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Human body photobiomodulation: history and future perspectives

Leonardo Longo,[1,2] Carlo Fornaini[2-4]

[1]Former Professor, School of General Surgery, Siena University, Italy; [2]International Academy for Laser Medicine and Surgery, Florence, Italy; [3]Department of Surgery, Medicine, Dentistry and Morphological Sciences with Transplant Surgery, Oncology and Regenerative Medicine Relevance, University of Modena and Reggio Emilia, Modena, Italy; [4]Stomatology Department, Shijiazhuang 2nd Hospital, Shijiazhuang, Hebei Province, China

ABSTRACT

Photobiomodulation (PBM), previously named Low-Level Laser Therapy (LLLT), has ancient origins, with Hippocrates considered the first physician who recommended exposing ulcers and wounds to sunlight for accelerating the healing process. Subsequently, at the end of the 18th century, Joseph Priestley started his photochemical research, later continued by Antoine de Lavoisier, who constructed the basis of modern photobiology. In 1960, Theodore Maiman constructed the first laser device emitting a coherent, collimated, and monochromatic (red) beam, and Endre Mester, a few years later, discovered the possibility of using the coherent light at low power to increase the wound healing process. After him, Tiina Karu suggested that PBM activate cytochrome-c-oxidase, the unit IV in the mitochondrial electron transport chain, thus increasing the enzyme activity, oxygen consumption, and adenosine triphosphate (ATP) production by the inhibitory nitric oxide photodissociation. Moreover, a decrease in prostaglandin E2 concentrations and an increase in the production of endogenous opioids, such as endorphins, were demonstrated, along with the inhibition of pain transmission signals through effects on nociceptors, ultimately resulting in pain control. Hamblin underlined that PBM is more effective in reducing pain associated with C-fibers than A-delta fibers, supporting the hypothesis that it may preferentially target specific nerve pathways involved in pain transmission. The aim of this work was to focus on the state of the art of PBM, from the present to future possible applications.

Key words: photobiomodulation; laser therapy; low-level laser therapy; light-emitting-diode.

Corresponding author:
Leonardo Longo, International Academy for Laser Medicine and Surgery, Via Vincenzo Gioberti, 32/d, 50121 Florence, Italy.
Tel.: +39 0552342330.
E-mail: longo.leonardo@gmail.com

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Introduction

In recent years, we have assisted in the great development of photobiomodulation (PBM), also named by many authors as PBM therapy, to underline the important role that this approach may play in a high number of medical treatments.[1-10]

The reasons why, in the past, this practice was not accepted by the scientific community mainly stemmed from the low number of rigorous publications, which were often not evidence-based, as well as from the difficulty in describing its mechanisms of action and photochemical effects inside the cells that are not observable by the operator.[11,12] It was only after the understanding of these chemical processes, as described by several researchers such as Karu, Hamblin, and Anders, that PBM achieved approbation from the scientific community.[13]

In 1967, Endre Mester, considered the father of PBM, observing the improvement of the healing process in scarred rats after low-power ruby laser irradiation,[14] proposed the utilization of this procedure in medicine and started to successfully treat non-healing, difficult-healing human skin and mucosal ulcers and wounds. Subsequently, many authors studied in detail the mechanisms of action of low-energy laser irradiation in the tissues. Karu indicated mitochondria as the most cellular component sensitive to visible and near-infrared (IR) radiations[15] and Hamblin *et al.*, confirming this theory, suggested that the final result is the increase in adenosine triphosphate (ATP) production, DNA synthesis, reactive oxygen species (ROS), nitric oxide species (NOS) modulation, and transcription factor induction.[16] Moreover, Kulbacka *et al.* demonstrated that visible wavelengths, mainly blue and green, are also active in increasing intracellular calcium ions.[17] Low-power laser irradiation has now developed into a therapeutic procedure that is used in three main ways: to reduce inflammation, edema, and chronic joint disorders; to promote the healing of wounds, deeper tissues, and nerves; and to treat neurological diseases and pain.[18] In 2019, Juanita Anders *et al.*, to avoid confusion about the terminology adopted (Low-Level Laser Therapy [LLLT], soft laser, cold laser, biostimulation, and so on), proposed only to use the term "PBM", highlighting also that, with this technique, it is possible to make both stimulation and inhibition. At the same time, these authors affirmed that lasers and light-emitting diodes (LEDs), at low power, have the same kind of effects on biological tissues.[19] This was confirmed in 2018 by Heiskanen and Hamblin, who enhanced the advantages of LED light in PBM, including no laser safety considerations, ease of home use, ability to irradiate a large area of tissue at once, possibility of wearable devices, and much lower cost per mW.[20]

Photobiomodulation and photodynamic therapy

Types of lasers and wavelengths used: excimers (126-351 nm), diodes (445-1500 nm), and He-Ne (632 nm).

