Increase in pulp chamber temperature during irradiation with high-power diode laser: an in vitro study

Aumento da temperatura da câmara pulpar durante a irradiação com laser de diodo de alta potência: um estudo in vitro

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Abstract

Objective: The aim of this in vitro study was to evaluate the variation in pulp chamber temperature during diode laser irradiation using different power and time parameters. **Methods:** Ten human mandibular central incisors (n=10) were selected, and their root canals were enlarged and filled with thermal paste. The root portion remained submerged in a thermal bath at 37°C, and a thermocouple sensor connected to a digital thermometer was placed inside the pulp chamber to measure the temperature variation. The diode laser (810 nm) was applied at a distance of 1 cm from the dental surface, using power settings of 1, 2, and 3 W in continuous mode, for 5, 10, 15, 20, and 25 seconds. For each power setting and for each tooth, five temperature measurements were taken in addition to the baseline measurement. Data were analyzed using analysis of variance (ANOVA) and Tukey's post-hoc test (α = 5%). **Results:** A statistically significant difference was observed between all temperature readings compared to the baseline, as well as among all time intervals, indicating a progressive temperature increase over time for all three tested power settings. Furthermore, higher power resulted in greater temperature elevation ($P \leq 0.05$). **Conclusion:** The irradiation parameters used in this study led to a progressive increase in pulp chamber temperature, without exceeding the 5.5 °C threshold associated with irreversible pulpal damage.

Keywords: Temperature; Semiconductor Lasers; Dental Pulp Cavity.

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Introduction

The dental pulp maintains a dynamic physiological balance that can be disrupted by various pathological processes, including bacterial virulence factors, inflammatory responses, and, notably, thermal and electrical stimuli[1]. The occurrence of thermal stimuli is frequent in various clinical dental procedures[2]. Although heat transfer to dental tissues is inherent to clinical practice, caution must be exercised to prevent iatrogenic damage to the pulp. Classic studies, such as that of Zach and Cohen[3] (1965), have demonstrated that an increase in pulp chamber temperature rise (PCTR) greater than 5.5 °C can lead to irreversible biological effects on the pulp.

The dental pulp is directly related to the maintenance of tooth vitality and is vulnerable to temperature increases[2]. In this context, dental structures exhibit physiological protective mechanisms, such as the enamel and dentin layers, which function as thermal insulators[4]. Studies indicate that greater thicknesses of these layers offer increased protection against PCTR[5,6].

The defensive responses of the dentin–pulp complex to irritative stimuli range from dentin sclerosis and the formation of reactionary dentin to pulp inflammation and necrosis[7]. The literature suggests that temperature increases above 5.5 °C pose a risk of irreversible pulp damage, while increases between 3.3 °C and 5.5 °C may lead to reversible inflammation[3]. Therefore, dental procedures that generate heat should be thoroughly studied to ensure the preservation of pulp vitality.

The use of high-power lasers has become widespread in various fields of dentistry, including the disinfection of deep carious lesions without cavity preparation[8], endodontic procedures[9], treatment of dentin hypersensitivity[10], debonding of orthodontic brackets[11], and evaporation of adhesive system solvents[12]. However, these devices cause heating of the target and surrounding tissues due to their photothermal effect[12].

Several factors influence heat generation, including power output, wavelength, fiber diameter, and irradiation time[13]. Additionally, fiber distance and angulation[14], as well as the composition, optical, and thermal properties of the irradiated tissues, also affect heat dissipation[15,16].

Among high-power lasers, the diode laser stands out for its widespread use and increasing popularity in dentistry, driven by its cost-effectiveness, portability, and versatility[17]. This type of laser operates predominantly at wavelengths between 810 nm and 980 nm[18], a range that favors absorption by pigments such as melanin and hemoglobin[19]. Despite its broad clinical application[8–12] and the available knowledge regarding factors that influence thermal elevation[13–16], further specific investigations are needed to assess temperature variation in the pulp chamber caused by different combinations of power and application time with the diode laser. Understanding the thermal profile of this laser is crucial to optimize usage protocols and ensure pulp safety and vitality during procedures.

