivity must all be considered when determining treatment settings [13,25]. Additionally, operator experience remains a critical determinant of safety, emphasizing the need for proper training and protocol standardization.

4.3 Technology comparison

Significant differences exist between laser technologies, particularly between Nd:YAG and IPL systems, which directly impact parameter selection and safety profiles.

4.3.1 Nd:YAG laser (1064 nm)

Nd:YAG lasers operate at a wavelength of 1064 nm, which allows for deeper penetration into the dermis (up to 5-7 mm) due to lower absorption by melanin and hemoglobin compared to shorter wavelengths. This property makes Nd:YAG particularly effective for treating deeper vascular lesions and for use in patients with darker skin phototypes [20,21,9]. However, the reduced absorption by target chromophores requires the use of higher fluence values to achieve sufficient thermal damage. As a result, Nd:YAG treatments are associated with an increased risk of deep thermal injury [20], including burns and scarring, especially when parameters are not carefully optimized. Pulse duration plays a critical role in Nd:YAG treatments, as longer pulses are often required to safely deliver energy to deeper structures. Additionally, smaller spot sizes may limit penetration depth, while larger spot sizes improve efficacy but increase the risk of excessive energy delivery if not properly adjusted [4,8].

- fluence: **80–180 J/cm²**
- pulse duration: **10–50 ms**
- spot size: **3–10 mm [8]**

4.3.2. IPL (Intense Pulsed Light)

IPL systems differ fundamentally from lasers in that they emit non-coherent, polychromatic light across a broad wavelength spectrum. The use of interchangeable filters allows clinicians to target specific chromophores, making IPL a versatile tool for treating a wide range of dermatologic conditions, including vascular and pigmentary conditions as well as skin rejuvenation [7]. The flexibility of IPL systems enables precise adjustment of fluence, pulse duration and pulse sequencing. Multi-pulse delivery is commonly used to reduce peak temperature and improve safety by allowing intermittent cooling between pulses. Despite these advantages, IPL systems are inherently less selective than laser devices. The broader wavelength range increases the likelihood of non-specific absorption, particularly by melanin, which contributes to a higher risk of superficial burns and post-inflammatory hyperpigmentation [5,22,23].

- fluence: **20–45 J/cm²**
- pulse: **multi-pulse (2–5 pulses)**
- filters: **500–600 nm**

4.3.3.Modern systems (Cutera platforms)

Modern laser platforms, including those developed by Cutera, incorporate advanced technological features designed to improve both precision and safety. These systems often combine multiple wavelengths (e.g., Nd:YAG and KTP) within a single platform, allowing for tailored treatment of both superficial and deeper vascular lesions [13,25,26].

Key innovations include:

- enhanced pulse modulation for controlled energy delivery
- integrated contact cooling systems to protect the epidermis
- real-time adjustment capabilities

These features enable more refined parameter optimization and reduce the risk of adverse events compared to older systems. However, despite these advancements, improper parameter selection remains a significant cause of complications, highlighting the continued importance of operator expertise [13,20,27].

- fluence: **70–140 J/cm²**
- pulse: **10–30 ms**
- spot: **5–10 mm**

4.3.4 Comparative analysis

When comparing these technologies, several key differences emerge [17,24,25]:

Penetration depth**:**

Nd:YAG provides the deepest penetration, followed by IPL (depending on filter selection) [20,21].

Selectivity:

Nd:YAG offers higher selectivity for deeper vascular targets [14], while IPL provides broader but less specific targeting [22,24].

Parameter sensitivity**:**

Nd:YAG requires precise adjustment of fluence due to higher energy requirements, whereas IPL requires careful balancing of multiple parameters, including wavelength filters and pulse sequencing [18,22].

Safety profile**:**

IPL is more commonly associated with superficial adverse events such as erythema and hyperpigmentation, while Nd:YAG carries a higher risk of deep tissue injury. Modern platforms demonstrate improved safety but do not eliminate risk [20,25,27].

4.4 Clinical relevance

The results of this review have important implications for clinical practice [18,20]. First, parameter selection should be individualized rather than based on fixed protocols. Factors such as lesion characteristics, depth, skin phototype and anatomical location must be taken into account [15,20,21]. Second, the interdependence of laser parameters underscores the importance of comprehensive understanding rather than reliance on preset device settings [12,18]. Clinicians should be aware that small adjustments in one parameter may require compensatory changes in others.

Clinical outcomes are influenced by multiple interacting factors [18,20]:

Patient-related factors

- skin phototype
- vascular depth
- presence of pigmentation

Device-related factors

- wavelength
- cooling systems
- pulse modulation

Operator-related factors

- experience
- parameter selection

Incorrect parameter selection significantly increases the risk of burns, scarring and hyperpigmentation [20,27].

4.5 Limitations

This systematic review has several limitations, including significant heterogeneity in study design, treatment protocols and reported outcomes, which limited direct comparisons across studies. Inconsistent reporting of key laser parameters and reliance on observational studies with small sample sizes may affect the accuracy and generalizability of the findings [17,22].

Additionally, variability in patient characteristics, potential publication bias and rapid technological advancements in laser systems may further limit the applicability of the results [25,26].

4.6 Future directions

Future research should focus on the development of standardized, evidence-based guidelines for laser parameter optimization, integrating fluence, pulse duration and spot size with patient-specific factors [10,18]. Technological advancements, including artificial intelligence and real-time skin feedback systems, may enable personalized and safer treatment approaches [25,26]. Additionally, well-designed comparative studies between laser platforms, including systems developed by Cutera, along with improved reporting standards and long-term safety data, are needed to enhance clinical applicability [17,24].

5. Conclusions

Optimization of laser parameters is essential for achieving safe and effective outcomes in aesthetic dermatology. Fluence, pulse duration and spot size must be carefully adjusted based on individual patient characteristics, lesion type and device specifications [12,18].

Although modern laser systems offer improved safety features, improper parameter selection remains a major cause of adverse events. Standardized guidelines for parameter optimization are needed to improve clinical outcomes and reduce complication rates [20,27].

Future research should focus on developing evidence-based protocols and integrating advanced technologies, such as real-time feedback systems, to enhance treatment precision [10,25].

To our knowledge, this review is among the first to focus on the interaction between key laser parameters rather than their isolated effects.

Author's Contribution:

Here we present a detailed description of author's contribution to the creation of this manuscript. Conceptualization Karina Lewandowska, Wojciech Janikowski, and Agnieszka Jóźwicka; methodology, Aleksandra Stępka; software, Weronika Plichtowicz- Kordowska; validation, Lena Jaworowicz, Maria Wieczorek, Aleksandra Stępka and Wojciech Janikowski; formal analysis, Karina Lewandowska; investigation, Ewa Bąkowska; resources, Maria Wieczorek; data curation, Karina Lewandowska; writing - rough preparation, Agnieszka Jóźwicka; writing - review and editing Weronika Plichtowicz- Kordowska, Wojciech Janikowski; visualization, Karina Lewandowska, Agnieszka Jóźwicka; supervision, Lena Jaworowicz; project administration, Karina Lewandowska. All authors have read and agreed with the published version of the manuscript.

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