The In Vitro Thermal Effect of A 980-Nm Diode Laser In A Gingival Simulation Model

Mehmet Oğuzhan Ergin[1*], Hasan Gündoğar[2], Nuray Zulkadir Ergin[1], Mert Özalpay[3]

1. Gaziantep Şahinbey Oral and Dental Health Hospital, Gaziantep, Türkiye.
2. Hoca Ahmet Yesevi University, Faculty of Dentistry, Department of Periodontology, Kazakhstan.
3. Private Dental Practice, Istanbul, Türkiye.

***Corresponding author:** Ergin M O, MSc. PhD, Gaziantep Şahinbey Oral and Dental Health Hospital, Gaziantep, Türkiye.
E-mail : dtoguzhaergin@gmail.com

Abstract

Aim: In periodontology, photobiomodulation therapy applications are increasing due to their acceleration of regeneration and anti-inflammatory effects. It is known that there is an increase in temperature during laser therapy. The aim of this study is to measure the temperature changes while using a 980-nm diode laser with different parameters in a new gingival simulation method.
Materials and Methods: Silicone impression material was placed in a prefabricated 3-cm diameter teflon mold with the measuring tip of the digital thermometer in the center. To simulate gingiva, a 1x1 cm^2 bovine collagen membrane was placed. The diode laser was set at 0.4 watts (W), 0.6W, 0.8W, 1W, 1.5W, 2W, 3W, 4W, 5W, and 6W powers pulsed (PW), the continuous mode (CW) was applied to the dry membrane, and 0.05 cc and 0.1 cc of blood impregnated the membrane for 60 seconds. Temperature changes were measured with a digital thermocouple.
Results: The highest temperature change was 2.5°C and occurred during the 6W CW mode in a 0.1-cc bloody membrane. In addition, the CW mode created a temperature change ranging from 1 to 2.5 times greater compared to the PW mode. As the W value increased, it was observed that the temperature change increased in direct proportion.
Conclusion: According to the results of this study, it was determined that the photobiomodulation therapy applied with a 980-nm diode laser increased the temperature in the gingival simulation model, but this increase did not exceed 10°C, which is the critical value for bone tissue.

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Keywords: Photobiomodulation, thermal change, gingival simulation-model.

Introduction

"LASER" is an acronym derived from the words "Light Amplification by Stimulated Emission of Radiation." Theodore Mainman did the practical work of the laser in 1960, and the first worked laser was invented by Mainman. In this laser, Mainman used ruby crystals as the main substance, leading to the term "ruby laser." The thermal effect of the ruby laser on teeth was explained in 1965 by two researchers named Goldman and Taylor (1). Research showed that the ruby laser caused an increase in temperature both in the tooth itself and in neighboring teeth (2,3). After the discovery of the first ruby laser and its application in dentistry, a wide variety of lasers were invented and used in both soft and hard tissue treatments in dentistry. However, for the laser to act on biological tissues, it needs to be absorbed by them. Moreover, absorption is related to the physical and chemical properties of tissue (4). Following absorption, photothermal, photomechanical, and photochemical effects occur in the tissue. While these effects depend on the duration, wavelength, and power of the laser beam, the physical properties of the tissue are also important (2).

Photobiomodulation is a treatment method used to reduce inflammation and increase tissue repair and pain-relieving “analgesic” effects. The biostimulative effect of the laser was found incidentally in 1967 when Dr. Mester did research on the laser and cancer.

Since then, thousands of publications have been added to the literature, and the effect of photobiomodulation on reducing inflammation, accelerating wound healing, and pain reduction continues to be investigated (2,5,6). A number of changes occur in the laser-activated cell, such as a decrease in inflammation and acceleration in wound healing (5). Diode lasers and LEDs are generally used in photobiomodulation therapy. Generally, devices with wavelengths between 600-1000 nm are preferred, and energy density varies from 5 mW/cm^2 to 5 W/cm^2. The limits of photobiomodulation in dentistry have not been fully drawn compared to the treatment of skeletal and muscle diseases, but most current studies address this field (5).

Many effects of photobiomodulation therapy are explained by the absorption of light by the mitochondria. Cells can contain thousands of mitochondria, which take part in the cell's energy synthesis. In addition, mitochondria synthesize nitric oxide in ischemic cells. Nitric oxide binds to cytochrome-c oxidase (the terminal enzyme in the electron transport chain) to prevent oxygen from binding. Thus, it both reduces energy synthesis and increases oxidative stress. Increased oxidative stress also causes activation of NF-κB, which is one of the important keys of the inflammatory state (7). However, while all these cellular changes occur, another issue that is the subject of research is the photothermal effect of laser (8).