In light of the above, the present study aims to evaluate the temperature variation in the pulp chamber during irradiation with a high-power diode laser using different power settings and application times. The conceptual hypothesis of this study is that the PCTR resulting from diode laser use is proportional to the applied power and exposure time.

Materials and Methods

This study consisted of an in vitro experiment using extracted human teeth obtained from the Tooth Bank of the School of Dentistry at the Federal University of Santa Maria. The project was submitted to and approved by the Research Ethics Committee of the Federal University of Santa Maria, under protocol number CAAE 16516813.4.0000.5346.

Ten sound mandibular central incisors were selected, in accordance with sample sizes reported in previous studies employing similar experimental designs[10,20]. Teeth presenting pathological alterations such as calcifications or resorptions were excluded based on clinical and radiographic evaluation.

After selection, the teeth were cleaned using McCall 13-14 curettes (Millenium – Golgran, São Caetano do Sul, São Paulo, Brazil) and Robinson brushes (MK Life, Porto Alegre, Rio Grande do Sul, Brazil) moistened with pumice paste (Asfer, São Caetano do Sul, São Paulo, Brazil) and water. For disinfection, the specimens were stored for thirty days in a 0.5% thymol solution at room temperature, with weekly replacements. One day before the experiment, the teeth were rinsed in running water and stored in distilled water.

Coronal access was performed on the lingual surface using a spherical diamond bur FG 1016 (KG Sorensen, Cotia, São Paulo, Brazil) attached to a high-speed handpiece (KaVo, Joinville, Santa Catarina, Brazil) under constant irrigation. Residual pulp and root tissues were removed with 0.5% sodium hypochlorite (Asfer, São Caetano do Sul, São Paulo, Brazil) and a manual K-file #25 (Dentsply Maillefer, Ballaigues, Switzerland). Subsequently, the root canals were enlarged using the same FG 1016 diamond bur.

The enamel and dentin thickness of each specimen was measured with a thickness gauge positioned 2mm coronally from the cementoenamel junction to ensure standardization of the preparation.

After preparation, the teeth were fixed in an acrylic support, with the roots submerged in a thermal bath at 37 °C, controlled by a digital thermometer (Incoterm, Porto Alegre, Rio Grande do Sul, Brazil), to simulate in vivo conditions. All samples started the experimental protocol from equivalent baseline temperatures. The endodontic cavity was completely filled with thermal paste (Implastec, Votorantim, São Paulo, Brazil), allowing heat transfer from the dentin walls to the thermocouple sensor.

The laser device used was the Thera Lase Surgery diode laser (DMC Equipamentos Ltda., São Carlos, São Paulo, Brazil), with a wavelength of 810nm and a fiber diameter of 400μm. The laser was applied to the vestibular surface of the dental crown, positioned 1cm from the surface and 2mm from the cementoenamel junction, using power settings of 1, 2, and 3W in continuous mode, for up to 25 seconds. Temperature was recorded at intervals of 5, 10, 15, 20, and 25 seconds. For each power setting and each tooth, five temperature readings were taken, in addition to the baseline measurement.

Temperature was measured using the HI935005 thermometer (Hanna Instruments, Woonsocket, Rhode Island, USA), connected to a type K thermocouple sensor (Hanna Instruments, Woonsocket, Rhode Island, USA) with a diameter of 1.6 mm, was inserted through the root canal into the pulpal chamber until it came into close contact with the vestibular wall at the cementoenamel junction. To prevent displacement during laser irradiation, the sensor was stabilized using a small amount of flowable composite resin (Ivoclar Vivadent, Schaan, Liechtenstein). The internal positioning of the thermocouple ensured that it remained outside the laser beam path, receiving heat exclusively conducted through enamel and dentin. The device was used according to the manufacturer's standard calibration, with no additional calibration procedures performed.

The experiment was conducted in an environment with ambient temperature ranging from 20 to 24°C and relative humidity of approximately 50%, monitored by a digital thermo-hygrometer (Kasvi, Pinhais, Paraná, Brazil).

