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Impact of dual wavelength laser therapies in the treatment of hypertrophic scars and keloids: a systematic review

Impacto de las terapias con láser de doble longitud de onda en el tratamiento de cicatrices hipertróficas y queloides: una revisión sistemática

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ABSTRACT

Common skin diseases arising from improper wound healing, hypertrophic scars and keloids, may have a substantial influence on patients' quality of life. They are characterized by elevated, hard scars with varied color. The purpose of this narrative review is to evaluate the safety and efficacy of dual-wavelength laser therapy for the treatment of keloids and hypertrophic scars. A thorough literature analysis was carried out, including research from reputable sources like Google Scholar and PubMed. The review examined the mechanisms of action, safety profiles, and clinical results of dual-wavelength laser systems. Dual-wavelength lasers show notable changes in texture and elasticity as well as a considerable decrease in scar visibility. PDL (585–595) and Nd lasers (1064 nm) work well together to target deeper dermis layers as well as superficial vascularity. Clinical tests show significant improvements in skin texture and tone as well as a 40% decrease in scar scores. For example, the dual-wavelength technique led to significant improvements in patient satisfaction and reductions in Vancouver Scar Scale ratings. Positive safety profiles include mild and temporary side effects including pain and erythema. When treating complicated scars, the dual-wavelength approach consistently works better than single-wavelength lasers. Dual-wavelength laser treatments provide a complete and successful management strategy for keloids and hypertrophic scars. Although the results are encouraging, further studies using standardized methods and longer follow-up periods are required to confirm these outcomes and improve treatment plans.

Keywords: dual-wavelength lasers. hypertrophic scars. keloids. scar treatment. laser therapy.

RESUMEN

Las enfermedades cutáneas comunes que surgen de una cicatrización inadecuada de heridas, cicatrices hipertróficas y queloides pueden tener una influencia sustancial en la calidad de vida de los pacientes. Se caracterizan por tener cicatrices elevadas, duras y de color variado. El propósito de esta revisión narrativa es evaluar la seguridad y eficacia de la terapia con láser de doble longitud de onda para el tratamiento de queloides y cicatrices hipertróficas. Se llevó a cabo un análisis exhaustivo de la literatura, incluida investigación de fuentes acreditadas como Google Scholar y PubMed. La revisión examinó los mecanismos de acción, los perfiles de seguridad y los resultados clínicos de los sistemas láser de doble longitud de onda. Los láseres de doble longitud de onda muestran cambios notables en la textura y elasticidad, así como una disminución considerable en la visibilidad de las cicatrices. Los láseres PDL (585–595) y Nd (1064 nm) funcionan bien juntos para apuntar a las capas más profundas de la dermis, así como a la vascularización superficial. Se llevó a cabo un análisis exhaustivo de la literatura, incluida investigación de fuentes acreditadas como Google Scholar y PubMed. La revisión examinó los mecanismos de acción, los perfiles de seguridad y los resultados clínicos de los sistemas láser de doble longitud de onda. Los láseres de doble longitud de onda muestran cambios notables en la textura y elasticidad, así como una disminución considerable en la visibilidad de las cicatrices. Los láseres PDL (585–595) y Nd (1064 nm) funcionan bien juntos para apuntar a las capas más profundas de la dermis, así como a la vascularización superficial. Las pruebas clínicas muestran mejoras significativas en la textura y el tono de la piel, así como una disminución del 40 % en las puntuaciones de las cicatrices. Por ejemplo, la técnica de longitud de onda dual condujo a mejoras significativas en la satisfacción del paciente y reducciones en las calificaciones de la Escala de cicatrices de Vancouver. Los perfiles de seguridad positivos incluyen efectos secundarios leves y temporales, como dolor y eritema. Cuando se tratan cicatrices complicadas, el enfoque de longitud de onda dual siempre funciona mejor que los láseres de longitud de onda única. Los tratamientos con láser de doble longitud de onda proporcionan una estrategia de tratamiento completa y exitosa para los queloides y las cicatrices hipertróficas. Aunque los resultados son alentadores, se necesitan más estudios que utilicen métodos estandarizados y períodos de seguimiento más prolongados para confirmar estos resultados y mejorar los planes de tratamiento.

