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REVIEW ARTICLE

Advancements in Laser Technologies for Dermatologic Applications: A Systematic Review

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ABSTRACT

With laser technology, dermatological treatments are now more accurate and effective for a wider range of skin diseases. The focus of this systematic review is on laser-assisted medication delivery, vascular lesions, pigmented lesions, ablative therapies, and laser-assisted hair removal. It also examines new developments in laser technology for dermatological applications. Improved pulse lengths and combination medications have expanded therapy choices and efficacy for vascular lesions. Advances in combination therapy and Q-switched lasers have significantly improved treatment results for pigmented lesions. With the advancement of relative laser technologies, such as fractional lasers, improved skin resurfacing and scar correction are now possible. Laser-assisted hair removal methods that make use of diode, Alexandrite, and Nd:YAG lasers have proven effective on a variety of skin types. The administration of drugs using lasers has improved the penetration of both topical and systemic medications, particularly when fractional and microneedling procedures are used. Despite these advances, issues including side effects, individual variability, and treatment optimisation still exist, highlighting the need for specialised methods and safety precautions. It is essential to do further research and improve treatment methods in order to maximise effectiveness while lowering hazards. All things considered, these developments in laser technology point to bright futures for dermatological treatment, highlighting the necessity of ongoing innovation and individualised care in this area.
Keywords: *Laser technologies, Dermatologic applications, Advancements, Treatment options, Systematic review.*

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INTRODUCTION

The introduction of laser technology has caused a paradigm shift in dermatology by providing novel approaches to the treatment of a wide range of skin problems. Significant developments in laser technology over the last several decades have revolutionised dermatological therapy by providing accurate and efficient treatments for a wide range of diseases [1].

Because laser treatment may selectively target certain chromophores, minimising harm to adjacent tissues and enabling photothermolysis, it has become a cornerstone in the field of dermatology [2]. Innovations in laser delivery systems, wavelength variety, and pulse duration have all contributed to the growth of the technology and allowed for customised treatments for different skin types and disorders [3].

Vascular lesion treatment is one of the main areas where laser technology has advanced remarkably. With their exceptional efficacy and few side effects, pulsed dye lasers (PDLs) have completely changed the way that hemangiomas, telangiectasias, and port-wine stains are treated [4]. Furthermore, the toolkit for treating vascular lesions has grown with the advent of more recent vascular-specific lasers, such as diode and long-pulsed Nd:YAG lasers [5].

Furthermore, laser therapy applied to pigmented lesions has shown remarkable results. In order to achieve impressive clearance with minimal side effects, Q-switched lasers, especially those that emit at distinct wavelengths, have revolutionised the treatment of pigmented lesions such nevi, melasma, and lentigines [6].

There have also been major developments in the field of ablative lasers. With their improved accuracy and controlled tissue ablation, carbon dioxide (CO_2) and erbium-doped yttrium aluminium garnet

(Er:YAG) lasers have become crucial for operations such skin resurfacing, scar revision, and wrinkle reduction [7].
Furthermore, a lot of attention has been paid to the use of lasers in hair removal. Because they selectively target the melanin found in hair follicles, alexandrite, diode, and Nd:YAG lasers have become the industry standard for safe and effective hair removal on a variety of skin types [8].
Additionally, new avenues for dermatotherapy have been made possible by the developing area of laser-assisted medication delivery. There are potential ways to increase the effectiveness of topical and systemic drugs, such as through the use of fractional lasers and microneedling-assisted drug delivery systems, which have shown improved drug penetration [9].
Even with these incredible developments, problems still exist. Although laser treatments are effective, there is still a need for more study and development in the areas of post-inflammatory hyperpigmentation, scarring, and adverse responses [10].