Temperature data were tabulated and analyzed using descriptive statistics with the Statistical Package for the Social Sciences (SPSS), version 18.0 (IBM Corp., Armonk, NY, USA). The normality of the distribution was verified by the Shapiro-Wilk test, and homoscedasticity by Levene's test. Temperature variation (ΔT) at each of the five time intervals was compared across the different laser power settings using ANOVA, followed by Tukey's post-hoc test to account for multiple comparisons. The baseline temperature and the temperatures at each interval (T5s, T10s, T15s, T20s, T25s) were compared pairwise using the t-test. All analyses were performed with a significance level of 5%.

Results

The thickness of the remaining enamel and dentin in the specimens ranged from 2.0 mm to 2.4 mm, with a mean of 2.15 mm.

Temperature variation at all time intervals (ΔT5s, ΔT10s, ΔT15s, ΔT20s, and ΔT25s) was significantly influenced by the laser power setting ($P \leq 0.05$), with higher power levels resulting in greater mean temperature variations (Table 1).

Table 1. Temperature values (standard deviation) and temperature variation, in degrees Celsius (°C), according to recorded time intervals and different power settings tested.

	T 0s	T5s	ΔT5s	T10s	ΔT10s	T15s	ΔT15s	T20s	ΔT20s	T25s	ΔT25s
1W	28,77^{A}(0,82)	28,94^{A} (0,79)	0,17^{A}	29,16^{A} (0,81)	0,39^{A}	29,38^{A} (0,79)	0,61^{A}	29,63^{A} (0,75)	0,86^{A}	29,85^{A} (0,71)	1,08^{A}
2W	29,09^{A} (0,77)	29,42^{A,B}(0,70)	0,4^{B}	29,93^{A,B} (0,70)	0,91^{B}	30,45^{B} (0,75)	1,43^{B}	30,90^{B} (0,78)	1,88^{B}	31,32^{B} (0,81)	2,3^{B}
3W	29,16^{A} (0,76)	29,72^{B} (0,71)	0,63^{C}	30,48^{B} (0,64)	1,32^{C}	31,15^{B} (0,66)	1,99^{C}	31,75^{C} (0,69)	2,59^{C}	32,43^{C} (0,73)	3,27^{C}

T: temperature; ΔT: temperature variation.

Different letters indicate statistically significant differences between T and ΔT (ANOVA/Tukey, $p \leq 0.05$).

Each column represents an independent statistical test.

Considering the temperature measured at each interval (T5s, T10s, T15s, T20s, and T25s), the t-test indicated statistically significant differences both in comparison to the initial temperature and among the individual time intervals. A progressive temperature increase was observed over time for all power settings tested ($P \leq 0.05$).

Discussion

The conceptual hypothesis of this in vitro study was confirmed: the increase in pulp chamber temperature during diode laser irradiation proved to be proportional to the power used and the duration of application, with longer exposure times and higher power levels resulting in more significant thermal elevations.

The photothermal effect generated by high-power lasers arises from the conversion of electromagnetic energy into thermal energy within the irradiated tissues[15]. Therefore, controlling the amount of heat transmitted to the dental pulp is a critical factor in the safe use of these devices in vital teeth[16]. The classic in vivo study conducted in monkeys by Zach and Cohen[3] (1965) demonstrated that temperature increases above 5.5 °C in the dental pulp resulted in necrosis in 15% of the samples evaluated; increases between 3.3 °C and 5.5 °C caused reversible inflammation, and no damage was observed with temperature rises below 2.2 °C. In the present study, power settings of 1, 2, and 3 W, regardless of application time (5, 10, 15, 20, and 25 seconds), did not produce mean temperature increases greater than 3.27 °C. Therefore, the recorded values remained below the thresholds considered harmful to pulp vitality.

Khouja et al.[8] (2017) evaluated intrapulpal thermal variation during diode laser irradiation (808 nm, 1 W, continuous mode) for 30 seconds in premolars and observed a mean temperature rise of 0.9 °C ± 0.2. These values were lower than those recorded in the present study, which may be attributed to the greater thickness of enamel and dentin in the premolars used by those authors compared to the incisors analyzed in this research. Dentin and enamel exhibit low thermal conductivity, and thicker layers act as additional barriers to heat transfer[5,6].

