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RESEARCH

In vitro study of the effects of diode laser on dentin hypersensitivity and evaluation of intra-pulpal temperature variation

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Abstract

To evaluate the efficacy and safety of different wavelengths of high-power diode lasers for the treatment of dentin hypersensitivity by analyzing morphological changes and temperature variation. Human third molars were irradiated with five different commercially available lasers at wavelengths of 808 nm, 940 nm, 976 nm, and 980 nm, both with and without the use of a photoinitiator (activated charcoal). Temperature variations were monitored using thermocouples, and morphological changes were assessed through scanning electron microscopy. Lasers with wavelengths of 940 nm, 976 nm, and 980 nm, used without a photoinitiator, promoted dentinal tubule obliteration without causing thermal damage. Lasers with wavelengths of 808 nm, 940 nm, 976 nm, and 980 nm, when combined with a photoinitiator, resulted in even lower temperature variation compared to the non-photoinitiator groups, although no regular fused surface was observed. Diode laser parameters, except Group 1(808 nm without photoinitiator), are potentially safe for dentinal tubule obliteration. The use of a photoinitiator continues to be an effective strategy for minimizing temperature variations during irradiation.

Keywords Tooth hypersensitivity · Laser diode · Chromophore · Melting

Introduction

Dentin hypersensitivity (DH) is a painful symptom caused by an exaggerated response to the exposure of root dentin, which can range from mild discomfort to severe pain [1, 2]. DH is more prevalent in young adults and can affect both men and women [3, 4]. Dentin exposure can result from enamel loss due to occlusal issues, gingival recession, root scaling, or traumatic brushing [5, 6].

Brännström's hydrodynamic and neural theories explain that pain is caused by external stimuli that induce fluid movement within the dentinal tubules, compressing the outer odontoblasts in the pulp and associated nerve endings [7, 8]. Obliteration of the dentinal tubules or neural blockade of pulp receptors reduces dentin hypersensitivity [8, 9]. Several methods for treating DH have been investigated, including mechanical occlusion of the dentinal tubules with dentifrices containing tin fluoride, tin chloride, strontium acetate, arginine, use of adhesives, or high-power lasers [10], modification of the tubular content [11, 12], and the use of dentifrices containing potassium nitrate, potassium citrate for neural action [13–16]. Therapeutic agents should be non-irritating to the pulp, painless, easy to apply, fast-acting, long-lasting, and should not stain the tooth surface. Therapeutic agents should be non-irritating to the pulp, painless, easy to apply, fast-acting, long-lasting, and should not stain the tooth surface.

Currently, lasers are used in dentistry for the treatment of DH, with low-power lasers acting as neural factors and

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high-power lasers acting as obliterators. Among these, the neodymium yttrium-aluminum-garnet (Nd: YAG) laser has been used since the 1970s, while the semiconductor diode laser (InGaAlP) is a more recent technology [6, 17]. These lasers can help obliterate dentinal tubules and reduce dentin permeability [18].

The chromophores responsible for laser radiation absorption in dental tissues are hydroxyapatite and water in the enamel and dentin and hemoglobin and oxyhemoglobin in the pulp [19]. However, diode lasers are not absorbed by enamel and dentin (while being strongly absorbed by the pulp). To produce a thermal effect on dentin irradiated with lasers of wavelengths that the tooth's chromophores do not absorb, the use of absorbers, known as photoinitiators, has been suggested. These agents efficiently absorb laser radiation and convert it into heat.

There is a significant difference between diode and Nd lasers: Nd lasers can operate in a pulsed mode, concentrating the energy of a pulse within a short time frame, thus increasing its intensity and raising the temperature in the irradiated medium before heat diffusion occurs. In contrast, diode lasers operate in continuous mode, and their intensities are lower compared to pulsed lasers. Studies with diode lasers have shown favorable results in mitigating DH, with an efficacy of 85% in treating cervical DH [20].

