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REVIEW ARTICLE

Low-Level Laser Therapy: A Comprehensive Review of Anti-Inflammatory Applications and Therapeutic Potential

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ABSTRACT

Low level laser therapy (LLLT) has been studied for decades, but the medical establishment has yet to embrace it is a method of choice for those conditions in which it is highly documented. Light therapy as such has been known for centuries as an effective treatment for, for example, psoriasis. There have been numerous reviews of various aspects of the application of LLLT, but an overview of the various uses of the therapeutic applications is lacking. This review attempts to address that. A case is made for a holistic evaluation of the patient.

Keywords: Low level laser therapy, photobiomodulation, dermatology, chronic pain, whiplash syndrome, postconcussion syndrome.

Introduction

LLLT, also referred to as photobiomodulation therapy, has emerged as a non-invasive modality with promising applications across various medical and dermatological conditions. Initially employed in the 1960s, LLLT employs red or near-infrared light at low power to modulate cellular function, acting as a strong anti-inflammatory agent through reduction of cytochrome C in mitochondria, promoting fibroblast generation thereby promoting tissue repair, and alleviating pain without causing thermal injury to surrounding tissues. In dermatology, LLLT has been explored for a range of indications including wound healing, alopecia, acne vulgaris, psoriasis, and more recently, inflammatory skin disorders such as atopic dermatitis and eczema. Despite its widespread use, the therapeutic efficacy of LLLT remains a subject of ongoing debate, largely due to heterogeneity in treatment protocols, including wavelength, dosage, exposure time, and target tissue depth. Moreover, while in vitro and animal studies have consistently demonstrated anti-inflammatory and regenerative effects, human clinical trials have reported mixed outcomes, necessitating a thorough appraisal of the existing evidence base. Another reason for the lack of acceptance of LLLT is the general mistrust in the medical establishment of anything alternative, and the resistance of the pharmicomedical industry which correctly sees LLLT as a direct competitor to their income base. This is not documented anywhere, but it is perfectly clear to anyone with knowledge of the area.

This review aims to systematically evaluate the current literature on the application of LLLT in practice, with a specific focus on its biological mechanisms, clinical efficacy, safety profile, and areas of controversy. By integrating findings from randomized controlled trials, meta-analyses, and experimental studies, this work seeks to elucidate the potential role of LLLT as an adjunct or alternative treatment in clinical medicine and identify gaps warranting further investigation.

Modern medicine, in all of its facets and super subspecialization, has achieved many milestones in the treatment of diseases and disease states that have plagued humanity for centuries. Among the greatest achievements have been the control of infectious diseases, and the much-improved management of chronic diseases such as hormonal disorders and inflammatory conditions, for not to speak of modern cancer treatment. Meanwhile, a large proportion of patients are not among those who benefit from these advancements, and it is becoming increasingly clear that alternatives are necessary in order to improve these patients' condition. In this review, one treatment modality is described that has reached a large number of patients that are not helped by the traditional medical system - they are only medicated with painkillers and anti-inflammatory drugs that are not without side effects. LLLT has found its way into many different areas that are not effectively treated by traditional medicine. Among these are whiplash syndrome, postconcussion syndrome, tension headache, lower back pain, unspecified shoulder and elbow pain as well as unspecified hip, knee and ankle pain. LLLT has also shown improvements in COPD, asthma and in the management of all forms of eczema.

The author advises the reader to bear with him as he describes the often hard to believe results that are described in the various articles concerning LLLT. Indeed, the author has experienced an unwillingness to publish results that were hard to believe by those high up on the clinical research ladder. The author has brought one patient from a pulmonary capacity of 25% up to a pulmonary capacity to 44% over a period of 13 treatments with a concomitant improvement in quality of life. Before she came to the author, her outlook was to be tethered to an oxygen hose with the limitations that that entails. This is documented in the author's article LLLT and COPD[1]. The editorial board of the Danish medical weekly admonished the author and told him that they viewed the improvement as a "reversion to the mean", and not the treatment as such. This is nothing short of nonsense, as anyone with experience with COPD well knows - improvements in pulmonary capacity are not seen in the clinical setting, only incremental deterioration.