The interaction of laser light with dental tissues depends on the optical and thermal properties of the irradiated substrate, with absorption being the primary phenomenon responsible for the photothermal effect[15]. In the case of the diode laser, enamel - due to its high inorganic content- reflects between 30% and 60% of the incident radiation, whereas dentin reflects between 20% and 40%[21]. These high reflection rates reduce absorption and, consequently, limit the temperature increase. This proposition is supported by the study conducted by Umana et al.[22] (2013), who investigated thermal variation during diode laser irradiation (810 nm, continuous mode, 10 seconds) in third molars that were sectioned transversely at the middle third of the crown, exposing dentin directly. Under this configuration, the temperature increase observed for a 1 W power setting was 0.98 °C ± 0.04, which was higher than the value obtained in the present study for the same parameters (0.39 °C). This difference may be explained by the increased absorption of light by the exposed dentin tissue, due to its lower reflection index, leading to greater heat accumulation.

Laser power and exposure time were identified in this study as critical factors in modulating the pulp chamber temperature rise (PCTR) during irradiation, with the highest temperature increase recorded under the combination of maximum power (3 W) and maximum application time (25 seconds). These findings are consistent with previous studies, which also demonstrated that higher power settings and/or longer exposure times result in more significant increases in PCTR[8,22,23].

The difference observed between the temperature of the thermal bath (37°C) and the baseline measurements in the pulp chamber (28–29°C) reflects the low thermal conductivity of enamel and dentin[24]. Similar differences have been documented by Hans (2022)[25] even with an active microcirculation system. Our study focused on the temperature variation (ΔT) between groups, with strict standardization of initial conditions (Table 1), ensuring valid comparisons between protocols.

Although measures were taken to simulate *in vivo* conditions, such as maintaining a 37°C thermal bath and filling the endodontic cavity with thermal paste to promote heat transfer, it is important to note that temperature values obtained in *in vitro* studies tend to be higher than those observed under clinical conditions[26]. This occurs because the laboratory environment does not accurately reproduce physiological elements present *in vivo*, such as pulpal blood flow, fluid movement within the dentinal tubules, and the presence of surrounding periodontal tissues, all of which contribute significantly to thermal dissipation[26,27]. This methodological limitation restricts the direct extrapolation of results to clinical practice, highlighting the need for additional *in vivo* investigations to validate the findings.

Conclusion

The results of this in vitro experiment demonstrate that the application of the 810 nm diode laser, in continuous mode, at a distance of 1 cm from the irradiated surface, using power settings of 1, 2, and 3W for durations of 5, 10, 15, 20, and 25 seconds, resulted in a progressive increase in pulp chamber temperature, proportional to the power and exposure time applied.

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Resumo

Objetivo: *O objetivo deste estudo in vitro foi avaliar a variação da temperatura da câmara pulpar durante a irradiação com laser de diodo utilizando diferentes parâmetros de potência e tempo.* ***Métodos:*** *Dez incisivos centrais mandibulares humanos (n = 10) foram selecionados e seus canais radiculares foram alargados e preenchidos com pasta térmica. A porção radicular permaneceu submersa em um banho térmico a 37 °C e um sensor termopar conectado a um termômetro digital foi colocado dentro da câmara pulpar para medir a variação de temperatura. O laser de diodo (810 nm) foi aplicado a uma distância de 1 cm da superfície dentária usando configurações de potência de 1, 2 e 3 W no modo contínuo, por 5, 10, 15, 20 e 25 segundos. Para cada configuração de potência e para cada dente, foram feitas cinco medições de temperatura, além da medição da linha de base. Os dados foram analisados usando análise de variância (ANOVA) e teste post hoc de Tukey (α = 5%).* ***Resultados:*** *Uma diferença estatisticamente significativa foi observada entre todas as leituras de temperatura em comparação com a linha de base, bem como entre todos os intervalos de tempo, indicando um aumento progressivo da temperatura ao longo do tempo para todas as três configurações de potência testadas. Além disso, potências mais altas resultaram em maior elevação da temperatura ($P \leq 0,05$).* ***Conclusão:*** *Os parâmetros de irradiação utilizados neste estudo levaram a um aumento progressivo da temperatura da câmara pulpar, sem exceder o limite de 5,5 °C associado a danos pulpares irreversíveis.*

