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Technology and methodological perspectives

Development of a low-cost device for photobiomodulation using 3D printing

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ABSTRACT | INTRODUCTION: Photobiomodulation therapy (PBM) is a non-pharmacological and non-invasive therapeutic strategy that has shown promising results in several health conditions. Despite important advances in knowledge of its modulatory effects at the molecular, cellular, and tissue levels, the cost of PBM equipment still greatly limits its use in the clinical setting, especially in developing countries. In this context, the use of new technologies such as 3D printing has presented several possibilities for application in the health area. **OBJECTIVES:** To develop a 3D printing PBM device and test its technical and operational viability. **METHODS AND MATERIALS:** Development of Health Technology on a Photobiomodulation Device with 3D Printing Tests of the safety, emission, and support of the light beams were carried out. **RESULTS:** The PBM device demonstrated operational safety and good quality in the maintenance of light beams. **CONCLUSION:** A three-dimensional (3D) printed LED PBM device is technically, operationally, and financially viable. However, more experimental tests and clinical validation are required before this prototype can be used in human health applications.

KEYWORDS: Phototherapy. Diffusion of Innovation. Physical Therapy Modalities.

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1. Introduction

Therapy through photobiomodulation (PBM) is a non-pharmacological and non-invasive therapeutic strategy that is widely used in physical rehabilitation for various health conditions.[1-6] The mechanisms of PBM are still not fully understood, but some evidence suggests that parameterization plays a critical role in its effectiveness.[7,8] The wavelength and emission power, for example, stand out as key variables.[9] In physical rehabilitation, the most common forms of PBM are low-level laser therapy (LLLT) and light-emitting diode (LED) therapy. These PBM methods are frequently used to attenuate inflammatory processes[10] and stimulate tissue healing.[11-13] Currently, given its potential ability to optimize cellular reactions[14], several studies have investigated the effect of PBM in healthy populations. For example, it has been shown to reduce muscle fatigue[15,16], to improve oxygenation uptake and energy metabolism[17], as well as post-exercise muscle recovery.[18] Taken together, these findings suggest that PBM has enormous potential as a non-pharmacological and non-invasive resource for improving physical capacity and sports performance.[19]

Although much progress has been made in understanding the mechanisms of action and benefits of PBM with LED and laser, their use is still limited by their high cost and application methods. In this context, the use of new technologies, such as 3D printing, has opened up a slew of new possibilities and opportunities for the application of PBM. In the medical industry, there is an increasing demand for healthcare products. 3D printing is an innovative technology in healthcare that can be used to create custom prosthetic limbs, dental implants, organ development, physical therapy, and medical product development.[20] The ability to build patient-specific solutions at a low cost gives clinicians and patients more healthcare options. In comparison to traditional biomedical device manufacturing, 3D printing technology employs low-cost materials with excellent mechanical properties, such as thermoplastics.[21] It is worth noting that biomedical devices made with 3D printing must follow the same validation rules as traditional manufacturing before being used for human health. However, this revolutionary industry is rapidly transforming the healthcare system.

The purpose of this research was to develop a 3D printing PBM device and evaluate its technical and operational viability.