LLLT is a non-invasive treatment that uses low-intensity laser or light-emitting diodes (LEDs) to stimulate cellular function. LLLT made its debut in Hungary in the early 1960s. A Hungarian surgeon by the name of Edre Mester (EM) has been credited with using it for the first time[54]. It was shortly after the ruby laser was put into use. During experiments with mice, where EM wanted to demonstrate the effect on induced skin tumors which he could not detect, he noted difference in the hair growth rate in the treated group compared with the untreated group. Since then, attempts have been made to use LLLT over a number of conditions, of which myofascial pain is the area where the greatest effect is achieved[5]. There are numerous laser devices on the market, but the device that is best documented and with EU approval is the LX2 and LX2/2 from Thor Laser in the UK. LLLT has been the subject of study at the Harvard University School of Medicine, which has published an account of the mechanism of action [2]. It is a biphasic light source with a visible element of 720 nm and an invisible laser light of 613 nm. The visible light does not penetrate the skin, but the laser beam reaches 5-6 cm. under the skin, depending on the tissue type[13]. There is no complete clarity on how it works, but there is no doubt that it acts as a powerful antioxidant locally [50]. The role of antioxidants in reducing inflammation is well described[51]. It is less clear that myofascial pain is dependent on inflammatory processes, but what else should it be?

But what is inflammation? Since the early Roman days of calor (heat), ruber (redness), dolor (pain), and tumor (swelling), our understanding has deepened considerably. Today, inflammation is recognized as a complex biological response of the immune system to harmful stimuli -such as pathogens, damaged cells, or irritants. It is the body's attempt to restore homeostasis, initiate healing, and defend against further injury.

Broadly, we distinguish between acute inflammation, a short-term, protective response that helps contain and resolve damage, and chronic inflammation, a persistent, dysregulated process that can lead to tissue injury and underlies many modern diseases—from chronic pain syndromes, atherosclerosis and type 2 diabetes to Alzheimer's disease and certain cancers.

In a sense, inflammation can be triggered by any deviation from normal physiological function. Defining "normal" is elusive, but we might describe it as a state where the body operates without sensory disturbances, digestive dysfunction, or loss of expected muscle strength; where immune, coagulation, and circulatory systems remain in balance; and where proprioceptive and peripheral nerve signaling, cognition, and emotional well-being are all intact. Any injury, infection, trauma, or internal stress can set off an inflammatory cascade involving cytokines, chemokines, prostaglandins, and other molecular mediators that coordinate the body's response.

LLLT, or photobiomodulation, helps modulate this inflammatory cascade through several well-documented mechanisms. Upon absorption of red to near-infrared light (typically 600–1100 nm), cytochrome c oxidase in the mitochondrial respiratory chain is activated, enhancing ATP production and reducing oxidative stress[1]. This mitochondrial upregulation shifts cells away from a pro-inflammatory state and fosters cellular repair. Furthermore, LLLT downregulates pro-inflammatory cytokines like tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), and interleukin-6 (IL-6), while increasing anti-inflammatory mediators such as IL-10[51,52].

At the tissue level, LLLT reduces edema through improved lymphatic drainage and vascular perfusion, accelerates resolution of neutrophil infiltration, and promotes the activity of macrophages toward an anti-inflammatory (M2) phenotype[4]. Additionally, it has been shown to stabilize mast cells, reduce prostaglandin E2 (PGE2) levels, and inhibit COX-2 expression, further limiting the inflammatory signal[5]. These effects collectively help mitigate pain, swelling, and tissue damage while enhancing the body's regenerative capacity[49,50,51].

No one knows how many patients with tension headache have been diagnosed with migraine, but there is no doubt that this misdiagnosis exists. This is again one of those truths that everyone knows, but that no one has been able to document. This is one of the common elements of our methodology, that we are perfectly capable of documenting what we do right, but horribly incapable of documenting what we do wrong. This is wasteful and/or deleterious for our patients. The main reason for this misdiagnosis is the lack of examination of the condition of the neck muscles, which is the cause of tension headaches. In the author's experience, none of the patients that he has examined have ever had their neck muscles examined by any of up to 35 different doctors and other therapists. Examining the muscles of the neck, one can determine whether or not the platysma, the scalenes and trapezius muscles have normal consistency or, as is the case with patients with tension headaches, have increased tension and often with myoses, in other words, chronic inflammation. It takes a little training to complete a sufficient examination, but everyone with reasonable fingertip sensibility, knowledge of anatomy and pathophysiology can easily learn to do a qualified exam of the tension status of the neck. Specifically, myoses on the medial scalene can cause visual disturbances that contribute to the misdiagnoses[5,54].