In clinical studies in the fields of periodontology and implantology, lasers are usually applied on gingiva or inside the periodontal pocket(9,10); however, the extent to which the temperature increases during these applications in the alveolar bone is unclear in gingival simulation models. Moreover, Eriksson et al. showed that a change in temperature above the threshold of 10°C in the alveolar bone causes bone injury and endangers its regeneration (11,12). The purpose of this pilot study was to evaluate the photothermal effect of a 980-nm diode laser applied at different powers and durations using an in vitro gingival simulation with different hemoglobin densities.

Materıal and Methods

Preparation

To create the main structure, a 3-cm diameter prefabricated prepared teflon was used as a mold. The mold was filled with a condensation silicone impression material (Optosil Xantoprene, Heraeus Kulzer Germany), and a thermocouple (305 handheld thermometer) probe (J type 1 mm diameter) was placed in the center. During this filling, a negative space was created using a piece of cardboard material with an area of 1x1 cm^2 and depth of 2 mm. During the laser application, a Collprotect® native collagen membrane (Straumann, Botiss Biomaterials, Zossen, Germany) was adjusted in the specified dimensions (1x1 cm^2) to simulate the gingiva (Figure 1A, 1B, 1C).

Laser application

Laser application was conducted using a 980-nm GaAlAs diode laser (CHEESETM, GIGAA Laser, Wuhan Gigaa Optronics Technology Co., Ltd., China) and low laser therapy application tip (Therapy handpiece, Wuhan Gigaa Optronics Technology Co., Ltd., China) on a collagen membrane. The tip was placed at its standard distance by adjusting the spot diameter to 1 cm. The laser powers were 0.4W, 0.6W, 0.8W, 1W, 1.5W, 2W, 3W, 4W, 5W, and 6W, respectively, in both a continuous wave (CW) and pulsed wave (PW) (500ms stop, 500ms irradiation) mode for 60 seconds at an adjusted distance of 1 cm from the membrane. Each laser application was performed while the membrane was dry, while the membrane absorbed 0.05 cc of blood, and while it absorbed 0.1 cc of blood. Peripheral venous blood applied to the membrane was obtained from the author (H.G.). In addition, the membrane was replaced after each laser application (Figure 1D, 1E).

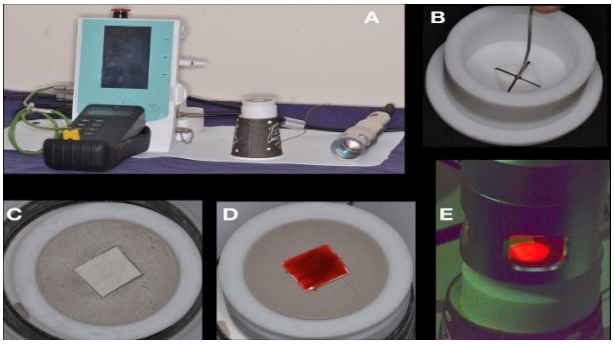

Figure 1: A: Experimental tools and laser,
B: Placement of thermocouple tip,
C: Placement of the collagen membrane in to impression material,
D: Application of blood,
E: Application of laser.

Assessment of temperature change

Temperature changes were detected on the digital thermometer screen before the laser application and after 60 seconds of exposure. The temperature difference was calculated, and the temperature change for each application was recorded with Microsoft Excel (Microsoft, Office 365, Redmond, WA, USA). Tables and graphics were also created with Microsoft Excel.

Results

Temperature changes and applied doses are are summarized in Table 1 and Figures 2 and 3, respectively. Temperature changes were between 0 and 2.5°C. The highest temperature change occurred with a 6W CW on the 0.1 cc bloody membrane. With a doubling of the blood density, a temperature changes 1-2.5 times greater than the initial temperature was observed at different doses, with the highest temperature occurring with the 1W pulsed wave. The critical threshold of 10°C was not exceeded under any doses or conditions.

Table 1: Temperature differences at different laser dose.

Temperature differences		No blood	0,05cc	0,1cc
0,4W	**CW**	0	0,1	0,2
	PW	0	0,1	0,1
0,6W	**CW**	0,1	0,3	0,4
	PW	0,1	0,1	0,2
0,8W	**CW**	0,2	0,3	0,6
	PW	0,1	0,2	0,2
1W	**CW**	0,2	0,5	0,7
	PW	0,1	0,2	0,5
1,5W	**CW**	0,2	0,7	0,9
	PW	0,2	0,4	0,5
2W	**CW**	0,3	1,1	1,4
	PW	0,3	0,4	0,6
3W	**CW**	0,5	1,5	1,7
	PW	0,4	0,7	0,9
4W	**CW**	0,6	1,9	2
	PW	0,5	0,8	1,1
5W	**CW**	0,8	2	2,2
	PW	0,6	0,7	1,1
6W	**CW**	0,9	2,3	2,5
	PW	0,8	0,9	1,3

W: watt, CW; continuous wave, PW; pulsed wave.

