Our Dermatology Online

Review Article

LED photobiomodulation: From dermatological care to neuroprotection and pain management – review

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ABSTRACT

Photobiomodulation (PBM) using LED light in the red (600–650 nm) and blue (400–495 nm) spectra is a promising non-invasive approach in aesthetic and dermatological treatments. This study reviews PBM's effects, focusing on red light's deeper skin penetration that stimulates mitochondrial cytochrome c oxidase, enhancing ATP production, fibroblast proliferation, and collagen synthesis, which supports anti-aging and reduces inflammation. Blue light activates porphyrins, exhibiting antibacterial properties effective against acne. However, in darker skin phototypes (Fitzpatrick IV–VI), blue light may worsen hyperpigmentation through Opsin-3–mediated melanogenesis. Additionally, PBM benefits mood and sleep by improving neuronal metabolism and cerebral blood flow. The review compares LED-based PBM, which is safer and more accessible for home use, with laser-based PBM, offering higher precision. Current studies show promising clinical results but highlight the need for optimized treatment protocols and long-term outcome assessments.

Key words: Photobiomodulation, LED Therapy, Red Light, Blue Light, Skin Rejuvenation, Acne, Hyperpigmentation, Mood Disorders, Sleep, Aesthetic Medicine.

INTRODUCTION

Photobiomodulation therapy (PBM) or low-level light therapy (LLLt) is increasingly appearing commercially as LED masks using red light at 650-1000 nm (with 600-650 nm being the most common) and blue light at 400-495 nm [1,2]. Their regenerative and healing effects on the skin have been known for years, but it is important to note that they differ in their properties [3-5].

STATE OF KNOWLEDGE

Blue light masks with a wavelength of 400-495 nm, have less penetration of the skin layers due to their shorter wavelength [6,7]. In contrast to UV visible light (UVA, UVB, UVC) with a wavelength of 200-400nm, their carcinogenic effect on the skin has not been proven [6]. In aesthetic medicine, both diffuse light from LED bulbs (incoherent) and in focused form from lasers (coherent), pulsed light and continuous light are used [8].

Light from lasers is focused, penetrates deeper and is often used in pulses, making it more suitable for deep wounds, pain treatment, where LED light treatment is safer it can be useful for superficial skin treatment - treating hyperpigmentation, acne, alopecia, improving skin condition and appearance [9-13]. Due to the fact that laser treatment shows partial traumatic

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effects on the skin, it can only be used by professionals under specific conditions, whereas LED light treatment can be performed safely at home.

LED LIGHT THERAPY AND "ANTI-AGING"

The mechanism of action is based on the trapping of light by chromophores in the skin. Chromophores are compounds that absorb light of a specific wavelength. In the skin, we distinguish between melanin, water, cytochrome c oxidase [14,15]. Cytochrome c, by absorbing light with a wavelength of 620-850 nm located, among others, in the inner mitochondrial membrane of fibroblasts, by absorbing photons, increases the amount of AtP in the cell thereby accelerating metabolism and proliferation of fibroblasts, thereby increasing collagen production, contributing to the lauded anti-aging effect [14-18]. A significant increase in the expression of LOXL1, ELN, COL1A1 and COL3A1 genes has also been reported [16]. LOXL1 encodes an enzyme responsible for the formation of cross-links in elastin and collagen, stabilising the structure of connective tissue. The ELN gene encodes elastin, COL1A1 and COL3A1 collagen. There are many studies conducted in vitro as well as in vivo documenting this effect, but it is important to remember that although most of these studies analyse red light with a wavelength of 630-750 nm, they mainly describe the effect of laser, not LED light. Although there is an overlap between the wavelengths used in laser therapy and LED light, laser light is more focused, more precise and it is this that is better described in the literature [18-21]. A study that shows that LED light, although a diffuse light, can have this effect, but less intense, is a study comparing a study group in which LED light was shone on one half of the face and not on the other. Biopsies were then taken from both halves of the face comparing the tissues obtained. Histologically, they differed in the thickness of the dermis, collagen thickening, number of fibroblasts, reduction of wrinkles by 36%, increase in skin elasticity by 19%, which supports the positive effect of the LED mask in favor of healthy skin [22,23].

