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LITERATURE REVIEW

Dermatologic Lasers: Comprehensive Review of Cosmetic and Therapeutic Uses

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Abstract

Laser and light therapy for dermatology has revolutionized the practice of dermatology to offer highly accurate, effective therapies for a wide range of skin conditions. This article provides a comprehensive description of dermatologic lasers, covering their history, mechanism of action, classification, application, and relative efficacy. It covers a wide variety of conditions amenable to laser treatment, including vascular lesions, anti-aging, scar revision, tattoo removal, and hair removal. In addition, the paper reviews the developing face of laser technology and how it is anticipated to revolutionize dermatology in the future.

Keywords

Vascular lasers, Fractional resurfacing, Light-based therapies, Laser hair removal, Laser-assisted drug delivery (LADD)

Introduction

Dermatological laser and light-based therapies have transformed dermatology into a new era of controllable, safe, and selective treatment of many different dermatologic disorders. From the time they were discovered to the most advanced technology today, lasers have undergone great strides to be highly sought-after instruments for customized treatment for numerous conditions ranging from vascular lesions to scar revision and much more.

The safety, effectiveness, and clinical application of dermatologic lasers for various dermatologic conditions are covered in this review. Relying on the summarization of current data and analysis of current trends in laser technology, this review provides valuable information on the current and future of both medical and cosmetic dermatologic care.

Methods

This review was conducted using Google Scholar. Articles were selected based on relevance to dermatologic laser application in clinical practice. The inclusion criteria preferred peer-reviewed studies, clinical trials, and reviews written in English in the 2000-2025 range. The first 1983 Anderson and Parrish selective photothermolysis paper was added for background information. Exclusion criteria eliminated duplicates, non-dermatologic uses, and non-clinically applicable articles. No statistical meta-analyses were performed. This review was sought to effect a broad synthesis of the literature in place of pooled quantitative analysis.

Results

Laser development

Since the 1960s, when the first medical laser was developed, lasers have developed and diversified, with widespread application in dermatology [1].

A laser is an emission of light by stimulated emission of radiation and electively acts on a specific chromophore within the skin, including melanin or hemoglobin [1].

Selective photothermolysis, originally termed by Anderson and Parrish in the 1980s, refers to the selective delivery of light energy for the destruction of the target chromophores without damaging overlying tissue [1-3].

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Laser therapy in dermatology relies on the adjustment of wavelength, pulse duration, and energy levels to treat particular skin issues, with both medical and cosmetic dermatology applications [1,4].

Vascular lasers

History: Vascular lasers are a subset of medical lasers designed to treat blood vessels and skin vascular lesions. Vascular lasers are able to selectively target hemoglobin (RBC pigmentation) at different wavelengths. The interaction results in coagulation and subsequent death of the targeted vessels [5]. Additionally, the evolving technological progress of vascular laser technology has provided the opportunity for the introduction of new devices with better precision, safety, and therapeutic success.

Types and Comparisons: Vascular lasers apply to a wide variety of vascular conditions and cosmetic problems, such as telangiectasia, spider veins, port-wine stains, cherry angiomas, hemangiomas, linear red vessels or broken capillaries, rosacea, and craniofacial erythema [3,6]. However, for chronic issues such as rosacea, maintenance check-ins are necessary after a course of treatments [7]. Further, the thrombosed vessels induced by vascular lasers preserve the epidermis intact for no damage, contributing to the safety and efficiency of vascular lasers in dermatologic treatments [5]. The PDL treatment with the 595 nm wavelength is a very accurate treatment to administer with little damage inflicted upon the tissues surrounding the area, thus making it the ideal choice to apply on sensitive regions like the face [7].

The KTP laser, which is of green wavelength, is best used for the treatment of surface vascular lesions such as telangiectasia and spider veins. Its hemoglobin absorption is selective enough to make the treatment site-specific while minimizing any adverse effects and is therefore ideal for those who are looking for quick and efficient treatments for vascular lesion. This is achieved using the KTP laser, which emits a green light of 532 nm that is preferentially absorbed by hemoglobin [8].

