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Clinical use of lasers and energy-based devices in selected skin diseases

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Abstract

Introduction and purpose

In recent years, there has been notable progress in the role of light-emitting technologies, including lasers and other energy-based devices, across various medical disciplines. Dermatology stands out as one of the prominent fields where laser treatments have gained significant popularity. In the clinical setting, a variety of laser types are utilized. A fundamental aspect of ensuring the safe use of laser devices involves comprehending their mechanisms at the tissue level. This knowledge enables practitioners to attain the desired outcomes effectively while minimizing the risk of complications. Lasers have demonstrated effectiveness in treating cutaneous vascular conditions because of their capacity to selectively target intravascular oxyhemoglobin. Rosacea, juvenile hemangioma, and port wine stains are among the vascular skin conditions for which laser therapy has shown notable success. Laser therapy is employed in treating hypertrophic scars, keloids, and acne scars because it facilitates the restructuring of the skin's architecture at the scar site, with the goal of minimizing its size and visibility. Laser therapy stands as the gold standard for removing tattoos.

Materials and methods

The methodology for conducting literature search involved utilizing medical subject headings terms to explore PubMed. Search terms included: “lasers”, “intense pulsed light”, “dermatology”, “rosacea”, “acne”, “scars”, “tattoo removal”.

Conclusions

Laser dermatological treatments are gaining popularity worldwide, driving new innovations and clinical applications. This review highlights the significant role and diverse clinical applications of lasers and intense pulsed light in dermatological practice. Improving the quality of skin in patients suffering from skin diseases can significantly increase their quality of life.

Keywords: “laser”, “intense pulsed light”, “dermatology”, “rosacea”, „scars”, „acne”, “tattoo removal”

Introduction

Lasers and energy-based devices are widely utilized in dermatological treatments for skin resurfacing. [1] A laser, an acronym for light amplification by stimulated emission of radiation, serves as a source of electromagnetic radiation that can cut, coagulate, ablate, or remodel tissues. [2] In addition to numerous cosmetic applications, lasers have proven effective in the treatment of various skin diseases, including skin cancer. Lasers and intense pulsed light have been employed safely and effectively to treat a wide range of skin conditions, such as vascular and pigmented lesions, tattoos, scars, and unwanted hair. [3,4] The safe and effective use of these devices necessitates an understanding of the histologic interactions between the laser and the tissue. [1]

Objective of the work

This review aims is concentrate on the clinical utilization lasers and energy-based devices in dermatology.

Description of the state of knowledge

General Knowledge of lasers

Laser light is a coherent beam of waves, which means it moves in phase spatially and temporally. It is also characterized by the fact that it is monochromatic- it consists of one wavelength, unidirectional and intense. Its emission can occur in either continuous or pulsed mode. It works using wavelengths in the visible, infrared and ultraviolet range. Every wavelength corresponds to a distinct receptor within the skin. Chromophores exhibiting particular wavelength absorption profiles. Endogenous cutaneous chromophores are water, melanin and hemoglobin; tattoo ink serves as an exogenous chromophore. Each wavelength penetrates to a distinct depth. This diffusion is also affected by variables such as the spot diameter, fluence, and pulse duration. [2,3] The depth to which laser energy penetrates the skin is influenced by absorption and scattering. Light scattering is minimal in the epidermis but significant in the dermis, primarily due to the abundance of collagen fibers. [3] Photothermal, photochemical or photomechanical effects may occur after absorption of laser energy by the skin. [2,3] The photothermal effect refers to the conversion of light energy into heat. The photochemical action is achieved by administering a photosensitizer. That accumulates in the target area, absorbs light, and induces either biostimulation or cell death. The photomechanical effect occurs when the energy of the wave surpasses the binding energy of molecules, resulting in the breaking of bonds and the expulsion of fragments. [2] The theory of selective photothermolysis elucidates how controlled destruction of a specific cutaneous target can be accomplished without causing significant damage to surrounding tissues. This theory has been pivotal in the advancement of laser surgery. IPL is a flash with a non-laser filter. Unlike lasers, IPL devices emit polychromatic, incoherent and non-collimated light with different pulse durations. [3]