2. Methods and materials

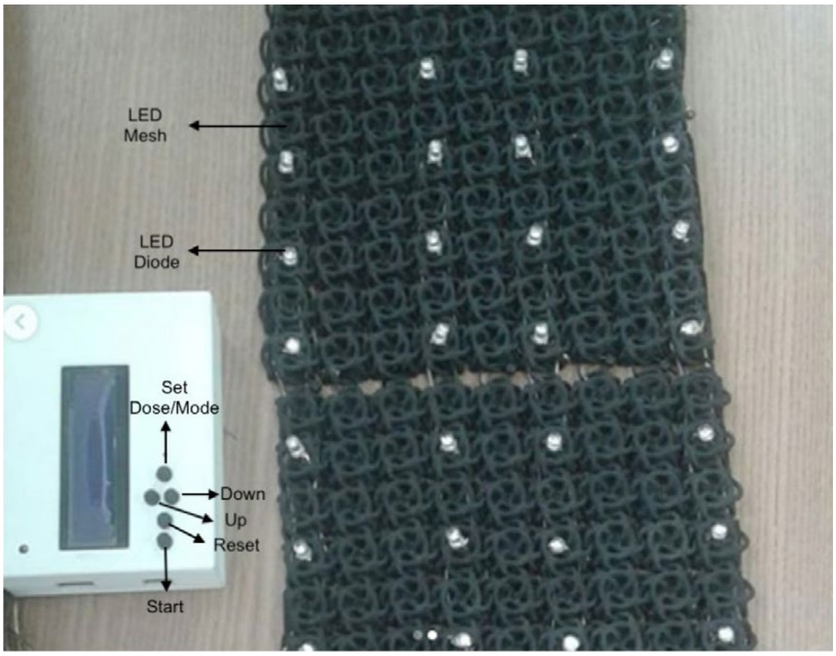
2.1. Equipment Development

2.1.1. Polymers and LEDs

The polymer chosen to be used in the printing was ABS (Acrylonitrile Butadiene Styrene) for its rigidity and lightness and for presenting a good balance between flexibility and resistance, ensuring good durability for the equipment. During printing, to minimize potential damage from the Warp Effect (“warping”), the longitudinal arches that join the mesh rings suffer a slight opening of 0.5 mm radius; after cooling, the structure has the exact dimensions expected before printing.

The LEDs were chosen based on their wavelength, which is the most important physical aspect of light in terms of treatment, given its direct relationship with penetration into biological tissue.[14] Because LEDs with visible light wavelengths reach very low wavelength ranges, 850 nm and 940 nm infrared LEDs were provided because they have a greater tissue reach (Figure 1).

Figure 1. PBM device



Source: the authors (2023).

2.2. Software

The software was written in the C++ programming language, which supports multiple paradigms, is object-oriented, and is widely used. Since a complex integration environment is not necessary, it is unique in how easily it can integrate with machines. The man-machine interface (MMI) was developed to receive information through the display with an interface that is easy for the user to access and can receive various information, such as the mode, the intensity, and the time of application. The interface was designed so that the user could interact in a simple way, allowing for the development of a better model and its application to the patient. At the same time, the user will not have access to some parameters of the source code of the equipment that stores the most complex information for controlling the different variations of excitation of the LEDs, which only the developer has access to, thereby preventing application errors based on the software.

2.3. Hardware

The system hardware basically consists of: an Arduino® Uno R3 board; a board widely used for control and automation of several prototypes[22]; a 16x2 LCD; an Arduino® keypad shield keyboard; and an excitation module for LEDs, developed at the Sensoriomotor Performance and Pain Neuromodulation Laboratory (LANDS) of the Parnaíba Delta Federal University (UFDPar), as well as a case made in a 3D printer (Creality FDM Ender-2 Pro, Shenzhen - China).

The UNO R3 was chosen because of its ease of adaptation to the most diverse systems and because it has a wide range of utilities, including the ability to control not only the energizing of the circuit but also the frequency and working time (duty cycle), the application, and wave frequency, which favors different ways of using the plate for different irradiation modes, such as different irradiation sectors at different times of work.

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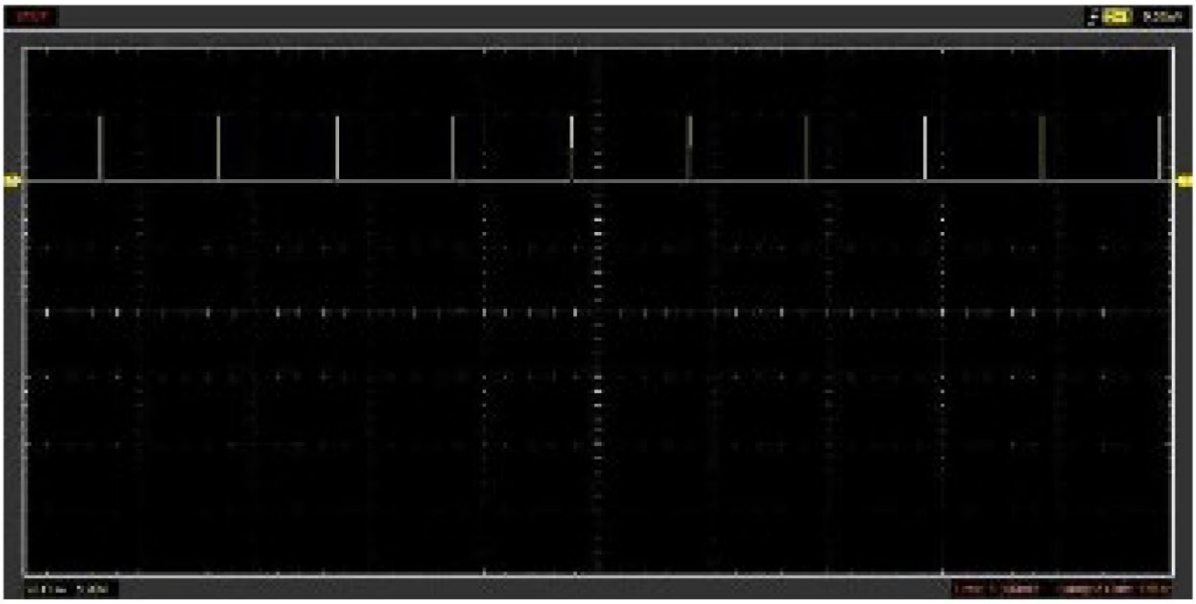
2.4. Safety Test