Given the above, this in vitro study aimed to evaluate the morphological changes in dentin (determining whether or not there was tubule occlusion) and the temperature variations occurring in the pulp chamber and apex region during sample irradiation with diode lasers, using four different wavelengths and identical irradiation parameters, with or without the use of activated charcoal as a photoinitiator. Thus, the following are admitted as null hypotheses: The different wavelengths of the diode laser will not cause intrapulpal temperature variation; and the use of a photoinitiator will not influence intrapulpal temperature variation.

Materials and methods

The study evaluated the increase in intrapulpal temperature with and without a photoinitiator ($n=10$) using thermocouples for temperature control and the structural changes in human third molar dentin through scanning electron microscopy ($n=2$). Were used 120 (one hundred and twenty) sound human third molars obtained from the Human Tooth Bank of the School of Dentistry at the University of São Paulo (FOUSP), previously approved by the Ethics Committee for Research with Human Subjects (CEP) of the School of Dentistry at the University of São Paulo (Approval No. 3.683.852).

Samples for temperature evaluation testing

Out of the total of 120 samples, 100 were used for the evaluation of intrapulpal temperature. The root apices were polished for 5 s with 600-grit sandpaper to expose a larger diameter of the apical foramina. Subsequently, the foramina was enlarged using a Gates-Glidden rotary instrument, and the root canals and pulp chamber were cleaned using K-type endodontic files #80 and distilled water. A thermocouple was inserted into the opening created on the lingual surface of the cervical third of each tooth. After etching with phosphoric acid (H_3PO_4) and rinsing, K-type thermocouples were positioned in the pulp chamber and the root canal (Fig. 1).

The canal was filled with distilled water, and the surface was dried before the application of a single-bottle adhesive system. The adhesive system was photoactivated using a halogen light curing unit. The opening was restored with light-curable composite resin, and the teeth were radiographed to confirm the position of the thermocouples. The specimens were then divided into 10 groups (Table 1) and maintained in a humid environment under refrigeration until the experiments were conducted.

Lasers and irradiation conditions

- Thera Lase Surgery diode laser (DMC Equipamentos, Brazil): 808 ± 10 nm, 100 µs pulse width, 300 µm optical fiber, 1 W power, continuous emission, 0.167–1 kHz repetition rate. (Groups G1 and G2)
- Epic X diode laser (Biolase, USA): 940 ± 10 nm, 100 µs pulse width, 400 µm optical fiber, 1 W power, continuous emission, > 20 kHz repetition rate. (Groups G3 and G4)
- Solase diode laser (Lazon Medical Laser, China): 976 nm, 1 W power, 400 µm optical fiber, continuous emission. (Groups G5 and G6)
- Thera Lase Surgery diode laser (DMC Equipamentos, Brazil): 980 nm, 100 µs pulse width, 400 µm optical fiber, 1 W power, continuous emission, 0.167–1 kHz repetition rate. (Groups G7 and G8)
- Gemini diode laser (Ultradent, USA): 980 nm, 1 W power, 400 µm optical fiber, continuous emission (no conflict of interest). (Groups G9 and G10)

Samples for surface morphology evaluation by scanning electron microscopy

Twenty healthy human third molars were selected for the study. The crowns of the teeth were sectioned from the roots, and dentin discs were prepared from the crowns using