Palavras-chave: *Temperatura; Lasers semicondutores; Cavidade pulpar.*

References

1. Zhan C, Huang M, Yang X, Hou J. Dental nerves: a neglected mediator of pulpitis. Int Endod J. 2021 Jan;54(1):85-99. doi: 10.1111/iej.13400.
2. Lau XE, Liu X, Chua H, Wang WJ, Dias M, Choi JJE. Heat generated during dental treatments affecting intrapulpal temperature: a review. Clin Oral Invest. 2023 Apr;27:2277–2297. doi: 10.1007/s00784-023-04951-1
3. Zach L, Cohen G. Pulp Response To Externally Applied Heat. Oral Surg Oral Med Oral Pathol. 1965 Apr;19:515-30. doi: 10.1016/0030-4220(65)90015-0
4. Niu L, Dong SJ, Kong TT, Wang R, Zou R, Liu QD. Heat Transfer Behavior across the Dentino-Enamel Junction in the Human Tooth. PLoS One. 2016 Sep 23;11(9):e0158233. doi: 10.1371/journal.pone.0158233
5. Lipski M, Woźniak K, Szyszka-Sommerfeld L, Borawski M, Droździk A, Nowicka A. In Vitro Infrared Thermographic Assessment of Temperature Change in the Pulp Chamber during Provisionalization: Effect of Remaining Dentin Thickness. J Healthc Eng. 2020 Nov 10;2020:8838329. doi: 10.1155/2020/8838329
6. Kincses D, Jordáki D, Szebeni D, Kunsági-Máté S, Szalma J, Lempel E. Effect of Ceramic and Dentin Thicknesses and Type of Resin-Based Luting Agents on Intrapulpal Temperature Changes during Luting of Ceramic Inlays. Int J Mol Sci. 2023 Mar 13;24(6):5466. doi: 10.3390/ijms24065466
7. Galler KM, Weber M, Korkmaz Y, Widbiller M, Feuerer M. Inflammatory Response Mechanisms of the Dentine-Pulp Complex and the Periapical Tissues. Int J Mol Sci. 2021 Feb 2;22(3):1480. doi: 10.3390/ijms22031480
8. Khouja F, Abdelaziz M, Bortolotto T, Krejci I. Intra-pulpal and subsurface temperature rise during tooth irradiation with 808 nm diode laser: an in vitro study. Eur J Paediatr Dent. 2017 Mar;18(1):56-60. doi: 10.23804/ejpd.2017.18.01.12
9. Kıvanc BH, Arısu HD, Sağlam BC, Akça G, Gürel MA, Görgül G. Evaluation of antimicrobial and thermal effects of diode laser on root canal dentin. Niger J Clin Pract. 2017 Dec;20(12):1527-1530. doi: 10.4103/1119-3077.187333
10. Morsi A, Haidary D, Franzen R, Gutknecht N. Intra-pulpal temperature evaluation during diode laser (445 nm) irradiation for treatment of dentine hypersensitivity: in vitro a pilot study. Laser Dent Sci. 2020 Sep;4,139–144. doi: 10.1007/s41547-020-00085-9