Clinical use of lasers

Treatment of vascular lesions

Vascular lesions are commonly addressed using lasers and intense pulsed light (IPL) because these systems can precisely target intravascular oxyhemoglobin. Oxyhemoglobin absorbs the laser light, converting it into heat, which is then transferred to the vessel wall, resulting in coagulation and closure of the vessel. [3] Laser therapy can utilize a range of lasers, such as flash-lamp pulsed dye laser (PDL), carbon dioxide (CO2) lasers, neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers, or intense pulsed light (IPL) devices. [5] Laser heating can effectively target both small-diameter and large vessels. [6] The Flash-lamp pulsed dye laser (FPDL) is widely regarded as the most precise laser available for treating superficial vascular lesions. The FPDL functions by selectively photothermolysis of cutaneous blood vessels, preserving surrounding tissue and reducing the risk of scarring. [5]

- **Rosacea**

Rosacea is a chronic inflammatory condition characterized by various facial skin symptoms, including flushing, persistent erythema, pustules, telangiectasia, and phymatous changes. One of the treatment paths are laser and intense pulsed light (IPL) therapy. There was no notable distinction observed in either the melanin or erythema index between short-pulsed IPL therapy and pulsed dye laser therapy for treating rosacea when applied with equivalent energies and pulse settings. [7,8]

Zhang et al. conducted a retrospective study focusing on the use of light/laser therapy in treating nasal rosacea. The classification of rosacea types (erythema/telangiectasia;

papules/pustules, rhinophyma,) was determined based on photographic evidence. Erythema or papules lesions were primarily addressed using noninvasive devices such as IPL, Dye pulse light, or Dual wavelength laser system (DW), while rhinophyma lesions were treated with fractional carbon dioxide laser therapy. On average, approximately 70% of the studied patients achieved a 50% improvement after 2-4 therapeutic sessions. Numerous sequential laser devices can be safely employed to treat rosacea including rhinophyma, with effectiveness varying depending on the specific type of rosacea being addressed. [9]

One study in Koreans found that pretreatment with topical niacin safely increased the effectiveness of pulsed dye laser therapy targeting redness associated with rosacea. All of fifeteen patients experienced an improvement in erythema after three sessions of PDL treatment, regardless of whether they received niacin pretreatment. However, the overall clinical improvement and patient satisfaction on the niacin side was significantly higher. No notable side effects were observed, except for transient erythema and edema. [10]

Luo et al. conducted a study to evaluate the clinical effectiveness and safety of using intense pulsed light (IPL) with a wavelength of 540 nm for treating telangiectasia in the advanced stages of rosacea. Patients from the research group were qualified for three 540 nm IPL treatments at 4-week intervals. It was found that the rates of successful treatment and overall effectiveness in this group were significantly higher compared to the control group, and the relapse rate was lower. [11]

- **Hemangiomas**

Infantile hemangiomas (IH) are common benign vascular tumors in children. The incidence of IH is estimated at 5–10% in one-year-old children, predominantly affecting female, Caucasian, and low birth weight infants. Most IHs resolve on their own, but approximately 10% require treatment to prevent complications such as bleeding, ulceration, cosmetic disfigurement, functional impairment, or life-threatening issues. laser treatment of this vascular anomaly serves as a preventive measure against scar formation. The pulsed dye laser (PDL) is commonly used to treat IHs, although its use remains controversial. [5,12,13] A clinical trial demonstrated that PDL yielded better results than topical timolol cream for treating superficial proliferating IH. However, further studies with longer follow-up periods and larger sample sizes are needed. [14] Another type of laser is the long-pulsed Nd:YAG laser, which operates based on the theory of selective photothermolysis and is primarily used in infants who are intolerant to propranolol. Integrating laser therapy with other treatments provides significantly better outcomes than a single treatment. Combining multiple laser sessions with systemic propranolol therapy may be more beneficial than monotherapy. [13]

- **Port wine stains**

Port wine spots (PWS) are benign congenital capillary malformations that occur in 0.3% of all newborns and most often appear on the face and neck. At present, 595 nm pulsed dye laser (PDL) therapy is considered a viable and effective treatment option for port wine stains. [15,16] Shi et al.'s study examined a total of 848 cases treated with PDL. An independent dermatologist evaluated these changes using before and after photographs. The response rate was 69.9%, with a cure rate of 6.3%. Patients with smaller lesions achieved better results [15] The double PDL/Nd:YAG laser method (λ = 595 nm/1064 nm) is another treatment option. With the Nd:YAG laser pulse becoming more effective, the synergistic thermal effect reduces the required fluence for adequate photocoagulation, potentially minimizing tissue damage. This dual laser approach has demonstrated successful outcomes for refractory and hypertrophic port wine stains [17]