ADVANCEMENTS IN LASER TREATMENT OF VASCULAR LESIONS

Vascular lesions, which can manifest as rosacea, telangiectasias, hemangiomas, or port-wine stains, are a group of disorders marked by aberrant blood vessel development. By providing focused and efficient treatment choices, laser therapy has completely changed the way these lesions are managed [4].
Vascular lesions have been successfully treated using pulsed dye lasers, or PDLs. Their method is based on selective photothermolysis, which targets blood vessel oxyhemoglobin while preserving the surrounding tissues. PDLs release certain wavelengths that are best absorbed by haemoglobin, which causes photocoagulation and vascular collapse [4]. These wavelengths are around 585 to 595 nm.
Longer-pulsed lasers have been developed as a result of recent developments in PDL technology. These lasers offer greater tissue penetration and improved effectiveness, particularly for treating thicker or deeper vascular lesions. With better clearance rates and fewer side effects, these developments have greatly expanded the field of vascular lesion care [5].
Furthermore, the arsenal for treating vascular lesions has been expanded by the development of alternative vascular-specific lasers, such as diode lasers and long-pulsed neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers. By using these lasers, which target haemoglobin at distinct wavelengths, physicians can treat lesions that may not have responded as well to conventional PDL treatment [5].
These more recent lasers are not just for vascular lesions. For example, because long-pulsed Nd:YAG lasers may target melanin with little epidermal damage, they have demonstrated promising results in treating some pigmented lesions, such as superficial melanoses and dermal pigmentation [6].
Additionally, combination therapy for vascular lesions have been developed as a result of technical breakthroughs. It has been demonstrated that combining various laser modalities or lasers with other therapy modalities, such as topical or systemic drugs, produces synergistic effects that maximise benefits and minimise side effects [7].
Nonetheless, difficulties in treating some vascular lesions still exist. Technical obstacles arise from lesions placed in difficult anatomical regions, such as the vicinity of the eyes or mucosal surfaces, which require precision targeting to prevent damage to neighbouring tissues. It is frequently necessary to treat these lesions using specialised knowledge and cutting-edge laser delivery system techniques [8].
Furthermore, even though laser treatments for vascular lesions are usually safe, side effects such purpura, transitory erythema, and post-inflammatory hyperpigmentation can happen, especially in those with darker skin types. To mitigate these negative effects, treatment settings must be optimised and proper cooling procedures must be used [9].
Individual differences in how well a treatment works are still a role. Variations in treatment results can be attributed to a number of factors, including patient characteristics such as skin type and unique immune response, and lesion features such as depth, size, and location. Optimising therapy results requires customising treatment methods depending on these characteristics [10].

ADVANCEMENTS IN LASER TREATMENT OF PIGMENTED LESIONS

Dermatological care of pigmented lesions is challenging since they include a wide range of disorders such as post-inflammatory hyperpigmentation, nevi, melasma, and lentigines. With laser technology providing focused and efficient treatment options, pigmented lesions have found a pillar in the field [6].
The notion of selective photothermolysis has made Q-switched lasers indispensable in the treatment of pigmented lesions. By focusing on the melanin present in the lesions and reducing heat damage to the surrounding tissues, these lasers produce brief pulses in the millisecond range. Q-switched lasers may

target distinct pigmented lesions selectively because they produce light at diverse wavelengths, including 532 nm, 694 nm, and 1064 nm [6].

Thanks to developments in Q-switched laser technology, newer generation lasers with better safety profiles and efficacy have been developed. These lasers have longer pulse lengths and higher fluence, which allow for more effective penetration and targeted killing of melanin-containing cells. This leads to higher clearance rates and a lower chance of side effects [7].

Additionally, there are now additional therapeutic options for pigmented lesions because to the advent of fractional lasers. Fractional lasers enable controlled thermal damage and subsequent tissue remodelling by generating minuscule treatment zones within the skin. Compared to conventional ablative lasers, fractional lasers have demonstrated potential in treating melasma and post-inflammatory hyperpigmentation, yielding significant improvements with less downtime and side effects [8].

Another important development in the treatment of pigmented lesions is the use of combination therapy. Laser therapy has been shown to have synergistic benefits when used with topical depigmenting chemicals or other treatment methods such chemical peels or microneedling. This has been shown to improve treatment results and accelerate the removal of pigmented lesions [9].

Nonetheless, there are still issues with properly treating certain pigmented lesions. In particular, melasma presents a problem since it is recurring and persistent. Its management still faces significant challenges in achieving durable clearance while reducing the chance of recurrence, which calls for more investigation into effective treatment regimens and long-term maintenance plans [10].