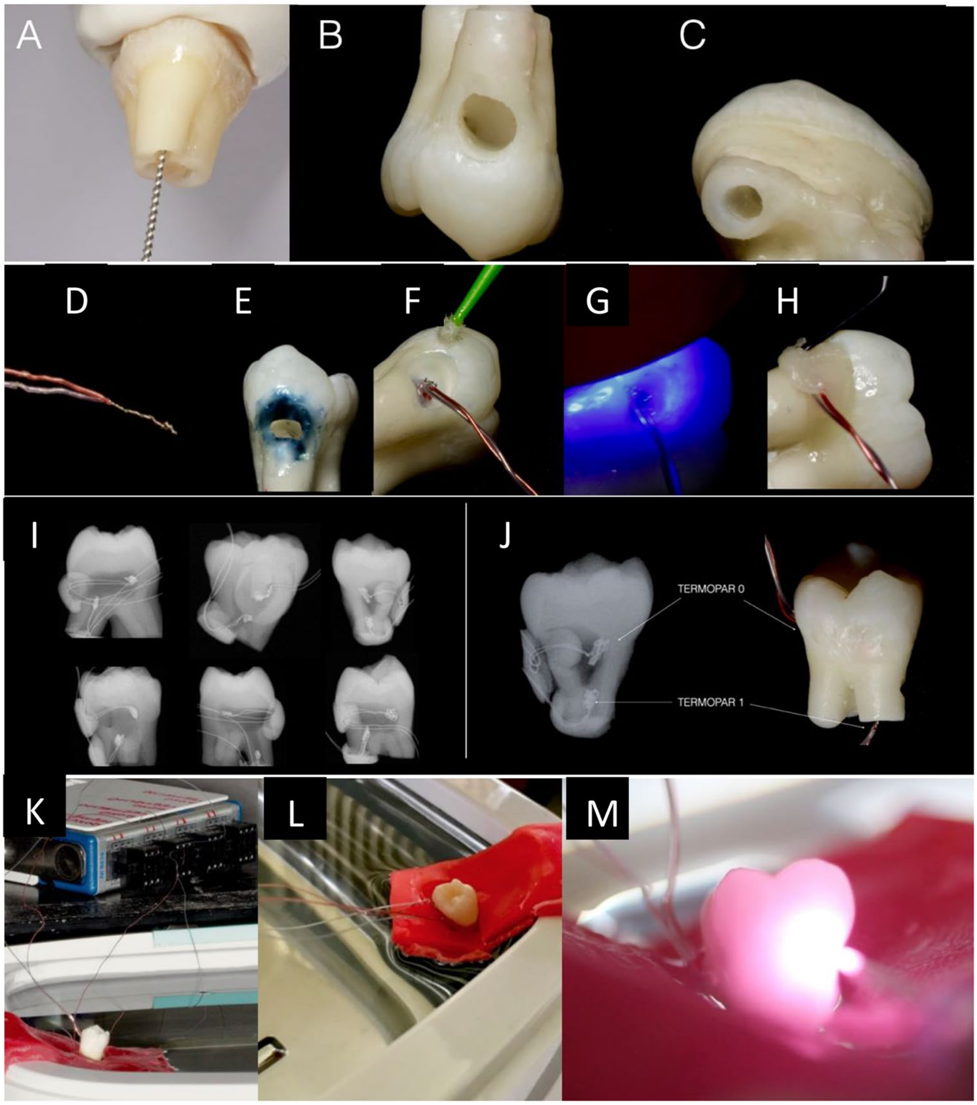


Fig. 1 Cleaning with endodontic file (**A**); opening of the cervical third (**B**); opening of the root apex (**C**); Type K thermocouples (chromel-alumel – NiCr-NiAl, Omega Eng. Inc., Stanford, USA), with a thickness of 127 µm (**D**); application of phosphoric acid (**E**); positioning of thermocouples and application of the adhesive system (**F**); light curing (**G**); thermocouple positioned and fixed with the composite resin (**H**); radiographic evaluation of the positioning of thermocouples inside the samples (**I**); radiographic and actual comparison of the positioning of thermocouples in the samples (**J**); thermocouples connected to the analog/digital converter (**K**); sample positioned inside a temperature simulator of the oral cavity (**L**); irradiation with high-power diode laser in the cervical tertium (**M**)

a precision cutting machine. Two perpendicular cuts were made in the middle region of the crown, removing the pulp horns and occlusal enamel. The dentin samples were cut to dimensions of 4 × 4 × 2 mm and polished using water-cooled abrasive discs on a polishing machine. The thickness of the discs was verified with a digital caliper. Between each polishing step, the samples were cleaned in an ultrasonic bath with distilled water. To simulate hypersensitive dentin and remove the smear layer, the specimens were immersed in a 17% EDTA solution for 5 min. After the immersion time, the specimens were rinsed in an ultrasonic bath with distilled water for an additional 5 min to remove any organic residue and were randomly distributed into 10 groups (Table 1).