The 755 nm alexandrite laser, a distinct laser modality, has exhibited efficacy in addressing hypertrophic or nodular lesions, which may be correlated with deeper vascular involvement. This laser system has demonstrated notable efficacy in managing hypertrophic and PDL-resistant port wine stains, particularly when employed alongside pulsed dye laser (PDL) therapy. The therapeutic effectiveness of the alexandrite laser, with its wavelength of 755 nm falling within the therapeutic window, enables deeper tissue penetration. This wavelength is more strongly absorbed by deoxyhemoglobin than by oxyhemoglobin, theoretically targeting the veins comprising the vascular system of port wine stains (PWS) over arterioles, thus potentially leading to preferential damage. Is important that longer wavelength lasers are associated with an increased risk of adverse events such as pigmentation changes and scarring. [16]

Other study explore whether IPL could serve as an alternative to PDL for treating PWS. While IPL has demonstrated effectiveness in clearing pink and red PWS, the median clinical improvement was notably superior with PDL compared to IPL. Nonetheless, IPL may be considered for treating PDL-resistant PWS. [17]

Treatment of scars

- **Keloid and Hypertrophic Scar**

Abnormal wound healing can lead to the formation of hypertrophic and keloid scars. The condition results from chronic inflammation of the reticular dermis due to skin trauma or irritation, such as burns, surgery, vaccinations, skin piercing, acne, and shingles. Generally speaking, scars where the skin inflammation resolves on its own over time are classified as hypertrophic. Thus, the temporary and resolving inflammation in hypertrophic scars prevents them from spreading beyond the original boundaries of the wound. However, scar inflammation causing them to grow into the surrounding healthy skin are defined as keloids.. [18,19] Laser therapy is used to treat such scars. Mainly used to reduce redness or telangiectasia caused by steroid therapy, the long-pulse Nd:YAG laser is employed for flattened keloids and hypertrophic scars. The fractional ablative laser triggers a wound healing response, leading to increased production of collagen III, which promotes scar remodeling. [18]

Leszczynski et al. conducted a comprehensive analysis comprising 15 randomized controlled trials focusing on the treatment of hypertrophic or keloid scars. Their study compared laser therapy with placebo, no intervention, or another intervention. Eight of the studies compared laser treatments with no treatment. The evidence, which is of low certainty, indicates that the 585 nm pulsed dye laser (PDL) can reduce the severity of keloid and hypertrophic scars compared to no treatment, showing improvements of 50% or more over a 32-week follow-up period. However, the evidence for all other outcomes remains uncertain due to small study groups and potential statistical errors. Other forms of laser therapy, including non-ablative fractional lasers and fractional CO2 lasers, were also compared to no treatment. However, the results regarding their impact on scar severity are inconsistent. Some studies suggest potential benefits from these laser treatments, while others do not demonstrate any superiority over no therapy. Despite the inconclusive results, the success observed in certain studies highlights the need for further research. [19]

The use of lasers in scar treatment extends beyond controlled local thermal destruction and stimulation. Drug delivery through the skin can also be done using fractionated devices. Preclinical investigations validate augmented drug retention with a variety of topically administered medications subsequent to ablative fractional laser therapy. This occurs because laser pretreatment of the skin can enhance the permeability and depth of penetration of topically applied drug molecules. [20]

- **Burn Scars**

Burn scars can result in contractures, skin deformities, and discomforting symptoms like pain and itching. Additionally, they significantly affect the patient's psychological well-being, thereby diminishing their quality of life. Carbon dioxide laser resurfacing is the most frequently employed technique for reducing scar thickness, addressing textural irregularities, and managing contractures. [21] In particular, ablative fractional laser therapy shows great promise in relieving contractures and increasing the range of motion of affected joints. [22] For diminishing erythema in recent scars and averting subsequent hypertrophic scarring pulsed dye laser therapy can be employed. [21]

- **Acne scars**

Acne scars arise from inflammatory acne lesions, and despite the availability of various treatment modalities, they can exert a detrimental psychological impact on social interactions and relationships. This is a very common problem, as the prevalence of acne is estimated at over 90% in teenagers and in approximately 12-14% of them it persists into adulthood. [23,24] Clinical and histopathological studies have demonstrated the effectiveness of CO2 laser resurfacing in treating atrophic facial acne scars, showing an improvement of 50–80%. To qualify for CO2 laser resurfacing, patients must meet several criteria: they should not be in the active phase of acne, must have abstained from oral isotretinoin for at least one year, and should not have experienced a herpes virus skin infection in the six months prior to treatment. Additionally, they must have no history of keloids or hypertrophic scars. It is important to note that excessive treatment with high energy or density may exacerbate skin conditions. Potential side effects include transient infections, persistent discoloration, erythema, and scarring. [23]