Photodynamic therapy (PDT) is also based on intracellular photochemical effects, but it differs from PBM because, unlike the latter, the chromophore that interacts with the light must be supplied externally. In both PBM and PDT, the ultimate outcome is the production of ROS, which are responsible for the effects observed in the tissues.[21,22]

Photodynamic diagnosis (PDD) allows the selective identification of neoplastic cells through an agent binding to them and is activated by a proper laser wavelength. It can be coupled with PDT, where the agent (chromophore), activated by the laser, selectively eliminates the neoplastic cells.[1-10]

It was first proposed worldwide by Tom Dogherty[21] at the end of the 1960s, and the first centers to adopt this method were in England, Germany, the USA, France, Japan, Israel, and Lithuania. It has not yet become widespread in routine due to a series of inconveniences and limitations:

i) Rather low fluorescence decay time of substances and variable quantities of primary and secondary fluorescence for the same substance, depending on the time of use (poor stability).
ii) High costs and difficult availability in many countries, where such therapies are not permitted, except at an experimental level.
iii) Impossibility of irradiating many deep tissues with the laser and the "shield effect" of the first most superficial layers of the substance-tissue complex, which, necrotizing during irradiation, prevent the penetration of the rays to deeper levels.
iv) Only relative substance-tissue selectivity, with the possibility of the photodynamic substance binding to other cells with a high mitotic index, such as liver and skin cells, in addition to neoplastic cells and/or not binding to poorly vascularized neoplastic cells.

PDD and PDT are, however, mainly used for the diagnosis and therapy of skin and hollow organ tumors. Today, attempts are being made to use these methods also in the treatment of skin diseases such as acne, pigmented keratosis, vitiligo, psoriasis, and eczema,[23-27] and in chronic osteomyelitis.[1-7]

Photobiomodulation therapy

Types of lasers and wavelengths employed: CO_2 (10200 nm), Nd:YAG (1064 nm), He/Ne (632 nm), diodes (445-1500 nm), excimers (126-351 nm), pulsed light (280-1200 nm), and LED (445-1100 nm).

Even if non-surgical applications of lasers have gained more and more popularity in the world for their great number of advantages, their progression was not so easy. In fact, during the early years of their introduction, their effects were less immediate and demonstrable than in surgical applications. Moreover, due to their low costs, they were initially adopted mainly by Eastern European countries.[28,29] In the United States, experimental use of non-surgical physical therapies was not permitted by the pharmaceutical industry until the Clinton presidency (1992). Meanwhile, the first therapeutic lasers were marketed in Europe in an unregulated manner, including through teleshopping, often with inadequate information about their proper applications, frequently ending up in the wrong hands.

Fortunately, in recent years, the scrupulous research conducted according to international scientific rules,[30-33] as well as the great number of clinical case studies appearing in the literature have been able to give PBM the deserved dignity and importance.

During Laser Florence 2001,[9] the diode laser was successfully employed by Prof. Pretidev Ramdawon to reduce blood sugar levels in insulin-dependent diabetics. The same technique has been used for about 30 years in several Eastern European countries, as well as in China, India, and Finland.[11,33] During Laser Florence 2002 and 2003, other groups also discussed this topic, and our team also began collecting clinical cases, completing phase 2 of the experimentation with excellent results in both type 1 and type 2 diabetes, achieved solely by modifying the irradiation method. By using diode lasers during the digestion phase, we tried to avoid secondary hyperglycemia, thus maintaining the results obtained for as long as possible. In fact, the follow-up is positive as long as the patients follow the basic rules of hygiene with regard to diet and physical activity.[11,33] During Laser Florence 2002, the effect of lasers on the healing of an experimental ulcer model was demonstrated, where fibroblast growth factors increased by 98%.[34,35] This is a contributing factor that may explain the extremely positive clinical effect of non-surgical lasers on the healing of experimental ulcers and wounds.[30-33]