The examination technique requires palpation of the named muscles with a light hand, so that the muscle structure can be felt through the skin. It is decisive to examine the entire muscle. There is often a significant difference from side to side, which makes the discovery easier, as the difference is clearly felt. The author finds it most expeditious to do the exam on a gurney with a head holder so that the patient relaxes as much as possible during the exam.

Once such tensions have been discovered, there is a basis for referring to a clinic with experience in resolving these tensions. When the tension is resolved, the symptoms disappear. This is evidenced by the author's experience.

The past efforts have not been satisfactory. Although also not based in the literature, no treatment modality to date has been successful with these diagnoses. The same applies to tension states that cause pain in other body parts than in the neck and in the head. It is clearly more difficult to detect tension in the deeper muscles, but a thorough history and prior examination with blood samples (exclusion of cancer, rheumatoid arthritis and vitamin D deficiency), ultrasound, X-ray, CT and/or MRI scan, which exclude more serious causes of pain, are usually negative in myofascial pain patients[5]. When all studies show normal results, one can conclude that muscle tension and/or inflamed tendons and/or joints are the cause of the pain. In the following, 5 cases are represented which illustrate the power of this treatment modality.

Patient No. 1 was a young man who had fallen off a horse 4 years earlier and had hit his head and neck and his back on the hard ground underneath. There were no immediate signs of major damage and no visible wounds. In the weeks following the fall, the boy developed a severe, constant headache, which was the subject of numerous studies. Among other things, a syringomyeli was detected at the L1 level, low pressure in the spinal canal and a moderate Scheuermann. None of these conditions could be linked to the headache. Various neurosurgical departments, pediatric wards and other specialists had found and accepted indication for treatment with Tradolan, Ibumetin and Paracetamol as well as Omeprazole to protect against the side effects of the Ibumetin. There was no focus on the neck muscles. On one out of approximately 100 pages of documentation in the case, there was one sentence describing the tense neck muscles by a physiotherapist. This passage did not have any consequence that one could glean from the documentation. When the author met the patient, he had a very knotty neck, where especially the medial scalene was a chain of myoses, which was extremely sore. There were, as is usual for this type of patient, large myoses in trapezius both near the cranium and in the mid-clavicular level (MCL). After a series of treatments with LLLT and massage and the physical training I directed for the patient, he was completely free of the medicine and had a slight headache approximately once a week that did not require medication. His neck muscles were without myoses, but still a little tense. The treatment was completed 2 years ago, and the condition has remained pain free.

Patient no. 2 is a middle-aged man who 2 years before the exam in the author's clinic, was involved in a classic rear-end collision that hit the patient's car with such speed that neither of the cars could drive from the scene of the accident. The patient was wearing a seat belt and airbags were released. As usual for these cases, the primary examination at the hospital was without special findings. Approximately one year after the accident, the patient was awarded 8% disability and had been diagnosed with incipient dementia due to his reduced memory and concentration (common accompanying symptoms of whiplash syndrome). Again, no one in the process had examined the patient's neck muscles. When the author met the patient, he had severe tension in the neck muscles and myoses in the medial and posterior scalenes as well as in the trapezius near his cranium and in the MCL. After a series of 32 treatments, he had become pain free, his neck muscles relaxed, and he had regained his memory and concentration. The treatment had been completed 3 years before this report, and the condition has remained pain free.

Patient No. 3 was a young woman suffering from whiplash syndrome after two rear-end collisions. She had constant headaches, strained neck muscles and was depressed all the time. After a few treatments she felt much better, and her treatment could end after 9 sessions. The patient had no longer any pain and a relaxed neck. She had regained her energy and was happy again (an unusually short process). The treatment had been completed 3 years prior to this report, and the condition has remained pain free.

Patient no. 4 was a middle-aged man who suffered a concussion of medium severity approximately 3 years previous to his appearance in the clinic. He had been examined by neurologists, neurosurgeons and his own GP and treated with various measures, including physiotherapy and strong painkillers. He suffered from severe, daily headaches, difficulty in concentration and memory and pain in the neck and back. His physical condition made him so depressed that he had seriously considered taking his own life. After approximately 10 treatments, his medication could be reduced. The headache and neck tension gradually disappeared. Life returned little by little, and after 42 sessions he could be discharged without medication and without pain. His memory and concentration had returned and he could get back to his working life. The treatment was completed 3 years prior to this report and the condition has remained pain free.