Irradiation protocol

Irradiations with high-power diode lasers were performed on samples from specific groups. The irradiation was conducted on the buccal surface of the cervical region, simulating the application at the most common site of non-caries cervical lesions. The irradiation was performed without contact, at a distance of 2 mm, and perpendicular to the dentin surface. Mesiodistal and occluso-apical scans were performed for 30 s each over a 5 × 5 mm area of cervical root dentin. During the procedure, the samples were immersed in a thermal bath at 37ºC to simulate oral temperature conditions.

In the groups that used the photoinitiator, the cervical portion of the samples was covered with a paste containing activated charcoal diluted in ethanol and deionized water [21]. This was done to promote better interaction of the laser with the dentin tissue [21–23], as lasers in these wavelength ranges are more absorbed by pigmented tissues. The application of the photoinitiator was performed uniformly using a microbrush (Cavibrush Extra fine Disposable Micro Applicator; FGM Produtos Odontológicos, Joinville, SC, Brazil).

Table 1 Distribution of samples and their respective groups

Grupos	MEV (n)	°C (n)	Tempo de Exposição*
G1:808 nm sem fotoiniciador 1.0 W	2	10	2x30 polegadas
G2:808 nm com fotoiniciador 1.0 W	2	10	2x30 polegadas
G3:940 nm sem fotoiniciador 1.0 W	2	10	2x30 polegadas
G4:940 nm com fotoiniciador 1,0 W	2	10	2x30 polegadas
G5:976 nm sem fotoiniciador 1.0 W	2	10	2x30 polegadas
G6:976 nm com fotoiniciador 1.0 W	2	10	2x30 polegadas
G7:980 nm sem fotoiniciador 1.0 W	2	10	2x30 polegadas
G8:980 nm com fotoiniciador 1.0 W	2	10	2x30 polegadas
G9:980 nm sem fotoiniciador 1.0 W	2	10	2x30 polegadas
G10:980 nm com fotoiniciador 1.0 W	2	10	2x30 polegadas

*30s interval between the two applications (time to thermal relaxation)

The samples from the groups without photoinitiator (groups 1, 3, 5, 7, and 9) were irradiated with the high-power laser according to the specified parameters. The samples from the groups with photoinitiator (groups 2, 4, 6, 8, and 10) underwent photoinitiator application and were then irradiated with the high-power laser, following the same irradiation criteria mentioned earlier.

Temperature measurements

Temperature changes in the pulp chamber and on the root surface were measured during and immediately after irradiation with the high-power laser, following the protocol previously described. Two K-type digital temperature sensors were used: one was positioned inside the pulp cavity to measure the temperature generated by the laser as it was absorbed by the dentin, while the other was placed in the internal region of the apical third.

The sensors were connected to a monitoring system consisting of an analog-to-digital converter, a thermocouple amplifier, and a personal computer. The room temperature was kept constant at 25 °C and was monitored throughout the experiment. The experiments were conducted in a controlled temperature and relative humidity environment.

Temperature monitoring by the thermocouples was initiated before the irradiations, recording the initial temperature of each sample, and was maintained for one minute. The temperature data were analyzed using LabView software and transferred to spreadsheets for statistical analysis.

Scanning electron microscopy

Twenty specimens were prepared to analyze the occlusion pattern of dentin tubules after irradiation with a high-power laser. The specimens were analyzed by Scanning Electron Microscopy (SEM) without metal coating in a high vacuum. For this purpose, the surfaces were covered with adhesive tape, leaving a central exposed area of 4 × 1 mm. Two samples from each group, randomly selected among the 10 groups described, were re-analyzed by SEM at different magnifications (100x, 3000x, and 5000x). The objective was to visualize morphological changes on the dentin surface caused by irradiation, as well as to identify the presence of cracks and carbonization.