Palabras clave: láseres de doble longitud de onda. cicatrices hipertróficas. queloides. tratamiento de cicatrices. terapia con láser.

INTRODUCTION

Common skin problems that arise from aberrant wound healing include keloids and hypertrophic scars (Seifert & Mrowietz, 2009). Any area of the skin's surface that has been traumatized or infected can be affected; however, keloid and hypertrophic scars are more likely to form on the skin's more elastic areas, such as the trunk, upper arm/shoulder (deltoid region), and knees. When palpated, they feel hard and have a smooth, raised scarred surface. Their color may range from pink-purple to light (hypopigmented) to black (hyperpigmented). They may be linked to symptoms including discomfort and pruritus, or itching. According to Bock et al, individuals with keloid and hypertrophic scars may experience a reduction in their quality of life as a result of the psychological and physical effects of these scars (Bock et al., 2006).

Hypertrophic scars and keloids are thought to be more likely to develop in certain situations due to the anatomical location of the initial skin lesion, a history of trauma or infection related to the initial injury, burn injuries, sutures under tension, adolescence, pregnancy, and family history (Alster & Tanzi, 2012)(Seifert & Mrowietz, 2009). Multiple cells and chemical substances cooperate to support tissue restoration throughout the normal healing process. The natural healing process of a scar is attributed to the balance between the creation and degradation of collagen throughout this phase. This equilibrium is thrown off in keloids and hypertrophic scars, with increased collagen synthesis and decreased collagen breakdown (Cho et al., 2010). Overgrowth of scar tissue arises from the accumulation of collagen inside the lesion. There are some clinical, biological, and evolutionary distinctions between hypertrophic scars and keloids despite their similarities (Seifert & Mrowietz, 2009).

The formation of keloid and hypertrophic scars is influenced by genetic predisposition and skin damage (Alster & Tanzi, 2012). Although they may develop at any age, keloids often affect people in the 10 to 30 age range. Their occurrence varies from 4.5% to 16% in Black and Hispanic groups, and it may reach up to 16% in Black African people (Alster 2003). In people with lighter complexion, they are less common. Hypertrophic scars range in frequency from 5% to 37% in white individuals (Li-Tsang et al., 2005), suggesting that their occurrence is likely greater than that of keloid scars, while exact statistics are not available. According to Li-Tsang (2005), the percentage of white individuals with hypertrophic scars varies from 15% to 63% (Li-Tsang et al., 2005). After therapy, both hypertrophic and keloid scars often return (Cassuto et al., 2010).

As a result of the lesions' recurring nature, gradual progression, and lack of a proven treatment, treating hypertrophic scars and keloids is very difficult (Cassuto et al., 2010). The main therapeutic approaches for treating hypertrophic and keloid scars include medications, compressive measures, surgical procedures, radiation therapy, and light therapy.

Corticosteroids are regarded as first-line medications for the treatment of hypertrophic and keloid scars; they are often administered intralesionally (Gupta & Sharma, 2011). Other medications include intralesional 5-fluorouracil and intralesional bleomycin (Alster & Tanzi, 2012). Many kinds of silicone are employed, such as gel, cream, spray, or flexible gel sheets. Cryosurgery is a surgical procedure that induces tissue ischaemia, or a decrease in blood flow, and scar tissue necrosis. This makes it a beneficial therapy. It is also possible to do surgeries to eliminate the scar's volume, core, or whole (Gupta & Sharma, 2011). Additional therapies include the use of light sources like laser therapy and Intense Pulsed Light (IPL), which attempts to induce vascular ischaemia by interfering with the formation of collagen (Erol et al., 2008).