Patient No. 5 was a middle-aged woman who slipped and fell on ice in the winter and hit the back of her head. She had a very bad time during the ensuing days, but the symptoms subsided for a short while, but after a few weeks, headaches and neck tension started. This increased over a couple of months and remained unchanged until she presented in the clinic about half a year after the accident. She had been at a pain center where they had put her on treatment with pain medication. In the author's clinic she was treated with LLLT and massage. It took about 7 sessions before she could feel any improvement, and after approximately 11 treatments, she could discontinue one of 2 painkillers. After approximately 18 treatments, she could stop using the other, and within a few weeks she was completely free from headaches. After 34 sessions, she had fully recovered and was able to go to work again. She was happy and cheerful again. The treatment was completed 2 years prior to this report, and the condition has remained pain free[5].

LLLT is widely used for pain relief, tissue repair, and inflammation reduction. Unlike surgical lasers, LLLT does not cut or burn tissue but instead enhances biological processes at the cellular level. In the above-mentioned article from Harvard Medical School, it has been demonstrated that the anti-inflammatory function of LLLT is contingent upon the reduction of superoxide in the mitochondria in inflamed tissue[2]. This is also the basis for anti-inflammatory drugs in general, but the utilization of LLLT allows for the alleviation of the inflammatory process at the site where it is needed, instead of medicating the whole body. Furthermore, in all of the literature concerning LLLT which is comprised of hundreds of articles in peer-reviewed journals, there has never been reported any negative or side effects of the treatment. The only caveat in connection with LLLT is not staring directly into the probe. This can cause damage to the retina[3,4].

This caveat is easy to adhere to. Given that, the anti-inflammatory facet of LLLT makes it an obvious treatment modality for any inflammatory syndrome, and they are many. In the author's experience, the neck muscles are involved in a large number of pain syndromes[5,6]. The most intractable of these in terms of the ability of conventional medicine to deal with them are whiplash syndrome, postconcussion syndrome and tension headache. Furthermore, other pain syndromes have neck muscle tension and/or myoses as a major part of their syndrome cross-section. Examples of these include fibromyalgia patients, migraine headache, stress-related issues, and the great majority of psychiatric patients[5]. The inflammatory nature of many other pain issues is obvious to clinicians, but the resolution of many of these pain syndromes with LLLT points to the inflammatory basis of these. These include lower back pain, shoulder pains including frozen shoulder, lateral and medial elbow pain, de Queverains syndrome, carpal tunnel syndrome, hip joint bursitis, nonspecific knee pain as well as ankle and foot pains that may or may not be demonstrated in picture diagnostic techniques (ibid).

Wound healing and treatment of sprains, muscle pains and inflammation in ligaments, tendons and the oral cavity are areas where LLLT shows great promise. It is especially in areas where the traditional treatment modalities are plagued by marginal success [wound and ulcers}. Wound is a catch-all phrase that covers everything from a severe bullet wound to a light bruise from an equally light trauma. The latter is commonly complicated by an untoward psychic state[53]. Meanwhile, the facets of LLLT treatment, which include inflammation reduction, enhancement of mitochondrial function and promotion of fibroblast proliferation, keratinocyte migration, and angiogenesis — are all pivotal for tissue repair and regeneration. Wound healing is often delayed due to inflammation causing swelling and fever[29], and the reduction of this inflammation aids the repair process. Fibroblasts play a vital role in the proliferation and remodeling phases of wound healing. They are responsible for producing extracellular matrix, components such as collagen, fibronectin, and hyaluronic acid, which provide structural support for tissue regeneration. In response to growth factors like TGF-β, PDGF, and FGF, fibroblasts proliferate and migrate into the wound bed.

Fibroblasts also differentiate into myofibroblasts, which express alpha-smooth muscle actin (α-SMA) and generate contractile force to close the wound. Impaired fibroblast activity leads to chronic wounds, while overactive fibroblasts contribute to hypertrophic scarring and fibrosis[30].