Statistical analysis

Both the surface temperature variation data and the pulp temperature variation data during irradiation were analyzed individually using statistical tests with a significance level of 5%. The distribution of mean values was normal and homogeneous, and Analysis of Variance (ANOVA) followed by Tukey's post-hoc test was performed.

Results

Temperature variation

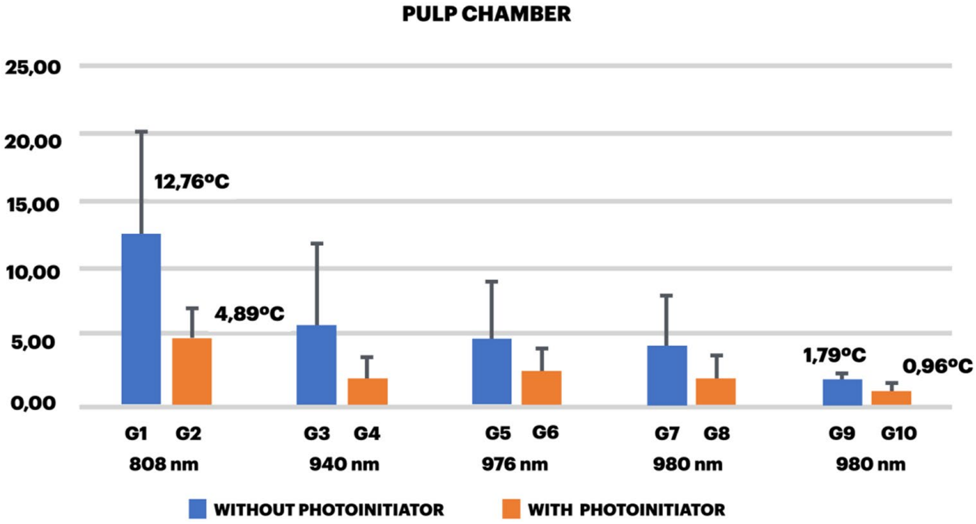
The 808 nm laser exhibited the highest increase in temperature within the pulp chamber, with average values of 12.76 °C without a photoinitiator (G1) and 4.89 °C with a photoinitiator (G2). The Gemini 980 nm laser showed the lowest temperature increase, with average values of 1.79 °C without a photoinitiator (G9) and 0.96 °C with a photoinitiator (G10) (Graph 1).

When analyzing the temperature at the root apex, the 808 nm laser again demonstrated the highest increase, with average values of 3.29 °C without a photoinitiator (G1) and 2.15 °C with a photoinitiator (G2). The Gemini 980 nm laser showed the lowest temperature variation at the apex, with average values of 0.62 °C without a photoinitiator (G9) and 0.18 °C with a photoinitiator (G10) (Graph 2).

Statistical analyses indicated significant differences between the groups that used a photoinitiator compared to those that did not, both in the pulp chamber and at the root apex (Tables 2 and 3).

The study results provide important insights for selecting appropriate irradiation parameters to prevent thermal damage to dental tissues. This allows for controlling temperature elevation in the pulp and establishing the necessary intervals for thermal relaxation to avoid undesirable changes.

Graph 1 Average value and standard deviation of the temperature increase recorded by the thermocouple in the pulp chamber



Graph 2 Average value and standard deviation of the temperature increase recorded by the thermocouple in the apical region