11. Mousa MM, Sultan K, Ajaj MA, Hajeer MY, Al-Manadili A, Awawdeh M. Effectiveness of Two Intensity Levels of Diode Laser in Debonding Metallic Brackets Regarding Enamel Surface Integrity and Pulpal Temperature: An Ex-Vivo Study. Cureus. 2023 Jul 4;15(7):e41372. doi: 10.7759/cureus.41372
12. Maenosono RM. Efeito da irradiação com laser de Diodo sobre adesivos dentinários: estudo in vitro [Dissertação de Doutorado]. Bauru: Faculdade de Odontologia de Bauru, Universidade de São Paulo; 2017.
13. Cerisier P, Pasquetti R, Simeone D. The radicular dentine temperature during laser irradiation: a numerical modeling. J Clin Laser Med Surg. 1996 Aug;14(4):157-62. doi: 10.1089/clm.1996.14.157
14. Rodriguez CGB. Estudo in vitro dos efeitos do laser diodo na hipersensibilidade dentinária e avaliação da temperatura intrapulpar [Dissertação de Doutorado]. São Paulo: Faculdade de Odontologia da USP; 2022. doi:10.11606/T.23.2022.tde-30012023-160523
15. Lago ADN. Laser na odontologia [recurso eletrônico]: conceitos e aplicações clínicas. São Luís: EDUFMA, 2021.
16. Stabholz A, Zeltser R, Sela M, Peretz B, Moshonov J, Ziskind D. The use of lasers in dentistry: principles of operation and clinical applications. Compend Contin Educ Dent. 2003 Dec;24(12):935-948; quiz 949
17. Luke AM, Mathew S, Altawash MM, Madan BM. Lasers: A review with their applications in oral medicine. J Lasers Med Sci. 2019;10:324-9. doi: 10.15171/jlms.2019.52
18. Arias-Herrera S, Sánchez-Martos R, Alfaro-Ochoa L. Introduction to Diode Laser Therapies in Dentistry [Internet]. Dentistry. IntechOpen; 2024. doi: 10.5772/intechopen.1004531
19. Fasbinder DJ. Dental laser technology. Compend Contin Educ Dent. 2008;29:452-4, 456, 458-9.
20. Sari T, Celik G, Usumez A. Temperature rise in pulp and gel during laser-activated bleaching: in vitro. Lasers Med Sci. 2015 Feb;30(2):577-82. doi: 10.1007/s10103-013-1375-5. Epub 2013 Jun 21. PMID: 23793339.
21. de Alencar Mollo M, Frigo L, Favero GM, Lopes-Martins RA, Brugnera Junior A. In vitro analysis of human tooth pulp chamber temperature after low-intensity laser therapy at different power outputs. Lasers Med Sci. 2011 Mar;26(2):143-7. doi: 10.1007/s10103-009-0752-6

22. Umana M, Heysselaer D, Tielemans M, Compere P, Zeinoun T, Nammour S. Dentinal Tubules Sealing by Means of Diode Lasers (810 and 980 nm): A Preliminary In Vitro Study. Photomed Laser Surg. 2013 Jul;31(7):307-14. doi: 10.1089/pho.2012.3443
23. Kıvanç BH, Arısu HD, Sağlam BC, Akça G, Gürel MA, Görgül G. Evaluation of antimicrobial and thermal effects of diode laser on root canal dentin. Niger J Clin Pract. 2017;20:1527-30.
24. Lin M, Xu F, Lu TJ, Bai BF. A review of heat transfer in human tooth--experimental characterization and mathematical modeling. Dent Mater. 2010 Jun;26(6):501-13. doi: 10.1016/j.dental.2010.02.009. Epub 2010 Mar 19. PMID: 20303579.
25. Oliveira HHA. Avaliação da temperatura da câmara pulpar durante a cimentação de facetas pela técnica de resina composta termicamente modificada: um estudo “in-vitro” [Dissertação de Mestrado]. Belo Horizonte: Faculdade de Odontologia, Universidade Federal de Minas Gerais; 2022.
26. Lipski M, Woźniak K, Szyszka-Sommerfeld L, Borawski M, Droździk A, Nowicka A. In Vitro Infrared Thermographic Assessment of Temperature Change in the Pulp Chamber during Provisionalization: Effect of Remaining Dentin Thickness. J Healthc Eng. 2020 Nov 10;2020:8838329. doi: 10.1155/2020/8838329
27. Dimopoulos F, Dervenis K, Gogos C, Lambrianidis T. Temperature Rise on the Plugger Surface of 2 Commercially Available Gutta-percha Heating Devices. J Endod. 2017 Nov;43(11):1885-1887. doi: 10.1016/j.joen.2017.07.007

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