Laser therapy was created in the 1980s to treat keloid lesions, and many kinds of lasers with various wavelengths were investigated and recorded (Zin & Singthong, 2024). Due to its better outcomes, medical experts have lately concentrated on laser therapy for keloids, and they are doing research to compare its efficacy to other therapies already in use. Lasers that are vascular, ablative, or non-ablative are now being used widely (Zin & Singthong, 2024). Furthermore, after analyzing the data from many laser devices, Mamalis et al. (2014) came to the conclusion that laser treatment techniques result in better patient outcomes than other procedures (Mamalis et al., 2014).

Dual-wavelength laser treatments have gained popularity recently as an innovative scar therapy method. These technologies enable the simultaneous or sequential targeting of numerous tissue components by combining two distinct wavelengths into a single device. One such PDL derivative technology is the dual-wavelength laser (DWL), which combines PDL and Nd:YAG lasers into a single device. It operates at 585 nm for PDL and 1064 nm for neodymium-doped yttrium aluminum garnet (Nd:YAG). Two types of lasers with varying wavelengths are sequentially emitted by the apparatus. To accomplish the therapeutic goal, PDL generates a yellow light pulse with a wavelength of 585 nm, which works on the hemoglobin (HGB) in the focus to absorb it. This causes RBCs to be destroyed and capillaries to coagulate (Wen et al., 2024). PDL causes the blood's hemoglobin (HGB) to momentarily change into a mixture of methaemoglobin and thrombus. This results in a stronger absorption of the Nd:YAG laser, three to five times stronger than that of a single 1064 nm wavelength. While the body of research on laser therapy generally is insightful there aren't many thorough evaluations that concentrate on dual-wavelength lasers. To fill this knowledge gap, this narrative review summarizes the most recent research on the effectiveness of dual-wavelength laser therapy for the treatment of keloids and hypertrophic scars.

METHODOLOGY

To assess the impact of dual-wavelength laser therapies on the treatment of hypertrophic scars and keloids, a narrative review was conducted. This review involved a thorough examination of available literature from reliable databases, including PubMed, Google Scholar, and Scopus. The search was performed within a timeframe spanning from 2018 to 2023. The key search terms used included "dual-wavelength laser," "hypertrophic scars," "keloids," "Pulsed Dye Laser (PDL)," "Nd laser," "laser therapy efficacy," "laser safety," and "scar remodeling."

Inclusion and Exclusion Criteria

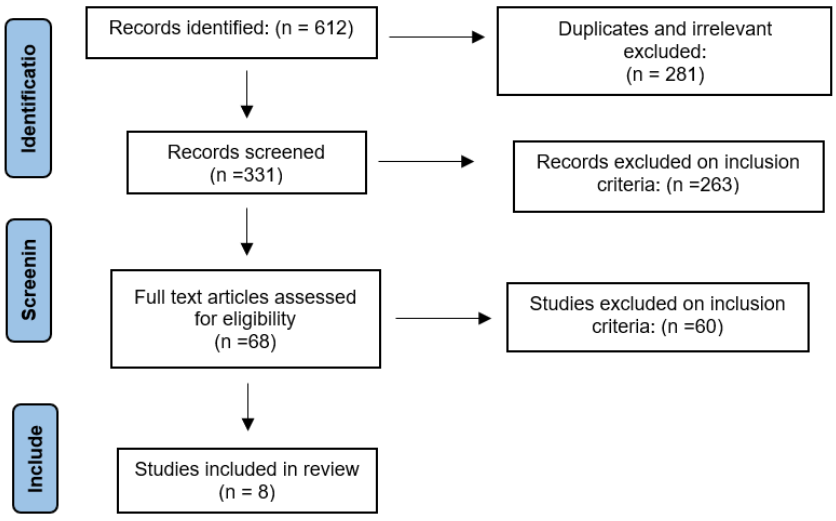
Studies were included in the review if they reported on the use of dual-wavelength laser therapies in treating hypertrophic scars and keloids, specifically human studies published in English within the specified period. Articles that provided detailed information on clinical outcomes, safety, and efficacy of these treatments were prioritized. Studies that did not meet these criteria, lacked methodological rigor, or did not contribute significantly to the understanding of dual-wavelength laser therapies in scar treatment were excluded from the review. Each included study was critically evaluated for its relevance and applicability to the review's objectives.