We used the data sheet of the instruments used in the device's preparation to perform calculations on the equipment. The duty-cycle information (Figure 2) and waveform were collected using an oscilloscope (Hantek 6022bl, Qingdao - China), and data from the circuit were collected using a multimeter (ET-1639 Minipa, Sao Paulo - Brazil).

Figure 2. Duty-cycle. Graphical representation generated by the oscilloscope guarantees that the analog signal has been corrected into a digital signal and that this signal is being sent to the board correctly. The duty cycle output was consistent with the treatment parameters



Source: the authors (2023).

We calculated the average power provided by each LED (Pm), the irradiance (Δp), and the energy density (Δe) based on the following equations:

$Pm\ (W) = P\ (W) \times T\ (s) \times f\ (Hz)$ equation (1)

$\Delta p\ (W/cm^2) = Pm\ (W) / \text{beam area}\ (cm^2)$ equation (2)

$\Delta e\ (J/cm^2) = \Delta p\ (W/cm^2) \times t\ (s)$ equation (3)

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3. Results

The system was tested with code variations using an oscilloscope to determine the correct waveform, duration, and pulse frequency until the desired dose was achieved (Table 1). The circuit and controller components were placed on the mesh's surface.

Table 1. Device specifications

LED Power (P)	30 mW
Pulse Duration (T)	3 s
Frequency (f)	490 Hz
Average Power (Pm)	44 W
Irradiance (Δp)	35 mW/cm²
Application Time (t)	300 s
Energy Density (Δe)	10 J/cm²

Source: the authors (2023).

4. Discussion

The main goal of this research was to develop a three-dimensional (3D) printed PBM device and evaluate its viability. In terms of operation, the device provided perfectly symmetrical waves at continuous intervals without overloading the processor. In terms of the device's financial viability, the manufacturing costs were approximately R$600.00. Given the prices of PBM devices on the Brazilian market range from R$1,797.00 to R$5,880.50[19-21], the PBM device using 3D printing technology had a low production cost, indicating that this technology has the potential to be useful in the future. However, more research is needed to refine our device, determine its effectiveness, and meet the needs of end-users. For instance, experimental tests to determine LED power and the distribution of relative light beam intensity with respect to the angle of incidence. A phase I and II randomized controlled trial, for example, is required to ensure the safety and best dosage to achieve clinical benefits.[23]

There is a large body of literature demonstrating the clinical benefits of photobiomodulation methods using lasers[24] or LED diodes.[25] However, PBM using light-emitting diodes has some advantages that should be considered when weighing the cost-effectiveness of these methods, particularly when used in public health systems where resources are generally scarce. PBM using LED therapy is, on average, much cheaper than laser devices. LEDs can also be used in conjunction with multiple diodes to increase the beam area and thus treat larger body areas more efficiently, including promising approaches like transcranial photobiomodulation.[26] Although the clinical equivalence of laser and LED remains debatable, there is evidence that both types of phototherapies can promote health benefits.[27]

The development of a photobiomodulation device using a 3D printer has some limitations that need to be addressed. First, the device lacks a full test for usability system and user satisfaction. Second, the rigid net mesh may need to be replaced with more flexible filaments. Third, the device is powered by a high-voltage current, limiting its portability. Finally, this prototype must be tested in terms of LED heating as well as data on the distribution of relative intensity in relation to the angle of light incidence.

5. Conclusion

A three-dimensional (3D) printed LED PBM device is technically, operationally, and financially viable. However, more experimental tests and clinical validation are required before this prototype can be used in human health applications.