It must be underlined that each effect of PBM is strictly dose-dependent.[27,28] In fact, the same wavelength on the same tissue kind may induce opposite effects: lasers used to stimulate healing can also inhibit it, and vice versa. This phenomenon, known as the "Arndt-Schultz Law", is useful in the case of pathological healing, such as hypertrophic scars and keloids,[36,37] or for collagenopathies, such as *induratio penis plastica*, also known as "La Peyronie's Syndrome",[33,38] where it has been seen that metal-sensitive collagen proteinase increases up to 80% after each laser irradiation, reaching its maximum after approximately 3 weeks of irradiation, while the transforming fibroblast factor (TGF) remains unchanged until the third or fourth application, which is performed at doses at least twice those normally used to stimulate healing.[39]

Lasers and pulsed light are also used in aesthetic medicine, according to the skin rejuvenation method: in these cases, an application of these radiations every 3-4 weeks, for an average of four to eight applications, can improve areas of dystrophic skin, reabsorbing dyschromia and small wrinkles, and giving the tissue a more toned appearance and more resistance to external insults. The Anglo-Saxon authors have carried out various histological surveys with the punch technique (which involves the use of a scalpel with a circular cutting edge called, precisely, "punch", which removes cylindrical portions of tissue), highlighting the reabsorption of damaged collagen and other skin impurities and the replacement with young collagen and revitalized tissue.[40,41] The same authors have hypothesized a mild dermo-hypodermic inflammation at the basis of these phenomena, but the same inflammation caused by violent pressure, such as slaps, does not produce the same effect. Therefore, we have proposed a totally different mechanism:[42] several *in vitro* studies have shown that red light is absorbed by cellular mitochondria and near-IR light by cellular walls, as well as by tissues of complementary wavelength. Under normal conditions, activated mitochondria have the exclusive peculiarity of producing H_2O, and this triggers the subsequent process of ATP production, not only by the mitochondria themselves but by all the cellular components. The large amount of energy formed stimulates the normal cell to work to its maximum capacity. However, in case of damaged cells, the mitochondria produce H_2O_2, with a consequent increase in activated oxygen radicals, called ROS, due to the degradation

of the unstable H_2O_2 itself. The small quantities of ROS "clean" the cytoplasm, putting the cell in the condition to resume its functions at its best. Larger quantities of ROS create in the tissue an inflammation with relatively active hyperemia, up to a toxic dose, which leads to the coupling of two oxygen ions in the mitochondria, so much so as to give an activated state called "singlet oxygen", which is cytocidal, since it causes the denaturation of the cytoplasm and cell death. The coagulation of the cytoplasm, on the other hand, prevents the cellular degeneration of severely damaged cells.
The acceleration of tissue metabolism, with consequent acceleration of cellular turnover and regeneration, would be mediated by ROS induced by light. A similar mechanism at the mitochondrial level has also been proposed by several authors,[7,8] for different PBM applications, such as the reabsorption of ear inflammation.[9,10]
Several clinical double-blind trials have been conducted by various groups on rheumatology and sports medicine. Every year during Laser Florence, the state of the art of this type of application is discussed, and the World Health Organization and Food and Drug Administration representatives illustrate their guidelines.[1-11,16]
Lasers are excellent local anti-inflammatories, and, according to many authors, particularly in Russia, they also have antibacterial, antiviral, and antiparasitic effects, stimulating the immune defenses, principally lymphocytes.[1-11,27,28,33] Some of these actions have been verified, especially in the oral cavity;[43-46] others still need confirmation by adequate experiments.
Ovsiannikov also proposed the "endovenous PBM",[47] where a fiber optic laser is inserted into a venous cannula needle on a brachial vein, with irradiation of all intracorporeal blooding, with the aim to increase the number and activity of lymphocytes and all cellular blood components and the oxygen pressure in the blood and positively influence all the hemato-chemical parameters; this technique is also called "photo-dialysis".
Toshio Oshiro[1-8] used lasers at the level of reflexogenic points controlling all the micro-vasomotor activity of the affected half-body; he checked tele-thermographically the patient's map before irradiation, highlighting hypoperfusion of the damaged areas, and demonstrated how they normalize after laser application. At a practical clinical level, this therapy is applied to all types of inflammation and pathologies where there is local hypoperfusion.
This may also accelerate venous-lymphatic drainage of tissues, particularly in zones subject to stasis, such as the lower limbs; moreover, it facilitates the "*restitutio ad integrum*" of areas subjected to acute trauma, such as sports injuries.
Wise[9] used a laser as "anti-stress" on some transcranial points, which were called "Chakra" by ancient civilizations. Transcranial laser therapy has also been proposed for the treatment of the aftermath of cerebral strokes, and is being tested for Alzheimer's disease, insomnia, anxiety, depression, and many other diseases of the central nervous system.[46,48]
Anders *et al.*[19] demonstrated the *in vitro* regeneration, increased growth, and reproduction of nerve fibers, linking to the discovery of Levi-Montalcini. The possibility of central and peripheral nerve fiber regeneration, confirmed by Rockhind, Asagai, and many other authors[49,50] who presented it in different editions of Laser Florence, has allowed for the effective treatment of lesions of the peripheral nervous system, such as trigeminal, post-herpetic, facial, and post-avulsion neuralgia, as well as traumatic lesions of the central nervous system,[11,27,33,46] such as tetraplegia and paraplegia, both spastic and flaccid, including those with "complete lesion", as a myelitic lesion is often defined with an exclusively presumptive diagnosis.
Attempts have also been made to treat degenerative diseases of the central nervous system, such as multiple sclerosis and its variants (amyotrophic lateral sclerosis and demyelinating leukodystrophy), with positive but transitory results, lasting a few months.[46-50]
Asagai successfully treated neonatal cerebral palsy due to the effects of the atomic bombs of the Second World War.[42] These applications of lasers on the central and peripheral nervous systems are continuously evolving positively and allow the treatment of lesions previously defined as incurable.[46-50] A meta-analysis of laser treatments for neck pain was published in The Lancet, which highlighted how treatment with different types of lasers should be considered the elective therapy for this syndrome, regardless of the causes.[51]