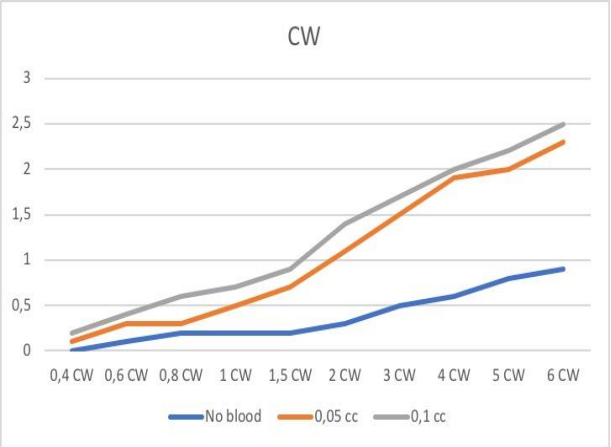

Figure 2: Temperature change graph in CW

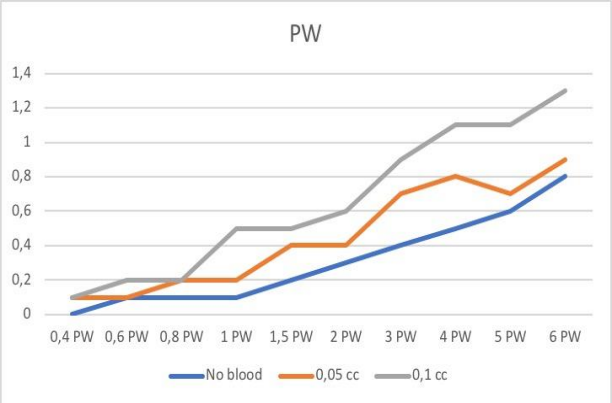

Figure 3: Temperature change graph in PW

Discussion

Studies on photobiomodulation are primarily animal studies or conducted in vitro. In vitro studies have been used to examine the effects of photobiomodulation applications and various laser doses on human periodontal tissues; laser application has been emphasized to have a positive effect on cell proliferation in gingival fibroblasts (13). However, studies on oral tissues have generally been on the proliferative effects of different doses. Although the photothermal effect of lasers is mentioned in studies in the field of dermatology (14), there are no in vitro studies regarding oral tissue simulation methods. Our study is one of the first studies showing gingival simulation in this context. In addition, according to the results of our study, it can be said that the temperature differences occurring in this in vitro model depended on the laser dose and hemoglobin density but did not exceed the critical threshold (10°C).

The recently published studies of Barros et al. emphasized that the color and thickness of skin affects the transmittance and reflectance of the laser light, and it was stated that the texture properties are important for laser dose and parameter selection (14). According to the results of the present study, it is not possible to say whether tissue thickness has an effect, and it can be counted among the limitations of this study. However, it can be said that the increase in blood density and hemoglobin density is associated with temperature increases. Eriksson et al. stated that a 10°C temperature change occurring in the bone can lead to necrosis in bone tissue (11); however, the results of our study determined that the 980-nm diode laser applied at different watts for 60s showed a maximum increase of 2.5°C, which is below the critical threshold. Moreover, although membrane was as close to the thermocouple type membrane as possible, it was estimated that there is little heat loss. In photobiomodulation treatments, J/cm^2 is used instead of W as the basic dose-related unit (9). W used in present study because it could be easily converted to J/cm^2.

In laser research, animal specimens are used more frequently than gingival modeling (15); however, in such studies, the temperature changes of the laser applied to an inorganic material, such as a dental implant in bone and close tissues, are tested. Studies with animal samples can mimic tissues such as human bones and teeth (16), but they are expected to have a similar blood composition to mimic soft tissues such as gingival. As such, in our study, human blood was combined with a bovine collagen membrane. In addition, this combination is often used in guided bone regeneration treatments in the field of periodontology.

In this study, a novel approach was undertaken to simulate gingival tissue in an in vitro setting. Utilizing a prefabricated teflon mold, filled with a condensation silicone impression material, alongside a collagen membrane to mimic the gingiva, provided a controlled environment for laser application. The inclusion of a thermocouple probe allowed for precise temperature monitoring during laser exposure. In this study, the collagen membrane was primarily employed for its ability to absorb blood and secondarily for its standardized thickness, mimicking physiological tissue. The inclusion of both continuous and pulsed modes in laser application holds clinical significance. Thus, to emulate clinical practice, both modes were employed in the study.