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Authors' contributions

All authors approved of the final version of the manuscript, substantially contributed to the revision and its reporting, and agreed to be accountable for all aspects of the work. Jacob RSR and Moreira LPC contributed to data collection, literature search, and writing. Santos RD, Vasconcelos Neto WR, Cardoso VS, and Hazime F contributed to the device's design as well as the overall methodological quality, study design, and writing.

Conflicts of interest

No financial, legal, or political conflicts involving third parties (government, private companies, and foundations, etc.) were declared for any aspect of the submitted work (including but not limited to grants and funding, advisory board participation, study design, manuscript preparation, statistical analysis, etc.).

References

1. Clijsen R, Brunner A, Barbero M, Clarys P, Taeymans J. Effects of low-level laser therapy on pain in patients with musculoskeletal disorders: a systematic review and meta-analysis. Eur J Phys Rehabil Med. 2017;53(4):603-10. http://dx.doi.org/10.23736/S1973-9087.17.04432-X

2. Darwin E, Heyes A, Hirt PA, Wikramanayake TC, Jimenez JJ. Low-level laser therapy for the treatment of androgenic alopecia: a review. Lasers Med Sci. 2018;33(2):425-34. http://dx.doi.org/10.1007/s10103-017-2385-5

3. Li S, Wang C, Wang B, Liu L, Tang L, Liu D, et al. Efficacy of low-level light therapy for treatment of diabetic foot ulcer: A systematic review and meta-analysis of randomized controlled trials. Diabetes Res Clin Pract. 2018;143:215-24. http://dx.doi.org/10.1016/j.diabres.2018.07.014

4. Yeh S-W, Hong C-H, Shih M-C, Tam K-W, Huang Y-H, Kuan Y-C. Low-Level Laser Therapy for Fibromyalgia: A Systematic Review and Meta-Analysis. Pain Physician. 2019;22(3):241-54. Cited: PMID: 31151332.

5. Jana Neto FC, Martimbianco ALC, Andrade RP, Bussadori SK, Mesquita-Ferrari RA, Fernandes KPS. Effects of photobiomodulation in the treatment of fractures: a systematic review and meta-analysis of randomized clinical trials. Lasers Med Sci. 2020;35(3):513-22. http://dx.doi.org/10.1007/s10103-019-02779-4

6. Gao Y, An R, Huang X, Liu W, Yang C, Wan Q. Effectiveness of photobiomodulation for people with age-related cognitive impairment: a systematic review and meta-analysis. Lasers Med Sci. 2023;38(1):237. http://dx.doi.org/10.1007/s10103-023-03899-8

7. Costa MS, Brito TV, Oliveira SB, Brauna IS, Mazulo Neto JCR, Teles RHG, et al. Photobiomodulation exerts anti-inflammatory effects on the vascular and cellular phases of experimental inflammatory models. Lasers Med Sci. 2022;37(1):563-71. http://dx.doi.org/10.1007/s10103-021-03298-x

8. Zein R, Selting W, Hamblin MR. Review of light parameters and photobiomodulation efficacy: dive into complexity. J Biomed Opt. 2018;23(12):120901. http://dx.doi.org/10.1117/1.JBO.23.12.120901

9. Toma RL, Oliveira MX, Renno ACM, Laakso E-L. Photobiomodulation (PBM) therapy at 904 nm mitigates effects of exercise-induced skeletal muscle fatigue in young women. Lasers Med Sci. 2018;33(6):1197-205. http://dx.doi.org/10.1007/s10103-018-2454-4

10. Langella LG, Casalechi HL, Tomazoni SS, Johnson DS, Albertini R, Pallotta RC, et al. Photobiomodulation therapy (PBMT) on acute pain and inflammation in patients who underwent total hip arthroplasty-a randomized, triple-blind, placebo-controlled clinical trial. Lasers Med Sci. 2018;33(9):1933-40. http://dx.doi.org/10.1007/s10103-018-2558-x

11. Santos JAF, Campelo MBD, Oliveira RA, Nicolau RA, Rezende VEA, Arisawa EAL. Effects of Low-Power Light Therapy on the Tissue Repair Process of Chronic Wounds in Diabetic Feet. Photomed Laser Surg. 2018;36(6):298-304. http://dx.doi.org/10.1089/pho.2018.4455

12. Vitoriano NAM, Mont'Alverne DGB, Martins MIS, Silva PS, Martins CA, Teixeira HD, et al. Comparative study on laser and LED influence on tissue repair and improvement of neuropathic symptoms during the treatment of diabetic ulcers. Lasers Med Sci. 2019;34(7):1365-71. http://dx.doi.org/10.1007/s10103-019-02724-5