The inflammatory elements of COPD is not well known. Although we know that a certain proportion of COPD is due to destruction of lung tissue, principally because of tobacco use[10] compounded by or even caused by exposure to different kinds of dust and air pollution[1,10,11,12]. An unknown proportion of COPD is inflammatory, and almost all of asthma is inflammatory [34]. The question then becomes can the therapy reach deep enough into the tissue to have an effect? It has been shown that LLLT has an effect 5 to 6 cm under the skin[13]. Depending on how much tissue must be transversed before the target is reached, it is clear that at least some of the anti-inflammatory light reaches the inflamed tissue in COPD and asthma patients, thus explaining the gains made by patients treated[1,14]. LLLT is typically applied using handheld or stationary laser devices that delivers light to the affected area for a specified time per site. Depending on the total area to be treated, the single session per patient can last from anywhere between 10 minutes to over an hour. The therapy is painless and does not produce heat, making it suitable for a wide range of conditions.

LLLT has found wide acceptance of its effect on exzema. Nearly all forms of exzema are inflammatory in nature with a varying amount of autoimmunity involved. A good example is psoriasis. Management of psoriasis is one of the more important uses of LLLT[15,16,17,18,19,20,21]. Larko and Swanbeck reported phototherapy for patients with psoriasis in 1997[15]. Kemeny et al. were impressed by LLLT's effect on psoriasis[19]. Devices allowing home use have also been developed which has led to high effectiveness and safety[18], and since then, it has become clear that LLLT treatment is superior to NB-UVB[17]. Compared with NB-UVB, LLLT effectively treats resistant and localized psoriasis lesions with fewer treatment sessions and a reduced cumulative dosage[20].

In a related albeit very different application LLLT has emerged as a non-invasive and effective treatment for various types of hair loss, particularly androgenetic alopecia (AGA) in both men and women. LLLT is believed to stimulate epidermal stem cells, prolong the anagen growth phase of the hair cycle, and increase follicular metabolism through mitochondrial activation and enhanced ATP production. Clinical studies have demonstrated significant improvements in hair density, thickness, and patient satisfaction with consistent use over several months. Devices such as laser combs and helmets have been FDA-cleared for home use, and are associated with minimal side effects. A double-blind, sham device-controlled trial by Leavitt et al. showed that LLLT using a 655 nm laser diode significantly increased terminal hair density in male patients with AGA over a 26-week period. While mechanisms are still under investigation, evidence supports LLLT as a promising adjunct or alternative to pharmacological options like minoxidil and finasteride[45,46,47].

Acne vulgaris is also treatable with LLLT [22,23,24,25,26]. In many case reports and meta-analyses, complete remission is the rule. This is the case with many other inflammatory conditions that are within 5-6 cm of the surface. The results are accomplished without any side effects or negative impression for the patient, which is definitely not the case in medical treatment of acne where many patients are simply intolerant of the medication given[26,27].

With other injuries, LLLT provides marked improvement in recovery times and pain reduction. Among these are burn injuries. LLLT stimulates cellular activity, particularly enhancing mitochondrial function and ATP production, which accelerates the healing process. Studies have demonstrated that LLLT can improve wound closure rates, reduce edema, and minimize scar formation in burn patients. Moreover, its non-invasive nature and minimal side effects make it a valuable adjunct to conventional burn care. As research continues, LLLT is increasingly being recognized as an effective tool in the management and recovery of burn injuries[44].

In the treatment of whiplash syndrome, postconcussion syndrome and tension headache, the utilization of LLLT is the only effective therapy that exists[5]. Utilizing this therapy, the author was able to achieve phenomenal results that have been published in the Journal of Pain Management [ibid].

There have been exciting case reports from authors utilizing LLLT as a treatment for disability after stroke. In one study, the authors present a case with a 29-year-old woman who was the victim of a stroke attack. She suffered acute infarctions involving the medulla, superior aspect of the cervical spinal cord and cerebellar hemispheres bilaterally. She was treated for 3 months at an inpatient stroke rehabilitation centre and then for 18 months at an outpatient centre (where she was seen 3x/week). At the end of this period, she was told that she had likely reached the pinnacle of her recovery. At presentation at the LLLT clinic, the patient had the following physical examination: Alert, relaxed and cooperative. Mood was melancholic, anxious and fearful (mostly of falling) and emotional. She exhibited no significant attention difficulties or perceptual difficulties. Long term memory was intact, but she exhibited difficulty with short term memory (a common symptom of a pain syndrome[5]. Major dysfunction of the right upper extremity without voluntary movement and with spastic movements. Moderate dysfunction of the left upper extremity. All four extremities without cyanosis or oedema. Core muscle strength severely compromised as evidenced by slumping in the wheelchair with the inability to straighten up. She was treated cranially and on the dysfunctional extremities totalling 32 positions per session. After 8 weeks of this treatment, she was able to stand without support and walk with a walker. The improvements were tested a year after the treatment and were still evident[48,33]. This is an area that definitely needs further examination in good trials that can establish the role of LLLT in stroke rehabilitation.