Terrence C Keaney, et al. published a comparative review of the 532-nm KTP laser versus 595-nm PDL for erythematous scars. Twenty equally matched bilateral scar patients or a single linear one over five cm was enrolled. A scar or half a scar was randomly treated with three exposures to either the KTP or PDL laser [9]. Post-final treatment assessment showed improvement in both groups, with no quantifiable difference between the two in several measurements like appearance of the scar, satisfaction with treatment, symptoms of the scar, and pain scores. In the follow-up of this comparison study, the KTP laser demonstrated significant improvement in the vascularity component of the scar measurements. Side effects were minimal, and subject satisfaction was excellent. The research found that the KTP is as safe and effective as the PDL laser in the management of erythematous surgical scars [9].

Excel V®, with both KTP (532 nm) and YAG (1064 nm) wavelengths, offers complete treatment options for a greater variety of treatment types, including vascular and pigmented lesions. Its two wavelengths provide an advantage in being able to treat both superficial and deep lesions, and thus offer a flexible and versatile treatment option for a range of dermatological conditions [3,8].

Resurfacing lasers

Background: Resurfacing lasers, both ablative and non-ablative resurfacing, are some of the dermatological technologies being utilized for skin rejuvenation and aging. Ablative lasers vaporize or remove the outer layers of skin to artificially wound the skin and induce new skin growth and collagen formation. Non-ablative fractional lasers, however, deposit controlled heat energy into the deeper layers of the skin without removing the very outermost layer of skin, inducing collagen remodeling and regeneration of the skin [10].

Every resurfacing laser presents distinct benefits and indications of use. Ablative lasers perform wonderfully for treating severe wrinkling, acne scarring, and more advanced photo damage, but they do take longer to recover from and carry a higher risk for complications. Non-ablative fractional lasers potentially have more restricted downtime, though, and are ideally treated for minor to moderate wrinkling, pigmentary issues, and general skin quality improvement [10,11].

Resurfacing laser types and comparison: Resurfacing lasers offer variable treatments for enhancing the looks of a wide variety of dermatologic conditions and aesthetic imperfections, including wrinkles, acne and surgical scars, pigmentary conditions, skin tightening, sun-damaged skin, abnormal skin texture, and others [10].

UltraPulse® Encore CO_2 is an ultra-deep 10,600 nm wavelength laser that offers ablative treatment for deeper wrinkles and scars with longer downtime but more intense effects. On the other hand, an ablative Erbium-doped Yttrium-Aluminum-Garnet (Er:YAG) laser at 2940 nm wavelength is utilized to offer more controlled tissue removal with reduced thermal damage and is thus utilized for fine wrinkles and pigmentation inconsistencies [10]. Preissig J, et al. made a comparison between ablative and non-ablative lasers in a study where patients who underwent treatment using ablative CO_2 lasers experienced a 45% reduction in facial wrinkles. The reduction was, however, accompanied by side effects such as oozing, bleeding, crusting, and uncomfortable procedure downtime. Other side effects such as acne, hyperpigmentation, and infection were also suffered by 55% of the patients [10].

Fraxel® (Re:store) is a 1550 nm fractional non-ablative laser with small treatment zones to create an injury, thereby causing collagen remodeling and skin rejuvenation with minimal downtime. Clear and Brilliant® (1440 nm and 1927 nm) and MOXI® (1927 nm) non-ablative fractional lasers respectively offer mild skin resurfacing aimed at improved texture and tone. These lasers are perfect for superficial issues that need a bit of touching up [10,12].

HALO® laser combines ablative and non-ablative wavelengths (1470 nm and 2940 nm) to offer hybrid fractional laser treatment, treating a broad range of skin and conditions with variable depth of treatment and downtime to suit the patient. Some of the appeal of the laser is 8 that it can give dramatic results without being entirely ablative, with resultant lower associated risks [10-13].

Compared to these resurfacing lasers, ablative lasers like UltraPulse® Encore CO2, Fraxel® CO_2, and Er:YAG are more invasive and are reserved for more extreme skin conditions, while non-ablative fractional lasers like Fraxel® (Fraxel Re:store), Clear and Brilliant®, and MOXI® are less invasive treatments with shorter downtimes, the most suitable being to less severe skin conditions and maintenance therapy [10].

Scar treatment with laser therapy

Scarring is a common issue in dermatology, and in most situations, it is of monumental cosmetic significance to patients, with significant implications for physical appearance and self-esteem.

The PDL, a selective coagulant of hemoglobin within blood vessels, reduces redness and vascular disorder of the acne scars and enhances overall skin color and tone [3,12,14]. Besides the vascular-targeted effect of the PDL, resurfacing treatments like Fraxel® lasers provide fractional resurfacing and act on the epidermis and dermis to induce collagen production and remodeling of scar tissue [13].