Photobiomodulation in dentistry and stomatology

One of the most important applications of PBM in this field is represented by pediatric dentistry, where pain control and discomfort may contribute to enhancing the compliance of young patients.
Fornaini *et al.*, in a literature review, analyzed 19 studies about PBM for prevention and treatment of oral mucositis associated with oncotherapy (chemotherapy, radiation,

and transplants), for postsurgical oral pain and for pulpotomies, stating that all these studies reported therapeutic benefits without adverse effects and concluding that PBM therapy is a safe and effective treatment modality for various clinical applications in pediatric dentistry.[52]
Orthodontics is one of the dental fields where most of the scientific papers regarding the use of PBM therapy were published. Caccianiga *et al.*, in 2021, investigated, by a randomized clinical trial on 30 patients, the effect of a LED with a combination of wavelengths from 450 to 835 nm on pain reduction during rapid palatal expansion (RPE), and they concluded that PBM is efficient in reducing the intensity and the time of pain felt by young patients who undergo RPE.[53]
Levrini *et al.*, in 2022, performed a retrospective study on 376 patients treated with Invisalign® (Align Technology, Inc., Tempe, AZ, USA) clear aligners in association with OrthoPulse® (Biolux Technology GmbH, Absdorf, Austria; continuous 850 nm wavelength, generating an average daily energy density of 9.5 J/cm^2) prescribed for 10 min a day for the entire duration of the orthodontic treatment and results showed that in the treated group the average number of additional aligners represented 66.5% of the initial aligners. In contrast, 103.4% of the initially planned aligners were needed in the control group.[54]
Kalhori *et al.*, in a literature review on oral medicine, stated that PBM has a positive effect on the treatment of oral lichen planus, recurrent aphthous stomatitis, hyposalivation, pemphigus vulgaris, recurrent herpes simplex, burning mouth syndrome, bisphosphonate-related osteonecrosis of the jaw, trigeminal neuralgia, facial nerve paralysis, geographic tongue, and chronic sinusitis, concluding that it can be effective (as an alternative treatment or in combination with other therapies) in improving symptoms or in the complete treatment of oral diseases.[55]
Matarese *et al.*, in their recent randomized controlled trial, showed that PBM associated with conventional treatment of scaling and root planing improved clinical parameters such as probing depth and clinical attachment loss significantly more than conventional treatment alone, maintaining the result until 1 year of follow-up;[56] similar results were reported by Mokeem in a recent systematic review.[57]
PBM protocols have recently also been proposed in the literature to reduce pain intensity and improve maximum mouth opening in patients with acute and chronic temporomandibular joint disorders who do not respond to other treatments.[58]
PBM has also been proposed for the application in pulp treatment procedures. Fernandes *et al.* described the improvement in radiographical success rate at different times of evaluation until the 18-month follow-up by adding PBM to calcium hydroxide.[59] Also, Ansari *et al.* reported similar results by adding PBM to a calcium-enriched mixture,[60] while Kuo *et al.* compared diode application and sodium hypochlorite, reporting positive results without a significant statistical difference.[61]
Fornaini *et al.*, in a narrative review of the literature, describe the advantages of using LED PBM in dentistry. In fact, in the case of treating a large area of tissue, the absence of collimation, a characteristic of lasers, allows simultaneous irradiation of LED light on the entire surface, thus saving time for the operator. Moreover, LED technology is simple, and consequently, its cost is lower compared to laser devices. Additionally, from a safety perspective, LEDs pose no risk – especially to the eyes – and therefore do not require special precautions, such as protective glass, which is necessary when using lasers.[62]