Categorization and Analysis

The selected studies were categorized based on key themes such as the mechanism of action, clinical efficacy, safety profile, patient outcomes, and comparison with single-wavelength laser treatments. Narrative analysis was performed to synthesize the findings, focusing on the mechanisms by which dual-wavelength lasers influence scar remodeling, the safety and efficacy of these therapies, and their overall impact on patient outcomes. This approach provided a comprehensive understanding of the potential advantages and limitations of dual-wavelength laser therapies in the management of hypertrophic scars and keloids.

Los recursos humanos empleados fueron: muestra de adolescentes de entre 12 - 19 años matriculados en el periodo 2019 – 2020 en la Unidad Educativa San Francisco de Asís de la ciudad de Loja; autoridades: de la Universidad Nacional de Loja (UNL), específicamente Decano de la Facultad de la Salud humana (FSH), y Directora de la Carrera de Medicina, Rector de la Unidad Educativa "San Francisco de Asís", Padre Luis Antonio Merino Guanga; la tesista: Alejandra Patricia Rosario Poma y Directora de tesis: Dra. Verónica Montoya Jaramillo. Mg. Sc. Los recursos materiales utilizados fueron: equipos, suministros, reactivos e instalaciones.

Figure 1. Method



Source; the authors.

RESULTS

Mechanism of Action

To cure scars of different kinds, such as hypertrophic scars, keloids, and acne scars, dual-wavelength laser treatments have shown promise. The use of many laser wavelengths in combination enables a thorough treatment plan that addresses various skin layers, leading to better clinical results and accelerated scar reformation.

Dual-wavelength lasers work by simultaneously targeting the outermost and innermost layers of skin, which is their mechanism of action. The microvasculature inside scars may be effectively targeted by the Pulsed Dye Laser (PDL), which commonly operates at wavelengths between 585 and 595 nm. By causing blood vessels to coagulate, this procedure lessens the scar's overall vascularity, redness, and inflammation. But, Nd lasers, which function at 1064 nm, reach farther into the dermal layer, encouraging the remodeling of collagen and the flattening of scars. Comparatively speaking, dual-wavelength lasers provide a more comprehensive therapeutic method since they attack the vascular as well as the collagen components of scars. A key factor in decreasing the size and prominence of these scars is blood circulation in keloids, which was dramatically decreased in the Xu et al. (2021) research using dual-wavelength PDL and Ndlasers together (Xu et al., 2021). To address various aspects of facial photoaging, acne scars, and surgical scars, dual-wavelength laser systems, such as those that combine 532/1064 nm picosecond Nd lasers with other wavelength combinations like 589/1319 nm, work in concert to penetrate different layers of the skin. When applied to the surface layers of the skin, the 532 nm wavelength efficiently reduces pigmentation and vascular components; conversely, the 1064 nm wavelength goes deeper into the dermis to encourage neocollagenesis and collagen remodeling.

In Zhang et al.'s research, for example, dual-wavelength picosecond lasers were shown to be able to enhance skin texture and elasticity by remodeling the collagen and elastin network via vascular injury and laser-induced optical degradation (Zhang et al., 2021). Similar benefits in surgical scars were seen by Vas et al. with their combined 585 nm PDL and 1064 nm Nd laser therapy, as shown by in vivo confocal microscopy (RCM) observations of decreased vascularity and altered collagen. According to these research, dual-wavelength lasers are preferable in treating complicated skin diseases because they can concurrently address superficial and deeper skin disorders.

Safety

Any therapeutic intervention must take patient safety into account, and the evaluated studies consistently show that dual-wavelength laser treatments are both patient-friendly and safe. Li Lin et al. (2018) found that after numerous sessions of combined PDL/Nd laser treatments, no serious side effects were seen in 25 Chinese patients with hypertrophic scars (Lin et al., 2019). The majority of adverse effects that were recorded were modest and temporary, such as erythema and mild pain, and they usually went away quickly. Xu et al. (2021) corroborate these results by observing that the therapy was safe and had no appreciable side effects in their prospective trial, which included 21 keloids patients (Xu et al., 2021). This research also highlighted that lower energy settings were possible with the dual-wavelength technique, which probably helped to lessen the occurrence of side effects including hyperpigmentation and scarring, which are often linked to single-wavelength lasers.