Laser application, performed using a 980-nm GaAlAs diode laser, was systematically conducted at varying power levels and modes on the collagen membrane. Notably, the study explored the effects of different blood densities, simulating physiological conditions encountered during clinical procedures. Temperature changes were measured and recorded meticulously, showcasing the impact of laser dose and hemoglobin density on thermal responses. Comparative analysis with existing literature underscored the novelty of this research, particularly in the context of oral tissue simulation. While previous studies predominantly focused on animal models or in vitro assessments without tissue simulation, this study provided valuable insights into the photothermal effects of lasers on simulated gingival tissue. The findings indicated that temperature variations remained below the critical threshold, suggesting safety within the parameters tested. Furthermore, limitations such as the influence of tissue thickness on laser effects were acknowledged, providing avenues for future research refinement.

Conclusions

In summary, our study is among the first to explore gingival simulation in the context of photobiomodulation. We investigated the impact of laser dose and hemoglobin density on temperature changes in an in vitro model, finding that the 980-nm diode laser, applied at different watts for 60 seconds, resulted in a maximum temperature increase of 2.5°C, below the critical threshold of 10°C.

While our study did not specifically address the potential influence of tissue thickness on the observed effects, we did establish a correlation between increased blood density and hemoglobin density with temperature increases. Our unique approach involved combining human blood with a bovine collagen membrane, commonly used in guided bone regeneration treatments in periodontology.

Our findings contribute valuable insights into the temperature dynamics associated with different laser doses on human oral tissues. By offering a novel perspective on gingival simulation and its relevance to photobiomodulation, our study may inform future research and clinical applications in periodontology.

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Compliance with ethical standards
This study was approved by …….. University Local Ethics Committee; decision no: 2020/361, date:16.12.2020.

References

1. Taylor R, Shklar G, Roeber F. The effects of laser radiation on teeth, dental pulp, and oral mucosa of experimental animals. Oral Surgery, Oral Med Oral Pathol 1965; 19(6), 786–795..
2. Blayden J, Mott A. Soft-Tissue Lasers in Dental Hygiene. John Wiley & Sons; 2012:124.
3. Taylor N. LASER: The inventor, the Nobel laureate, and the thirty-year patent war. 2002:157-166.
4. Newman MG, Takei H, Klokkevold PR, Carranza FA. Carranza's Clinical Periodontology.; 2014:1958-1962.
5. Carroll JD, Milward MR, Cooper PR, Hadis M, Palin WM. Developments in low level light therapy (LLLT) for dentistry. Dent Mater 2014;30(5):465-475.
6. Mester E, Szende B, Gärtner P. [The effect of laser beams on the growth of hair in mice]. Radiobiol Radiother (Berl) 1968;9(5):621-626.
7. Prindeze NJ, Moffatt LT, Shupp JW. Minireview Mechanisms of action for light therapy : a review of molecular interactions. 2012;237(11):1241-8.
8. Liu Y, Ai K, Liu J, Deng M, He Y, Lu L. Dopamine-Melanin Colloidal Nanospheres: An Efficient Near-Infrared Photothermal Therapeutic Agent for In Vivo Cancer Therapy. Adv Mater 2013;25(9):1353-1359.
9. Demirturk-Gocgun O, Baser U, Aykol-Sahin G, Dinccag N, Issever H, Yalcin F. Role of Low-Level Laser Therapy as an Adjunct to Initial Periodontal Treatment in Type 2 Diabetic Patients: A Split-Mouth, Randomized, Controlled Clinical Trial. Photomed Laser Surg 2017;35(2):111-115.
10. Gündoğar H, Şenyurt SZ, Erciyas K, Yalım M, Üstün K. The effect of low-level laser therapy on non-surgical periodontal treatment: a randomized controlled, single-blind, split-mouth clinical trial. Lasers Med Sci 2016;31(9):1767-1773.
11. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: A vital-microscopic study in the rabbit. J Prosthet Dent 1983;50(1):101-107.
12. Eriksson RA, Albrektsson T, Magnusson B. Assessment of bone viability after heat trauma: A histological, histochemical and vital microscopic study in the rabbit. Scand J Plast Reconstr Surg Hand Surg 1984;18(3):261-268.
13. Peplow P V, Chung T-Y, Baxter GD. Laser photobiomodulation of proliferation of cells in culture: a review of human and animal studies. Photomed Laser Surg 2010;28 Suppl 1:S3-40.
14. Souza-Barros L, Dhaidan G, Maunula M, et al. Skin color and tissue thickness effects on transmittance, reflectance, and skin temperature when using 635 and 808 nm lasers in low intensity therapeutics. Lasers Surg Med 2018;50(4):291-301.
15. Leja C, Geminiani A, Caton J, Romanos GE. Thermodynamic effects of laser irradiation of implants placed in bone: An in vitro study. Lasers Med Sci 2013;28(6):1435-1440.
16. Borges AB, Batista GR, Arantes PT, Wiegand A, Attin T, Torres CRG. Influence of simulated pulpal pressure on efficacy of bleaching gels. J Contemp Dent Pract 2014;15(4):407-412.