Discussion

Photobiomodulation of stem cells

From 1999 until 2004, at Bethesda University (Anaheim, CA, USA), 18 different types of lasers with different combinations of dosage parameters had been tested to obtain stem cells from different types of tissues without adding exogenous growth factors in irradiated cellular cultures.[63]
Starting with the irradiation of cells derived from the yellow fish's spinal cord, stem cells have been obtained from any type of human tissue, including adipose tissue resulting from liposuction. A "window" of wavelengths and a dosage range that stimulates the formation, proliferation, differentiation, and migration of stem cells *in vitro* was established. There is a worldwide patent on this discovery, and in 2006, it was published. Uri Oron has demonstrated the total reconstruction of the rabbit's infarcted myocardium,[8,9] after treatment with stem cells and laser. Rockhind obtained with the same system the reconstruction of the peripheral nerves of the rats.[8,9,48]

The "at-home" photobiomodulation

PBM therapy, as before described, is a non-invasive therapy already described as useful for the management of this complication; unfortunately, the limiting factor of this kind of treatment consists of the need for the patients to go to the therapist at least twice/three times weekly for treatments of some minutes, and this factor may negatively influence the compliance of the patient toward the therapy.

Due to its small size and its classification as a Class I laser under the American National Standards Institute, the "at-home" PBM laser device can be safely self-administered by patients, offering a novel and convenient approach to managing these types of conditions. The availability on the market of these new, cheap, small, and usable at home by the patients themselves PBM appliances might be included in standard therapy for this kind of problem, giving the possibility to the patients to receive PBM treatment also daily; having the patient only a time setting as part of the device, the danger of over-treating is reduced.[64]

The utilization of these "auto-administered PBM" devices reached great popularity during the COVID pandemic for the treatment, even if only symptomatic, of many chronic diseases in oncologic patients without going to hospitals, thus avoiding the risk of infection.[65]

Several authors described the successful utilization of this "at-home" PBM in the treatment of temporomandibular disease pain reduction,[66] neuronal disorders occurring in the oral district,[67] Bell's palsy,[58] and diabetic foot ulcers.[68,69]

A limitation of this type of device is its size, which, even when small, may prevent intraoral use. For this reason, several clinicians have proposed introducing a new family of appliances based on LED technology that can also be used inside the mouth.[62]

Conclusions

PBM, as well as all the treatments requiring the utilization of laser energy, is a field of medicine where specific education on the physical principles is needed,[70] and necessary to use laser devices in different clinical situations with correct parameters and without the risks of over-irradiation and by observing the safety rules. It may be, in some way, related to radiology also by the historical point of view: when X-rays were born, they were overused and subsequently eliminated as considered dangerous; finally, they were accepted and systematically classified as a new specialty, radiology.

To date, laser therapy, PBM, and PDT are successfully used for a great number of diseases, and they are subjects of specific training courses at the most important universities and academies. For these reasons, several years ago, we proposed the term "Laserology" to designate a new medical specialization. This field would serve as an umbrella for medical and surgical professionals using lasers across various disciplines, providing a platform to update their skills in line with the continual technological advancements that make laser treatments increasingly complex.[43,71,72]

Conflict of interest

The authors have no conflict of interest to declare.