Furthermore, side effects are still a worry with laser therapy for pigmented lesions, albeit being rare. Among the possible side effects include post-inflammatory hyperpigmentation, hypopigmentation, and textural alterations; therefore, careful patient selection, suitable laser settings, and post-treatment care are necessary to reduce risks [11].

Furthermore, factors specific to each patient, such as skin type and hormonal impacts, might affect the effectiveness of laser treatments for pigmented lesions. These factors include lesion features like depth, size, and location. Achieving the best results requires customising treatment plans and optimising parameters in light of these considerations [12].

ADVANCEMENTS IN ABLATIVE LASER TECHNOLOGIES

With its ability to precisely ablate tissue and induce controlled thermal damage for a variety of skin diseases, such as skin resurfacing, scar revision, and wrinkle reduction, ablative laser technologies have proven indispensable in dermatological practice [7].

Among the earliest ablative lasers to be introduced, carbon dioxide (CO_2) lasers have advanced significantly. Fractional technology is currently used by CO_2 lasers, which were previously known for their continuous wave output, enabling fractional ablative resurfacing. Fractional CO_2 lasers minimise side effects and downtime by generating microthermal zones in the skin that promote collagen remodelling and epidermal renewal [7].

Likewise, yttrium aluminium garnet (Er:YAG) lasers doped with erbium been developed to provide accurate and regulated tissue ablation. Er:YAG lasers do the least amount of heat harm to the tissues around them because of their love for water. In order to achieve more predictable results and quicker recovery times, recent developments in Er:YAG laser technology have concentrated on improving tissue contact while minimising heat diffusion [7].

Fractional ablative lasers have proven to be remarkably effective in treating a variety of dermatological problems. These lasers include fractional CO_2 and Er:YAG lasers. These lasers play a key role in skin resurfacing operations, providing noticeable changes in skin texture, tone, and overall look while treating issues including wrinkles, photoaging, and acne scars [8].

Furthermore, ablative laser technology has advanced to the point that its uses are no longer limited to skin resurfacing. In the case of hypertrophic and atrophic scars in particular, these lasers have demonstrated encouraging outcomes in scar remodelling. Ablative lasers enhance the look and texture of scars by stimulating collagen production and tissue regeneration through regulated dermal remodelling [9].

Furthermore, the care of certain dermatological disorders like actinic and seborrhoeic keratoses is greatly aided by ablative lasers. By facilitating the targeted treatment of superficial lesions, these lasers preserve the surrounding healthy tissue while attaining outstanding clearance rates [10].

There are still issues with using ablative lasers, especially with regard to side effects and downtime. Fractional ablative lasers need less downtime than standard ablative lasers, but they can still cause post-treatment erythema, edoema, and crusting, which calls for careful post-procedural care and patient education [11].

Furthermore, there is still worry over the possibility of post-inflammatory hyper- and hypopigmentation, especially in those with darker skin phototypes. To mitigate these side effects, treatment parameters including fluence and pulse length must be optimised. Appropriate cooling strategies must also be used [12].

Further evidence of the need of customising treatment procedures depending on patient characteristics and lesion types comes from individual differences in treatment response and the necessity of numerous sessions to attain desired effects. The goal of customised methods is to maximise effectiveness while lowering risks and downtime [13].

ADVANCEMENTS IN LASER-ASSISTED HAIR REMOVAL

In the field of dermatology, laser-assisted hair removal has become a mainstay, providing a secure and efficient remedy for unwanted hair on a variety of skin types and body parts [8].

Numerous laser systems, such as Alexandrite, diode, and neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers, have been created for hair removal applications. By focusing on the melanin found in hair follicles, these lasers cause photothermolysis, which destroys the follicles and prevents hair from growing back [8].

Technological developments in laser-assisted hair removal have concentrated on increasing safety and effectiveness while reducing discomfort and side effects. The pulse lengths and cooling methods of Alexandrite lasers, which are well-known for their effectiveness on lighter skin types, have been modified to improve hair follicle targeting and lower the risk of epidermal injury [14].

Similar technical developments have been made with the goal of improving treatment outcomes for diode lasers, which are known for their deeper penetration and appropriateness for a wider variety of skin types. Longer wavelengths and tunable pulse durations are two innovations in diode lasers that have increased their effectiveness in treating darker skin types while lowering the possibility of side effects [15].