Zhang et al. observed similar safety in treating face photoaging with both the 1064 nm and 532/1064 nm picosecond laser treatments, showing no significant differences in histological alterations or side effects (Zhang et al., 2021). No significant long-term adverse effects were seen in the research by Yang et al., which covered 18 patients receiving therapy for acne scars with a fractionated dual-wavelength picosecond laser, highlighting the safety of this method.

Additionally, Vas et al. demonstrated the safety of combined 1064 nm Nd laser and 585 nm PDL laser therapies for surgical scars, seeing no serious side effects (Vas et al., 2014). The moderate and quickly resolved temporary adverse effects, such as intraepidermal vacuoles and dermal hemorrhaging, were reported. The study by Fiorentini et al. further confirms the safety of dual-wavelength laser treatments across various applications by treating abdominal postsurgical scars with a combination of 10,600 nm CO2 fractional laser and 1540 nm laser. The combination produced a significant scar improvement without any reported patient pain or adverse effects.

Efficacy

Numerous studies have shown that dual-wavelength laser treatments are very effective, as seen by the notable changes in scar appearance, texture, and patient satisfaction. According to Li Lin et al. (2018), after many sessions of dual-wavelength laser therapy, hypertrophic scars dramatically improved, and ratings from both patients and observers indicated high levels of satisfaction (Lin et al., 2019). These gains were measured in the research using the validated instruments for

assessing scar outcomes, the Patient Scar Assessment Scale (PSAS) and Observer Scar Assessment Scale (OSAS). Following four sessions of dual-wavelength laser therapy for keloids, Xu et al. (2021) also noted a substantial decrease in Vancouver Scar Scale (VSS) scores (Xu et al., 2021). There was a substantial association (R^2 = 0.84) between decreased vascularity and better scar appearance, and the drop in VSS scores was followed by a decrease in blood perfusion as determined by Laser Speckle Contrast Imaging (LSCI). Dual-wavelength lasers (1319 nm and 589 nm) were used to treat acne scars in a study by Gold et al. (Gold et al., 2019). After four treatment sessions, there was a significant 40% reduction in the ECCA (Echelle d'évaluation clinique des cicatrices d'acné) score, providing additional evidence of the efficacy of dual-wavelength lasers in scar management.

Zhang and colleagues showed that after five treatment sessions, the 1064 nm and 532/1064 nm picosecond lasers dramatically decreased global photoaging scores. According to the research, neocollagenesis and elastic fiber rearrangement were shown histologically in both groups, demonstrating successful remodeling of the skin's structural elements. The dual-wavelength picosecond laser is effective in healing acne scars; Yang et al. found that after six treatment sessions, the global acne scarring grading system (GSS) scores of Goodman and Baron significantly decreased (Yang et al., 2020). A significant decline in the Visual Analog Scale (VAS) pain levels was also seen in the research, indicating that the therapy was not only successful but also well-tolerated by the patients.

The Vancouver Scar Scale (VSS) ratings of surgical scars were shown to be greatly reduced when combined PDL and Nd laser treatments were applied, according to research by Vas et al (Vas et al., 2014). Significant improvements in photographic evaluations conducted over a six-month period shown in the research by Fiorentini et al. further supported the effectiveness of dual-wavelength laser therapy in enhancing the texture and color of abdominal postsurgical scars.

Positive Outcomes

High patient satisfaction rates and notable clinical changes in scar characteristics are indicative of the benefits of dual-wavelength laser therapy. According to Li Lin et al. (2018), scar texture and look significantly improved in patients treated with dual-wavelength lasers for hypertrophic scars, and these favorable results were reflected in satisfaction ratings (Lin et al., 2019). According to Xu et al. (2021), there was a significant decrease in both blood perfusion and VSS scores in chest keloids (Xu et al., 2021). This implies that dual-wavelength lasers might be particularly useful in treating scars in this specific anatomical area. A substantial improvement in the majority of acne scarring patients was reported in the Gold et al research after dual-wavelength laser therapy; decreases in ECCA scores were noted at both the short-term (1-month post-treatment) and long-term (6 months post-treatment) follow-ups (Gold et al., 2019).