Ethics approval and consent to participate

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

References

1. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence '99: A Window on the Laser Medicine World. Proceedings Volume 4166. SPIE; 1999.
2. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence 2000: A Window on the Laser Medicine World. Proceedings Volume 4606. SPIE; 2000.
3. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence 2001: A Window on the Laser Medicine World. Proceedings Volume 4903. SPIE; 2001.
4. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence 2002: A Window on the Laser Medicine World. Proceedings Volume 5287. SPIE; 2002.
5. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence 2003: A Window on the Laser Medicine World. Proceedings Volume 5610. SPIE; 2004.
6. Longo L, Hofstetter A, Pascu ML, Waidelich W. Laser Florence 2017: Advances in Laser Medicine. Proceedings Volume 10582. SPIE; 2018.
7. Longo L, American Institute of Physics. Advances in Laserology: Selected Papers of Laser Florence 2011: A Window on the Laser Medicine World, Firenze, Italy, 4-5 November 2011. American Institute of Physics; 2012.

8. Longo L. Advances in Laserology: Selected papers of Laser Florence 2012-2019. Medimond Publisher; 2012-2019.
9. Longo L. Non-surgical laser and light in the treatment of chronic diseases. Laser Phys Lett 2010;7:771-86.
10. Longo L. Terapia laser. USES Editore; 1986.
11. Longo L. Laser Manual of Medical Technology. OEO Publisher; 2015.
12. Fleury M. Traité de physique générale et expérimentale. Eyrolles; 1957.
13. Niemz MH. Laser-tissue interactions. 3rd Ed., Springer; 2003.
14. Mester A, Mester A. The History of Photobiomodulation: EndreMester (1903-1984). Photomed Laser Surg 2017;35:393-4.
15. Karu T. Primary and secondary mechanisms of action of visible to near-IR radiation on cells. J Photochem Photobiol B 1999;49:1-17.
16. Hamblin MRH, Demidova TN. Mechanisms of low level light therapy. Proceedings Volume 6140. SPIE; 2006.
17. Kubackla J, Choroma ska A, Rossowska J, et al. Cell Membrane Transport Mechanisms: Ion Channels and Electrical Properties of Cell Membranes. Adv Anat Embryol Cell Biol 2017;22.
18. Chung H, Dai T, Sharma SK, et al. The nuts and bolts of low-level laser (light) therapy. Ann Biomed Eng 2012;40:516-33.
19. Anders JJ, Arany PR, Baxter GD, Lanzafame RJ. Light-Emitting Diode Therapy and Low-Level Light Therapy Are Photobiomodulation Therapy. Photobiomodul Photomed Laser Surg 2019;37:63-5.
20. Heiskanen V, Hamblin MR. Photobiomodulation: lasers vs. light emitting diodes? Photochem Photobiol Sci 2018;17:1003-17. Erratum in: Photochem Photobiol Sci 2018;18:259.
21. Overchuk M, Weersink RA, Wilson BC, Zheng G. Photodynamic and Photothermal Therapies: Synergy Opportunities for Nanomedicine. ACS Nano 2023;17:7979-8003.
22. Correia JH, Rodrigues JA, Pimenta S, et al. Photodynamic Therapy Review: Principles, Photosensitizers, Applications, and Future Directions. Pharmaceutics 2021;13:1332.
23. Longo L, Khatri K. I laser in Medicina Estetica. La Medicina Estetica 1999;23:175-82.
24. Mineroff J, Maghfour J, Ozog DM, et al. Photobiomodulation CME part II: Clinical applications in dermatology. J Am Acad Dermatol 2024;91:805-15.
25. Nouri K. Lasers in Dermatology and Medicine. Springer; 2013.
26. Seaton ED, Charakida A, Mouser PE, et al. Pulsed-dye laser treatment for inflammatory acne vulgaris: randomised controlled trial. Lancet 2003;362:1347-52.
27. Hohberger B, Schünemann M, Sperlich K, et al. Update: Laser - an Everyday Tool with Underrated Risks. Klin Monbl Augenheilkd 2026;243:30-43.
28. Mester E, Spiry T, Szende B, Tota JG. Effect of laser rays on wound healing. Am J Surg 1971;122:532-5.
29. Karu T. The Science of Low Power Laser Therapy. Gordon Breach Science Publishers; 1998.
30. Longo L, Evangelista S, Tinacci G, Sesti AG. Effect of diodes-laser silver arsenide-aluminium (Ga-Al-As) 904 nm on healing of experimental wounds. Lasers Surg Med 1987;7:444-7.
31. Lizarelli RFZ, Salgado ASI, Cardoso FDS, et al. Photobiomodulation for Degenerative Diseases: An Overview and Perspectives. Photobiomodul Photomed Laser Surg 2025;43:383-93.