LED LIGHT THERAPY IN TREATING ACNE

LED light has a proven effect on the treatment of superficial lesions such as acne [24,25]. The mechanism behind this acne treatment is based on the use of blue light activated porphyrins which release free radicals that kill the acne-causing cultures Cutibacterium acnes and Propionibacterium acnes [26,27]. In addition to reducing sebaceous gland proliferation, it reduces inflammation [26-28]. Red light reduces sebum production by sebaceous glands, and has an anti-inflammatory effect by reducing oxidative stress on cells [29]. Thanks to its anti-inflammatory effect by reducing pro-inflammatory cytokines (tNF-alpha and IL-6) and regulating the levels of neurotransmitters such as serotonin and endorphins, it reduces neuronal metabolism through the effect on cytochromes c described above - so it also has an analgesic effect [20]. The anti-inflammatory effect is also influenced by a reduction in the number and activity of neutrophils at the burn site following topical application of red-light therapy. This accelerates the closure and healing of scars [30]. Stimulates the production of repair proteins, growth factors (VEGF, tgf-beta), improves microcirculation through an increase in NO synthase, which dilates the vessels [18].

LED LIGHT THERAPY AND HYPERPIGMENTATION

When considering phototherapy, especially in dermatological applications, it is important to recognize the differential impact of specific wavelengths of visible light on skin pigmentation [31]. Blue light (wavelengths approximately 415–470 nm), while useful in certain therapeutic contexts, has been shown to exacerbate hyperpigmentation, particularly in individuals with darker skin phototypes (Fitzpatrick types IV–VI). Clinical and histological studies have demonstrated that blue light can induce more persistent and pronounced pigmentation compared to UVB radiation [32].

This effect is mediated by a specific photoreceptor—Opsin-3—expressed in melanocytes, which, upon blue light stimulation, activates intracellular signaling pathways leading to increased melanin synthesis [13]. The upregulation of melanin production in response to blue light is significantly enhanced in melanocytes derived from darker skin phototypes, contributing to more visible and longer-lasting post-inflammatory hyperpigmentation in these individuals.

In contrast, red light (typically in the range of 620–750 nm) does not activate the same melanogenic pathways and, in some cases, has been investigated for its potential to reduce hyperpigmentation by modulating inflammation and oxidative stress. This makes red or near-infrared light a safer and potentially beneficial alternative for phototherapy in patients prone to pigmentary disorders [32].

These findings underscore the importance of individualized wavelength selection in clinical and cosmetic LED light therapies, particularly for patients with darker skin tones, where inadvertent stimulation of melanogenesis by blue light may lead to undesirable outcomes.

LED LIGHT THERAPY AND BRAIN FUNCTION

Beyond its dermatological applications, LED light therapy—particularly in the form of photobiomodulation (PBM)—has shown promising results in supporting brain health and treating mood disorders. Several studies, including systematic reviews and meta-analyses, have demonstrated that PBM using near-infrared or red light can significantly reduce symptoms of moderate depression [33,34]. The proposed mechanism involves the absorption of photons by cytochrome c oxidase in neuronal mitochondria, leading to increased ATP production, improved cellular metabolism, and the modulation of key neurotransmitters such as serotonin and dopamine. These effects also promote synaptic plasticity, neurogenesis, and overall neural resilience.

Additionally, PBM has been associated with improved sleep quality -a critical factor for both mental health and cognitive function. Enhancements in melatonin regulation and circadian rhythm synchronization likely underlie these sleep-related benefits, which have been observed in both healthy individuals and patients with depression [35].

Animal model studies further underscore the neuroprotective potential of PBM. Repeated exposure to near-infrared light has been shown to increase cerebral blood flow and enhance lymphatic clearance of neurotoxic aggregates such as beta-amyloid plaques. These effects suggest a possible role for PBM in slowing or even preventing the progression of neurodegenerative disorders, including Alzheimer's and Parkinson's disease [36,37]. Collectively, these findings support the therapeutic versatility of LED-based light therapy not only in dermatology and pain management but also in psychiatry and neurology.

LED LIGHT THERAPY AND MUSCLE PERFORMANCE AND RECOVERY

Photobiomodulation therapy (PBMT), particularly when employing a combination of super-pulsed lasers and light-emitting diodes (LEDs), has demonstrated significant benefits in enhancing skeletal muscle performance and expediting post-exercise recovery. Evidence from controlled trials indicates that applying PBMT immediately after maximal voluntary muscle contractions can lead to a substantial reduction in delayed onset muscle soreness (DOMS), as well as a marked decrease in serum levels of creatine kinase—an enzyme commonly associated with muscle fiber damage [38].