The efficacy of combined laser therapy as a use of scar treatment is supported by a study conducted by Takafumi Ohshiro, et al. [12]. On assessing over 2000 patients, they obtained significant improvement in the appearance and symptoms of scars, along with statistically significant diminishment in the scores of scar severity following treatment ($p < 0.05$). However, adapting treatment protocols to accommodate individual scar features was identified for optimal benefit [12].

The simultaneous use of these two laser modalities has a synergistic effect in treating scars by fixing color and texture deformities with an overall improvement of the skin's appearance [3,12,14].

Q-switched lasers

Q-switched lasers of ultra-short pulse durations in nanosecond lengths offer precise control of treatment parameters and, hence, are exceedingly beneficial in removing multiple skin and subcutaneous lesions [15]. Ruby, alexandrite, and Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) lasers discharge pulses of nanosecond duration, thus offering selective pigmentation and hemoglobin. All these lasers also possess numerous applications including pigmentation disorders, onychomycosis, melasma, photoaging, treatment of telangiectasias, and tattoo removal. [16].

In onychomycosis treatment, 532 nm, 694 nm, and 1064 nm Q-switched lasers are found to be effective in causing fungicidal damage to the hyphae with nail plate cleansing and promoting growth. Clinical trials have established a marked reduction in trichophyton rubrum colony size and complete clinical and mycological response with few side effects [16].

For the treatment of melasma, Q-switched lasers have also been encouraged with reductions of lesions of 50% to 74% post-treatment sessions [16]. Treatment with a combination of Q-switched lasers and adjunctive agents like topical tranexamic acid or prescription hydroquinone leads to even further enhanced results [16].

In tattoo removal, Q-switched lasers are the reference standard due to their high efficiency and safety profile. These treatments are notoriously painful, even after using topical anesthesia, and require multiple sessions in an attempt to get and maintain results [15].

Light-based therapies

Treatment comparisons: Light-based therapies consist of a variety of modalities utilized in dermatology for numerous skin disorders. Unlike lasers that yield monochromatic coherent light, light-emitting equipment such as Intense Pulsed Light (IPL) and BroadBand Light® (BBL) utilize non-coherent polychromatic sources of light [17]. This basic difference allows IPL and BBL® machines to deliver a broad spectrum of wavelengths and hence target multiple chromophores in the skin. The IPL and BBL® machines also offer adjustable parameters and larger spot sizes, offering more flexibility in treatment and coverage when used appropriately [17]. Unlike the PDL, IPL-type devices can vary and target brown as well as red colors. Although this allows for more varied treatment uses, the IPL still needs to adjust to target red, while the PDL is selectively targeted for that chromophore. For instance, a prospective randomized trial compared three 540 nm wavelength IPL treatments in treating telangiectasia of late-stage rosacea and demonstrated significantly higher efficacy compared to control groups. Three 540 nm wavelength IPL treatments every 4 weeks were significantly superior for telangiectasia of late-stage rosacea compared to control groups. Recurrence rates were lower at 2-year follow-up in the IPL group (8.41% *vs.* 48.33%) [18].

Laser hair removal

Laser types and comparisons: Laser hair reduction is a sought-after method for achieving safe and permanent hair reduction, both cosmetically and medicinally.

Compared with traditional methods such as shaving or waxing, lasers offer a permanent solution by targeting melanin in the hair shaft as well as follicular epithelium.

The process, through selective photothermolysis, is done by melanin's absorption of light, leading to thermal damage of the hair follicle and inhibiting further hair growth. The uses of these laser technologies have also been found to be beneficial in the treatment of skin ailments like keratosis pilaris, folliculitis, hyperhidrosis, and others [1,19,20,21].

The Ruby laser, having red light at 694 nm from synthetic ruby crystals, is quite effective in individuals with light-colored skin (Fitzpatrick skin types I-III) and dark-hued hair, but this laser is not utilized on a widespread scale because of the high likelihood of complications caused by melanin absorption [19]. The Alexandrite laser (755 nm) is more penetrative and suited for light-colored hair and skin (Fitzpatrick skin types I-III) [21].