32. Baldini F, Dholakia K, French P, et al. Shining a Light on the Future of Biophotonics. J Biophotonics 2025;18:e202500148.
33. Hamblin MR, Pires de Sousa MV, Agrawal T, editors. Handbook of Low-Level Laser Therapy. Pan Stanford Publishing; 2017.
34. Cavalcanti MFXB, Cabette RA, Moraes AC, et al. The Effects *In Vitro* of Photobiomodulation Over Fibroblasts and Extracellular Matrix. Photobiomodul Photomed Laser Surg 2024;42:140-7.
35. Byrnes KR, Barna L, Chenault VM, et al. Photobiomodulation improves cutaneous wound healing in an animal model of type II diabetes. Photomed Laser Surg 2004;22:281-90.
36. Longo L. I lasers in flebologia. In: Mancini S, ed. Trattato italiano di flebologia. UTET; 2000.
37. Longo L, Postiglione M, Marangoni O, Melato M. Defocalized laser therapy 810 nm in cicatrization disorders. In: ASLMS Annual Meeting; 2001 Apr 18-20; New Orleans (LA). Abstract published in: Lasers in Surgery and Medicine. 2001.
38. Longo L, Mancini ST, Postiglione M. IPP and laser: a review. In: Longo L, Hofstetter A, Pascu ML, Waidelich W, editors. Laser Florence 2000: A Window on the Laser Medicine World. Proceedings Volume 4903. SPIE; 2001.
39. Lubart R, Wollman Y, Friedmann H, et al. Effects of visible and near-infrared lasers on cell cultures. J Photochem Photobiol B 1992;12:305-10.
40. Bitter PH. Noninvasive rejuvenation of photodamaged skin using serial, full-face intense pulsed light treatments. Dermatol Surg 2000;26:835-43.
41. Murad A, Ten-Shan Hsu, Dover J, et al. Non Ablative laser and light treatment: Hystology and tissue effects – A review. Laser Surg Med 2003;33:30-9.
42. Lubart R, Friedmann H, Lavie R, et al. A reasonable mechanism for visible light-induced skin rejuvenation. Lasers Med Sci 2007;22:1-3.
43. Fornaini C, Rocca J-P. Oral Laserology. Editografica; 2016.
44. Longo L. Terapia laser in Algologia: Fattori fisici e biologici. Algos 1984;1:36-9.
45. Longo L, Bernardini UD. Terapia laser nella nevralgia del trigemino: considerazioni preliminari. In: Atti del Congresso Nazionale dell'Associazione Italiana per lo Studio del Dolore (AISD); 1985.
46. Hamblin M, Huang YY (Ed.). Photobiomodulation in the Brain: Low-Level Laser (Light) Therapy in Neurology and Neuroscience. Academic Press; 2019.
47. Korotkov K. "Biophysical Mechanisms of Light Diagnostics and Treatment in Integrative Medicine – Laser Florence 2019" in Advances in Laserology – Selected papers of Laser Florence 2012-2019. Filodritto Publisher; 2019.
48. Rochkind S, Rousso M, Nissan M, et al. Systemic effects of low-power laser irradiation on the peripheral and central nervous system, cutaneous wounds, and burns. Lasers Surg Med 1989;9:174-82.
49. Longo L. Nonsurgical Laser Treatment (NSLT) of Central and Peripheral Nervous System Injuries. Photomed Laser Surg 2017;35:181-3.
50. Asagai Y. Application of LLLT in patients with cerebral palsy of the adult tension athetosis type. Nippon Laser Igakkaishi 2007;28:74-6.
51. Chow RT, Johnson MI, Lopes-Martins RA, Bjordal JM. Efficacy of low-level laser therapy in the management of neck pain: a systematic review and meta-analysis of randomised placebo or active-treatment controlled trials. Lancet 2009;374:1897-908.
52. Fornaini C, Arany P, Rocca JP, Merigo E. Photobiomodulation in Pediatric Dentistry: A Current State-of-the-Art. Photobiomodul Photomed Laser Surg 2019;37:798-813.
53. Caccianiga G, Caccianiga P, Baldoni M, et al. Pain Reduction during apid Palatal Expansion Due to LED Photobiomodulation Irradiation: A Randomized Clinical Trial. Life (Basel) 2021;12:37.
54. Levrini L, Carganico A, Deppieri A, et al. Predictability of Invisalign® Clear Aligners Using OrthoPulse®: A Retrospective Study. Dent J (Basel) 2022;10:229.
55. Kalhori KAM, Vahdatinia F, Jamalpour MR, et al. Photobiomodulation in Oral Medicine. Photobiomodul Photomed Laser Surg 2019;37:837-61.
56. Matarese G, Ramaglia L, Cicciù M, et al. The effects of diode laser therapy as an adjunct to scaling and root planing in the treatment of aggressive periodontitis: a 1-year randomized controlled clinical trial. Photomed Laser Surg 2017;35:702-9.