Participants in Zhang et al.'s research expressed satisfaction with both the 1064 nm and 532/1064 nm picosecond laser treatments for face photoaging, as well as high Global Aesthetic Improvement Scale (GAIS) ratings (Zhang et al., 2021). In a similar vein, Yang et al.'s research revealed that individuals treated for acne scars had significant changes in the look of their skin, with VAS ratings falling from 4.28 at baseline to 2.00 after treatment (Yang et al., 2020).

Similar results in treating surgical scars were reported by Vas et al., whose patients had notable changes in scar quality and appearance after receiving combined PDL/Nd laser therapy (Vas et al., 2014). Fiorentini et al.'s study's photographic examination, which demonstrates significant changes in the texture and color of abdominal scars after treatment, adds further evidence to the beneficial effects of dual-wavelength lasers (Fiorentini & Fusco, 2023).

Comparison with Single Wavelength Lasers

When it comes to treating complicated and resistant scars, dual-wavelength lasers have clear benefits over single-wavelength lasers. In a randomized controlled study, Wen et al. (2023) examined the efficacy of combining betamethasone injection (BI) with dual-wavelength laser therapy vs BI alone in the treatment of keloids (Wen et al., 2024). According to the research, the group that had dual-wavelength laser treatment showed better results than the group that just received BI, with larger decreases in keloid volume and VSS scores. The advantages of dual-wavelength lasers are increased by combining the powers of PDL, which is best at decreasing scar vascularity, and Nd, which is excellent at flattening scars and enhancing skin texture (Zin & Singthong, 2024). According to these results, dual-wavelength lasers, as opposed to single-wavelength lasers, seem to provide a more thorough and successful course of therapy, especially for those with complicated scarring problems.

The dual-wavelength technique has the benefit of concurrently targeting several layers of the skin, however Zhang et al.'s randomized controlled split-face trial revealed no significant difference in photoaging results between the 1064 nm and 532/1064 nm picosecond laser treatments (Zhang et al., 2021). The dual-wavelength technique considerably reduced surgical scars by targeting both vascularity and collagen deposition, a goal that may not be as efficiently attained with single-wavelength lasers, according to research by Vas et al. comparing combined PDL/Nd laser therapy with untreated controls.

Conversely, single-wavelength lasers have limited overall effectiveness since they usually only treat certain aspects of skin diseases, including deeper dermal remodeling or surface pigmentation (Vas et al., 2014).

DISCUSSION

In comparison to more conventional single-wavelength laser treatments, dual-wavelength laser therapies have shown significant promise in the treatment of hypertrophic scars and keloids. They provide a more thorough and efficient method. The improved results shown in several experiments may be attributed in large part to the capacity to target multiple layers of the skin concurrently with different wavelengths.

Because dual-wavelength laser treatments may target many layers of the skin at once, they have been shown to provide improved results. Dual-wavelength lasers, including those that combine Nd and Pulsed Dye Lasers (PDL), treat the vascular as well as the collagen components of scars, as the outcomes section explains. Due to its ability to reduce scar vascularity and encourage collagen remodeling, dual targeting is essential for more thorough scar treatment. Targeting both superficial and deeper skin layers has a synergistic impact that significantly improves scar look and texture, as shown by the research by Zhang et al. and Xu et al. (2021).

Any therapeutic intervention must prioritize safety, and the evaluated trials repeatedly show that dual-wavelength laser treatments are both safe and well-tolerated by patients. The most often reported adverse effects were slight pain and temporary erythema, which went away soon. Significantly, as Xu et al. (2021) pointed out, dual-wavelength lasers may employ lower energy settings, which probably helps to lessen the occurrence of side effects including hyperpigmentation and scarring, which are more often linked to single-wavelength lasers. The lack of notable negative outcomes in the examined research, such as those conducted by Li Lin et al. (2018) and Yang et al., supports the safety of dual-wavelength laser treatments for a variety of patient demographics and scar types. Dual-wavelength lasers are becoming more and more used in clinical practice, mostly due to their good safety profile.