13. Poorpezeshk N, Ghoreishi SK, Bayat M, Pouriran R, Yavari M. Early Low-Level Laser Therapy Improves the Passive Range of Motion and Decreases Pain in Patients with Flexor Tendon Injury. Photomed Laser Surg. 2018;36(10):530-5. http://dx.doi.org/10.1089/pho.2018.4458

14. Chung H, Dai T, Sharma SK, Huang Y-Y, Carroll JD, Hamblin MR. The nuts and bolts of low-level laser (light) therapy. Ann Biomed Eng. 2012;40(2):516-33. http://dx.doi.org/10.1007/s10439-011-0454-7

15. Souza CG, Borges DT, Macedo LB, Brasileiro JS. Low-level laser therapy reduces the fatigue index in the ankle plantar flexors of healthy subjects. Lasers Med Sci. 2016;31(9):1949-55. http://dx.doi.org/10.1007/s10103-016-2074-9

16. Hemmings TJ, Kendall KL, Dobson JL. Identifying Dosage Effect of Light-Emitting Diode Therapy on Muscular Fatigue in Quadriceps. J Strength Cond Res. 2017;31(2):395-402. http://dx.doi.org/10.1519/JSC.0000000000001523

17. Lanferdini FJ, Krüger RL, Baroni BM, Lazzari C, Figueiredo P, Reischak-Oliveira A, et al. Low-level laser therapy improves the VO2 kinetics in competitive cyclists. Lasers Med Sci. 2018;33(3):453-60. http://dx.doi.org/10.1007/s10103-017-2347-y

18. Fisher SR, Rigby JH, Mettler JA, McCurdy KW. The Effectiveness of Photobiomodulation Therapy Versus Cryotherapy for Skeletal Muscle Recovery: A Critically Appraised Topic. J Sport Rehabil. 2019;28(5):526-31. http://dx.doi.org/10.1123/jsr.2017-0359

19. Ferraresi C, Huang Y-Y, Hamblin MR. Photobiomodulation in human muscle tissue: an advantage in sports performance?. J Biophotonics. 2016;9(11-12):1273-99. http://dx.doi.org/10.1002/jbio.201600176

20. Javaid M, Haleem A, Singh RP, Suman R. 3D printing applications for healthcare research and development. Glob Health J. 2022;6(4):217-26. http://dx.doi.org/10.1016/j.glohj.2022.11.001

21. Mamo HB, Adamiak M, Kunwar A. 3D printed biomedical devices and their applications: A review on state-of-the-art technologies, existing challenges, and future perspectives. J Mech Behav Biomed Mater. 2023;143:105930. http://dx.doi.org/10.1016/j.jmbbm.2023.105930

22. Arduino. Homepage [Internet]. [s.d.]. Available from: https://www.arduino.cc/

23. Evans SR. Fundamentals of clinical trial design. J Exp Stroke Transl Med. 2010;3(1):19-27. Cited: PMID: 21533012.

24. Cruz AR, Minicucci EM, Betini M, Almeida-Lopes L, Tieghi Neto V, Cataneo AJM. Efficacy of photobiomodulation in the treatment of oral mucositis in patients undergoing antineoplastic therapy: systematic review and meta-analysis. Support Care Cancer. 2023;31(12):645. http://dx.doi.org/10.1007/s00520-023-08105-7

25. Ngoc LTN, Moon J-Y, Lee Y-C. Utilization of light-emitting diodes for skin therapy: Systematic review and meta-analysis. Photodermatol Photoimmunol Photomed. 2023;39(4):303-17. http://dx.doi.org/10.1111/phpp.12841

26. Martin PI, Chao L, Krengel MH, Ho MD, Yee M, Lew R, et al. Transcranial Photobiomodulation to Improve Cognition in Gulf War Illness. Front Neurol. 2020;11:574386. http://dx.doi.org/10.3389/fneur.2020.574386

27. Vanin AA, Verhagen E, Barboza SD, Costa LOP, Leal-Junior ECP. Photobiomodulation therapy for the improvement of muscular performance and reduction of muscular fatigue associated with exercise in healthy people: a systematic review and meta-analysis. Lasers Med Sci. 2018;33(1):181-214. http://dx.doi.org/10.1007/s10103-017-2368-6