Non-ablative skin remodeling systems, such as infrared and long-pulse Nd:YAG lasers, are gaining popularity in the treatment of blackheads and acne scars. They are considered a safer alternative to ablative lasers, as they minimize the risk of side effects. These non-ablative systems induce controlled thermal damage to the dermis, promoting neocollagenesis and remodeling of scarred skin. The improvement achieved with these non-ablative lasers was observed to be less significant compared to ablative lasers. Therefore, the balance of benefits and potential drawbacks for each patient should be assessed on an individual basis. [23]

Meghe et. al in comprehensive review compared these two types of laser therapy: CO2 laser and erbium-doped yttrium aluminum garnet (Er:YAG). Their mechanisms of action, safety profiles and effectiveness in the treatment outcomes of patients with acne scars were compared. Patients with concave scars benefit from fractional CO2 laser treatment as it improves skin texture and accelerates healing by stimulating collagen. [24] One of the comparative studies referenced in this review demonstrated that fractional CO2 laser therapy significantly surpassed Er:YAG laser treatment for acne scars, as indicated by higher subjective satisfaction and physician assessment scores. [24,25]

Combination therapy is also used to treat acne scars. [26] Platelet-rich plasma (PRP) is an autologous blood product derived from an individual's own blood, distinguished by elevated platelet concentrations compared to normal levels, and comprising growth factors typically associated with platelets. [27] In randomized controlled trial highlights the potential advantages of utilizing PRP as an adjunctive therapy to CO2 laser treatment for atrophic acne scars. The combination of these two therapies yielded superior results in terms of severity and degree of skin condition improvement. This combined approach was more comfortable for the patient, as it ensured faster recovery and was well tolerated due to fewer side effects. [26]

Tatto removal

Since ancient times, humans have adorned their bodies with various forms of decoration. For centuries, people have been characterized by their ever-changing nature. As a result, attempts to remove tattoos have likely been made for millennia. Once of modern tattoo removal began approximately 20 years ago. The gold standard in tattoo removal is laser therapy. Modern tattoo needles inject ink granules into the superficial and middle layers of the dermis. Consequently, deeply penetrating lasers are required for effective tattoo removal. [28,29]

The QS ruby laser (694 nm) was the first commercially available QS laser for tattoo removal, succeeded by the QS Nd:YAG laser (532 nm, 1064 nm) and the QS alexandrite laser (755 nm). Quality switched (QS) lasers have long been the predominant method for tattoo removal. Utilizing the principle of selective photothermolysis, laser light at various wavelengths is preferentially absorbed by specific endogenous chromophores. The treatment outcome is influenced by the colors of the tattoo pigments and the patient's skin tone. The choice of laser must be tailored to these parameters. Black and dark blue pigments respond most effectively to Nd:YAG and alexandrite lasers, whereas colored pigments are generally less responsive to treatment. [29] Professional tattoos are particularly challenging to remove, often necessitating 6-10 or even up to 20 treatment sessions. [30]

Picosecond lasers, with their shorter pulse duration, are more effective at targeting tattoo pigment, leading to increased photomechanical breakdown of the pigment. This results in quicker and more efficient tattoo removal compared to previous laser technologies. Picosecond pulses are more effective than nanosecond pulses in removing black tattoos. [29,31]

Conclusion

In contemporary dermatology, laser and IPL systems offer diverse clinical uses, furnishing an extensive array of therapeutic choices for skin ailments where conventional pharmaceutical or surgical interventions fail to deliver anticipated outcomes. These advancements have enabled the management of dermatological conditions addressed in this overview, including benign vascular and pigmented lesions, tattoo removal, hypertrophic scars, and keloids. Additionally, they extend to other conditions such as psoriasis, vitiligo, and unwanted hair growth, which, due to constraints in scope, were not covered extensively in this review. With laser devices being relatively recent therapy to the medical market, it becomes crucial to conduct new clinical studies to assess their efficacy and safety in dermatology and other related fields. Given the limited duration of patient trials, it is imperative to undertake numerous studies evaluating the outcomes of laser therapy. This approach aids in the selection of suitable laser types and optimal energy parameters for treating patients, thereby enhancing skin quality while minimizing potential side effects.

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