57. Mokeem S. Efficacy of adjunctive low-level laser therapy in the treatment of aggressive periodontitis: a systematic review. J Investig Clin Dent 2018;9:e1236.
58. Herranz-Aparicio J, Vázquez-Delgado E, Arnabat-Domínguez J, et al. The use of low level laser therapy in the treatment of temporomandibular joint disorders. Review of the literature. Med Oral Patol Oral Cir Bucal 2013;18:e603-12.
59. Fernandes AP, Lourenco Neto N, Teixeira Marques NC, et al. Clinical and radiographic outcomes of the use of low-level laser therapy in vital pulp of primary teeth. Int J Paediatr Dent 2015;25:144-50.
60. Ansari G, Morovati SP, Asgary S. Evaluation of four pulpotomy techniques in primary molars: a randomized controlled trial. Iran Endod J 2018;13:7-12.
61. Kuo HY, Lin JR, Huang WH, Chiang ML. Clinical outcomes for primary molars treated by different types of pulpotomy: a retrospective cohort study. J Formos Med Assoc 2018;117:24-33.
62. Fornaini C, Wang H, Li Y, Rocca JP. Light-Emitting-Diode photochemical effects in dentistry: an overview. Laser Ther 2024;31.
63. Anders JJ, Romanczyk TB, Ilev IK, et al. Light support neurite outgrowth of human neural progenitor cells in vitro: the role of P2Y receptors. IEEE J Sel Top Quantum Electron 2008;14: 118-25.
64. Gavish L, Houreld NN. Therapeutic Efficacy of Home-Use Photobiomodulation Devices: A Systematic Literature Review. Photobiomodul Photomed Laser Surg 2019;37:4-16.
65. Fornaini C, Merigo E, Huffer KW, Arany P. At-Home Photobiomodulation Treatments for Supportive Cancer Care During the COVID-19 Pandemic. Photobiomodul Photomed Laser Surg 2021;39:81-2.
66. Fornaini C, Pelosi A, Queirolo V, et al. The “at-home LLLT” in temporo-mandibular disorders pain control: a pilot study. Laser Ther 2015;24:47-52.
67. Merigo E, Rocca JP, Oppici A, et al. At-home laser treatment of oral neuronal disorders: Case reports. J Clin Exp Dent 2017;9:e595-8.
68. Merigo E, Tan L, Zhao Z, et al. Auto-Administered Photobiomodulation on Diabetic Leg Ulcers Treatment: A New Way to Manage It? Case Rep Med 2020;2020:7428472.
69. Raizman R, Gavish L. At-Home Self-Applied Photobiomodulation Device for the Treatment of Diabetic Foot Ulcers in Adults With Type 2 Diabetes: Report of 4 Cases. Can J Diabetes 2020;44:375-8.
70. Longo L. Medical laser technology: new technique or new specialization? In: Global Photonics Applications & Technology World Markets Research Centre. 2001.
71. Longo L, Postiglione M. LASERS: the applications continue to emerge. Private Hospital Healthcare Europe. Campden Publishing Ltd.; 2002.
72. Longo L. The Laser Academy – Facts and Words for an universal Specialization. In: Proceedings of the North American Laser Therapy Association Conference. Uniformed Services University; 2003.