Similarly, the Diode Laser (810 nm) possesses the feature of deep penetration with minimal epidermal damage, optimal for darker skin types (Fitzpatrick skin types I-V) [19]. Finally, the Nd: YAG (1064 nm) possesses adequate penetration with minimal epidermal damage that can treat deeper skin types (Fitzpatrick skin types I-VI) [5,19].

BBL® or IPL systems may also be used for hair removal with high-intensity pulses of non-coherent, polychromatic light (500-1200 nm). Since they are less intense and expensive than lasers, they also may require several sessions to achieve desired effects [5,19]. These devices must be used properly and applied on the right individual to avoid complications as well as burning, especially if the equipment is used at home.

Generally, individuals with darker skin tones will only react positively to lasers like the Nd:YAG. Skin and hair contrast color, hair thickness and color, Fitzpatrick skin types, tattoos, and so on are other considerations for laser hair removal [19].

Discussion

Risks and considerations

In dermatology, laser and light-based interventions should always be used with caution to avoid potentially dangerous and damaging risks.

They are also patients with medical conditions like active cutaneous infection, autoimmune dermatological conditions, history of keloid formation, or pregnant patients [5]. Patients with certain skin types or tones, for example, darker skin tone or recently sunburned skin, may also require additional modifications of the treatment to avoid potential unforeseen complications [5,6]. It is critical for candidates for laser treatment to have a comprehensive evaluation by a trained healthcare provider to establish candidacy and determine the safest and most optimal treatment strategy. In addition, resurfacing and vascular lasers both have a potential side effect of bruising or transient redness, swelling, and pain during and after treatment. However, their abuse can result in serious side effects in the form of burns, hyper- or hypopigmentation, and damage to the skin. Also, the potential risk of acquiring a pigmentation anomaly demonstrates that it is extremely critical to employ the laser precisely to avoid scarring or any worsening of skin condition [21,22]. Caution should also be exercised regarding the use of IPL and these machines as the risk of scarring and burning is high, especially in patients with darker skin types [22]. Irregular results may be due to the use of low-quality equipment, and therefore the need for strict quality control.

These procedures additionally come with short-term side effects, including swelling, bruising, or transient redness [21]. The qualifications and experience of the medical doctor who delivers such treatments are all-important to avoiding risks and bringing maximum benefits.

Clinicians knowledgeable in responses of the skin to laser treatments are able to personalize treatments and can avoid negative impacts. Their efficiency in settling complications ensures patients' satisfaction and protection. To that extent, then, light and laser treatment effectiveness lies with the skills and abilities of the treating doctor [23].

Future Advances

The future is bright and promising for lasers in dermatology with much scope for development in the future. Present research and development will continue to improve efficacy and extend the boundaries of dermatologic therapy.

Pivotal to this progress is the focus on chromophore specificity and laser versatility. Lasers are produced to operate on different chromophores; their targets that are specific depending on the absorption coefficients have been labeled. Hemoglobin is the most principal target of vascular lasers. This specificity in selecting lasers to suit each patient's condition accounts for the fact that today's treatment is extremely individualized, achieving maximum therapeutic benefit. Moreover, the field continues to evolve with additional targets being researched by scientists for improved accuracy and outcomes.

One of the most promising developments is Laser-Assisted Drug Delivery (LADD), which has the potential to transform not just cosmetic but medical dermatology

as well. In this procedure, a CO_2 laser is used to create microscopic pores through the skin. Because ablative lasers also produce tissue coagulation, these pores are durable, and topical agent penetration is enabled. This method significantly enhances the effectiveness of local treatment and opens new perspectives for therapy of various dermatological and medical conditions.

With ongoing progress in patient care, dermatologic lasers and LADD are rapidly developing with an incredibly promising future.

Conclusion

In summary, the role of lasers in dermatology today cannot be understated. Many diseases and disorders of the skin can be treated with lasers, which as treatment for the patient in a dermatological clinic are safe, versatile, and effective.

With the advent of every new development in laser technologies or therapies, coupled with our understanding of the physiology of the cutaneous tissue, the future is increasingly becoming more discriminant and advanced laser treatment therapy for further delivering enhanced patient outcomes and extending the boundaries of dermatologic practice. Dermatology in the future will continue to find treatment alternatives with lasers based on innovation and leading-edge evidence-based medical practice while having a commitment to provide lasers and LADD to address dermatologic pathologies and improve the quality of life for patients and individuals across the world.

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