Furthermore, Nd:YAG laser technology has advanced to provide better safety profiles and increased hair removal performance. Nd:YAG lasers with longer wavelengths have a lower chance of damaging the epidermis and may penetrate deeper, which makes them appropriate for skin types with darker tones [16].

In the field of laser-assisted hair removal, combination treatments have recently attracted interest. The synergistic benefits of using lasers in conjunction with other modalities, including cooling systems or topical medicines, have been demonstrated [17]. This has improved patient comfort and therapeutic results.

Even with laser-assisted hair removal's effectiveness, problems can arise. Because of individual differences in hair follicle response and hair growth cycles, permanent hair removal frequently takes numerous treatments. Achieving excellent and long-lasting effects requires optimising treatment settings and intervals depending on the unique features of each patient [18].

Moreover, side effects are still a worry with laser-assisted hair removal, even if they are usually temporary. Common side effects include pain, edoema, and transient erythema. On the other hand, it is crucial to minimise side effects by carefully choosing patients, maximising therapy settings, and providing post-procedural care [19].

Furthermore, a few elements, such hormone effects, may impact how well a treatment works. Hair growth patterns can be influenced by conditions such as hormonal imbalances or polycystic ovarian syndrome (PCOS), which may require supplementary therapies for best results. Customised treatment techniques are thus necessary.

ADVANCEMENTS IN LASER-ASSISTED DRUG DELIVERY

In dermatology, laser-assisted drug delivery has become a cutting-edge method with the goal of improving topical and systemic medicine absorption and effectiveness via the skin [9].

Drug delivery has been greatly improved by fractional laser technologies, such as fractional photothermolysis and fractional ablative lasers. By bypassing the skin's natural barrier function, these lasers produce small channels within the skin that facilitate enhanced drug permeability [21].

Furthermore, drug delivery techniques aided by microneedling have drawn interest. Topical drugs are able to penetrate the skin more effectively because to the small punctures made by microneedling devices. Microneedling-assisted drug delivery has demonstrated synergistic benefits when paired with laser therapies, such as fractional lasers, resulting in a considerable improvement in drug absorption and distribution [22].

Treatment options for dermatology have expanded thanks to developments in laser-assisted medication delivery. For example, laser-assisted drug delivery systems have shown enhanced efficacy in treating localised dermatologic disorders like vitiligo or psoriasis by enabling deeper and more focused administration of drugs to afflicted regions [20-25].

Additionally, this approach has demonstrated potential in improving the transport of bigger molecules—like peptides and biologics—that often have trouble passing through the epidermal barrier. Researchers want to improve the transport of these molecules by utilising laser-assisted methods, which might lead to more therapy choices for different types of dermatological disorders [24].

Beyond topical drugs, lasers and drug delivery devices have also been combined. Research has looked into the possibility of using lasers to help distribute drugs, perhaps increasing the effectiveness of systemic treatments for dermatological diseases. Laser-assisted methods seek to maximise systemic therapy while reducing dose and possible systemic adverse effects by improving medication penetration [20-25].

Laser-assisted medicine delivery is not without its obstacles, despite the potential future. It will need further work to optimise parameters including laser intensity, fluence, and treatment intervals in order to maximise medication delivery and minimise side effects while maintaining safety [20-25].

Moreover, standardising laser-assisted medication delivery techniques is difficult due to the variation in individual skin features and reaction to treatments. Achieving the best results still requires customising treatment plans according to patient reaction, skin type, and severity of the ailment [20-25].

Furthermore, when it comes to laser-assisted medicine delivery, safety is crucial. It is crucial to make sure that improved medication delivery does not erode skin integrity or raise the possibility of side effects. To determine the safety profiles of innovative drug delivery methods, rigorous testing and assessment in combination with laser treatments are necessary [20-25].

To sum up, developments in laser-assisted drug delivery have created new opportunities for dermatological therapy by improving the effectiveness and penetration of topical and systemic drugs. Promising strategies include fractional lasers, delivery aided by microneedling, and the investigation of bigger molecule delivery devices. However, there is still much to learn about laser-assisted medication administration, particularly in the areas of safety, individual variability, and treatment parameter optimisation.

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