It is well known that dual-wavelength lasers are effective in enhancing scar appearance and patient satisfaction. Patients with hypertrophic scars, keloids, and acne scars treated with dual-wavelength lasers reported significant changes in scar texture, color, and overall appearance across many trials, including those by Li Lin et al. (2018) and Gold et al. (2019). Utilizing proven evaluation tools, including the Vancouver Scar Scale (VSS), Observer Scar Evaluation Scale (OSAS), and Patient Scar Assessment Scale (PSAS), provides objective proof of these advancements.

The good effects of dual-wavelength laser treatments are further supported by the high patient satisfaction rates reported in studies by Zhang et al. and Shapiro et al. Patients reported less pain and discomfort throughout treatment in addition to seeing apparent changes in their scars, which added to a more positive treatment experience overall. A very persuasive conclusion drawn from this research is the relative benefit of dual-wavelength lasers in comparison to single-wavelength lasers. Dual-wavelength lasers are a more successful alternative for complicated and resistant scars because they may address numerous elements of scar pathophysiology, including vascularity, collagen remodeling, and pigmentation. Dual-wavelength lasers perform better than single-wavelength lasers in lowering scar severity and enhancing clinical outcomes, according to randomized controlled studies by Zhang et al. and Wen et al. (2023). Dual-wavelength lasers provide a more thorough approach that is not possible with single-wavelength lasers due to their wider therapeutic spectrum, which addresses both superficial and deeper skin issues.

High levels of patient satisfaction are indicative of the beneficial effects of dual-wavelength laser treatments, as are clinical measurements. Research has repeatedly shown that patients' scars seem and feel much better, which adds to their overall satisfaction with the course of therapy. Dual-wavelength laser systems should be included into routine clinical practice to treat hypertrophic scars and keloids, according to the data reported in this study. Dual-wavelength lasers are a preferable option, especially for patients with complicated scarring disorders, because to their increased effectiveness, attractive safety profile, and high patient satisfaction rates.

CONCLUSION

With dual-wavelength laser therapy, scar appearance and texture are significantly improved, which is a major development in the treatment of hypertrophic scars and keloids. A multimodal method that targets the vascular and collagen components of scars is made possible by the combination of wavelengths, such as those from Nd lasers and pulsed dye lasers. This improves scar reformation and increases patient satisfaction. The evaluated research consistently demonstrates that dual-wavelength lasers have a good safety profile and are useful in lowering scar redness, thickness, and overall visibility.

These results highlight the potential for dual-wavelength laser treatments to provide a completer and more efficient therapeutic alternative as compared to single-wavelength lasers.

This review has a few drawbacks in spite of the encouraging outcomes. The included research' differing approaches, approaches to therapy, and methods for measuring results might have an impact on how consistently and broadly the results can be applied. A thorough evaluation of long-term effectiveness and safety was further hampered by the small sample numbers and brief follow-up durations of several of the trials. It is difficult to come to firm conclusions on the ideal parameters for dual-wavelength laser therapy due to the variety of laser types and treatment plans. To overcome these constraints and provide more precise recommendations for clinical practice, further research using bigger, better-designed trials and standardized methodologies is required.

In order to confirm the effectiveness and safety of dual-wavelength laser therapy in a variety of patient demographics and scar types, future research should concentrate on carrying out extensive, multicenter studies. Enhancing treatment procedures and improving results may need research into the best laser settings, treatment intervals, and combination techniques. Furthermore, investigating the long-term consequences of dual-wavelength laser treatment and its possible advantages when combined with other therapeutic modalities may provide important new perspectives on its function in all-encompassing scar care. The effectiveness of dual-wavelength laser treatments will also be improved by developments in laser technology and a better understanding of the fundamental processes behind scar formation and treatment responses.

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