Mechanistically, PBMT appears to modulate mitochondrial function by enhancing cytochrome c oxidase activity, thereby increasing adenosine triphosphate (ATP) production and improving cellular respiration efficiency. This cellular bioenergetic boost supports faster muscle repair and regeneration while reducing oxidative stress and inflammation at the tissue level [39]. In treated muscle groups, this translates into improved strength recovery, greater fatigue resistance, and a quicker return to functional capacity compared to untreated controls.

Furthermore, PBMT's non-invasive nature, absence of adverse effects, and ability to target both superficial and deep tissues make it an appealing adjunct in sports medicine and rehabilitation. The synergistic use of super-pulsed lasers (which penetrate deeper tissue layers) and LED light (which offers broader coverage) optimizes therapeutic outcomes by combining penetration depth with photonic energy density.

These findings underscore the growing clinical relevance of photobiomodulation as a safe and effective strategy not only for enhancing athletic performance and reducing recovery time but also for preventing muscle overuse injuries and improving long-term musculoskeletal health.

LED LIGHT THERAPY AND PAIN

Photobiomodulation therapy (PBMT) using light-emitting diodes (LEDs) is gaining increasing importance as a non-invasive method of pain management [40]. LED is a promising alternative to lasers in PBMT, offering similar therapeutic effects at a lower cost, better portability and greater safety of use. The light emitted by LED can penetrate tissues to sufficient depth, stimulating mitochondrial activity and regenerative processes, resulting in a reduction in pain [41]. LED lamp therapy achieved excellent results in the treatment of oral mucositis following chemotherapy and radiotherapy in cancer patients [42,43]. Four of the five studies showed a significant improvement in pain reduction, while the remainder showed a significant improvement in wound healing [44,45]. Studies conducted on animal models indicate a potentially significant role for LED light therapy in the treatment of neuropathic pain. Two independent experiments have explored this: in the first, spinal cord injury was induced and the effects of LED light with a wavelength of 670 nm were assessed; in the second, both spinal cord and sciatic nerve injuries were induced, followed by treatment with LED light at 960 nm [46,47]. In both cases, LED irradiation led to a substantial reduction in neuropathic pain following nerve injury.

Neuropathic pain that develops post-injury involves the activation of microglial cells (macrophages) and an increase in inflammatory cytokines. LED light therapy has been shown to modulate microglial activation by reducing the pro-inflammatory M1 microglial population while simultaneously enhancing the anti-inflammatory M2 phenotype [46]. This shift in microglial polarization likely contributes to the downregulation of pro-inflammatory cytokines, thereby explaining the observed analgesic effect [47].

The role of LED light in peripheral nerve regeneration in neuropathies appears to be dose-dependent rather than wavelength-dependent. Studies examining nerve regeneration at wavelengths of 650–660 nm have yielded mixed results—some reporting success, while others have failed to show significant improvements [48,49]. Higher doses of LED light seem to promote nerve regeneration, whereas lower doses tend to exert primarily analgesic effects [47].

These findings underscore the importance of optimizing parameters such as wavelength and dosage when considering LED phototherapy as a potential therapeutic tool in managing neuropathic conditions.

LED THERAPY IN SNAKEBITE INJURY

LED therapy has also demonstrated promising effects in mitigating tissue damage caused by snake venom. In experimental models of acute inflammation induced by venom, LED photobiomodulation effectively reduced local swelling, redness, and oxidative stress, which are common pathological responses to envenomation. By modulating the inflammatory environment and enhancing tissue repair mechanisms, LED treatment accelerated healing and limited venom-induced tissue destruction. These findings suggest that LED therapy could serve as a valuable adjunctive treatment for snakebite injuries, supporting recovery and reducing the severity of local toxic effects [50].

CONCLUSION

Photobiomodulation therapy using LED light in the red and blue spectra represents a versatile, non-invasive approach with broad therapeutic potential across dermatology, neurology, sports medicine, and wound care. Red light enhances cellular bioenergetics, collagen synthesis, and skin rejuvenation, while blue light provides effective antibacterial action in acne treatment but requires caution in individuals with darker skin due to its potential to exacerbate hyperpigmentation. Beyond skin applications, LED therapy shows promising benefits for mood disorders, sleep quality, and neuroprotection through mitochondrial modulation and improved cerebral circulation. Additionally, PBMT supports muscle recovery, reduces pain, and accelerates healing in nerve injuries and snakebite envenomation by modulating inflammation and oxidative stress. Although laser-based photobiomodulation offers more precision, LED therapy provides a safer, accessible alternative suitable for home use [51]. Future research should focus on refining treatment protocols, optimizing wavelength and dosage parameters, and evaluating long-term efficacy to fully harness the clinical benefits of this emerging modality.

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