In other areas in the neurological sphere, LLLT has shown promising therapeutic potential in the management of neuropathy and various neurological disorders. In peripheral neuropathies, such as diabetic neuropathy and post-traumatic nerve injuries, LLLT has been associated with reduced pain, improved nerve conduction, and enhanced axonal regeneration by stimulating Schwann cells and increasing ATP production [43,44]. Its anti-inflammatory and anti-apoptotic effects also contribute to neuroprotection in central nervous system conditions. Experimental studies suggest that transcranial application of LLLT may improve outcomes in stroke, traumatic brain injury (TBI), and neurodegenerative diseases by promoting angiogenesis, reducing oxidative stress, and modulating neuroinflammation[5,42,43]. Clinical trials in patients with TBI and Alzheimer's disease have reported improved cognitive function, mood, and sleep quality following transcranial photobiomodulation therapy [ibid]. While further large-scale studies are needed, the current evidence highlights LLLT as a non-invasive, adjunctive therapy with significant potential in managing neuropathic pain and neurodegenerative conditions.

Last but not least, LLLT is an effective tool in the oral cavity demonstrating efficacy in the management of postoperative pain, acceleration of soft tissue healing, and reduction of inflammation following procedures such as extractions, periodontal therapy, and implant placement [36,37,38,39]. Clinically, it is also used to manage oral mucositis in cancer patients, relieve symptoms of temporomandibular disorders (TMD), and facilitate nerve regeneration in cases of paresthesia [ibid]. In periodontology, adjunctive use of LLLT with scaling and root planing has shown significant reductions in gingival inflammation and improvements in clinical parameters[39]. Furthermore, its application in orthodontics has been associated with reduced post-adjustment pain and potential acceleration of tooth movement[35,36,37,38]. The broad applicability and non-invasive nature of LLLT underscores its growing importance in contemporary dental practice.

Discussion

The listed clinical areas may not be exhaustive. The author has attempted to limit his discussion of uses LLLT to the evidence based areas that have been described above. The body of evidence on LLLT underscores its multifaceted biological effects and therapeutic potential in the clinical areas described above. Studies consistently demonstrate that specific wavelengths of light, particularly within the red (600–700 nm) and near-infrared (700–1000 nm) spectrum, penetrate tissue effectively, stimulating cellular metabolism and modulating inflammatory responses. Notably, LLLT enhances mitochondrial function and promotes fibroblast proliferation, keratinocyte migration, and angiogenesis — all pivotal for tissue repair and regeneration.

Clinical outcomes, however, present a more nuanced picture. For conditions such as acne vulgaris and androgenetic alopecia, LLLT has achieved measurable success, with several trials reporting statistically significant improvements in lesion counts and hair density, respectively. The antimicrobial effects of blue light and the anti-inflammatory properties of red light therapy have been particularly advantageous in acne management. In contrast, evidence supporting LLLT for chronic inflammatory dermatoses like eczema and psoriasis remains preliminary, often limited by small sample sizes, methodological variability, and inconsistent outcome measures.

Furthermore, while LLLT is generally well-tolerated, with minimal adverse effects reported across studies, concerns persist regarding optimal dosing parameters and long-term safety. The biphasic dose-response relationship, in which insufficient or excessive energy delivery yields suboptimal outcomes, further complicates treatment standardization. Variability in device specifications and treatment protocols also challenges reproducibility and broad clinical adoption.

Emerging research is exploring synergistic approaches, combining LLLT with topical therapies, photodynamic therapy, or systemic treatments to enhance efficacy. Personalized treatment protocols, guided by patient-specific factors such as skin phototype and disease severity, represent a promising frontier. Nonetheless, robust, large-scale randomized controlled trials with standardized methodologies are imperative to validate LLLT's role and establish evidence-based guidelines for clinical practice.

Conclusion

While LLLT holds significant promise as a versatile, non-invasive therapeutic modality in anti-inflammatory roles, its integration into standard care pathways necessitates further high-quality research. Future studies should prioritize elucidating optimal treatment parameters, understanding long-term safety, and exploring combinatorial strategies to maximize therapeutic benefits.

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