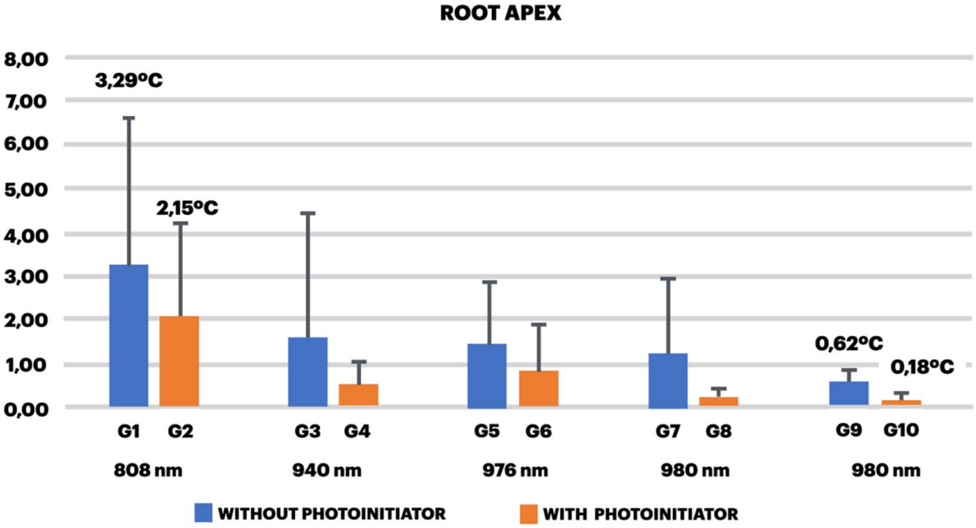


Table 2 Statistical analysis of temperature variation in the pulp chamber between the groups whose samples used a photoinitiator and those that did not

	MeanDiff	SEM	valor *q*	Proba	Alfa	Sinal	LCL	UCL
COM / SEM	-3,56009	0,75326	6,6839	8.58306E-6	0,05	1	-5,0568	-2,06337

Table 3 Statistical analysis of temperature variation in the apical region between the groups whose samples used a photoinitiator and those that did not

	MeanDiff	SEM	valor *q*	Proba	Alfa	Sinal	LCL	UCL
COM / SEM	-0,82701	0,36025	3,24653	0.02405	0,05	1	-1,54282	-0,1112

Scanning electron microscopy analysis

The objective of the SEM analysis was to examine the changes induced by irradiation with different laser wavelengths on the dentin surface, particularly focusing on the presence of open dentinal tubules.

Figure 2 (A) shows a pre-irradiation image obtained with a diode laser, where open dentinal tubules are visible, as a result of the EDTA protocol described earlier. This pattern of open tubules was observed across all samples.

Upon examining the groups without photoinitiators (G3, G5, G7, G9) using SEM, no cracks or areas of carbonization were detected. Instead, the samples exhibited uniform fusion of the dentinal tubules, resulting in a “melting” effect that led to the obliteration of the tubules, as illustrated in Fig. 2 (B).

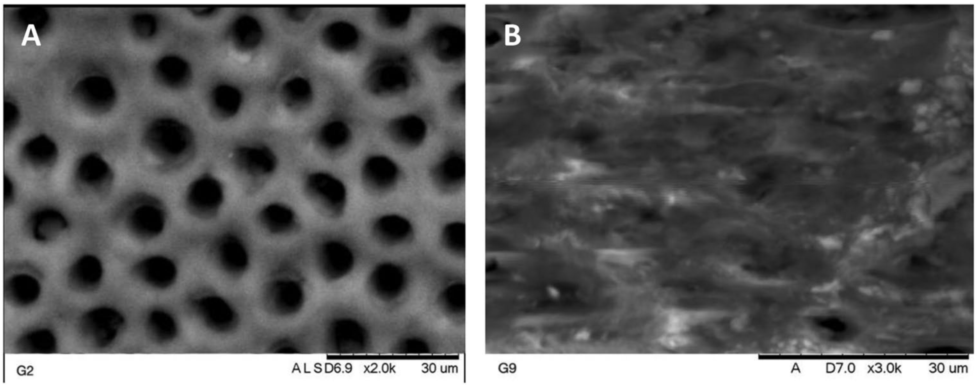


Fig. 2 Opening of dentinal tubules (**A**); ablation of dentinal tubules with absence of cracks (**B**)

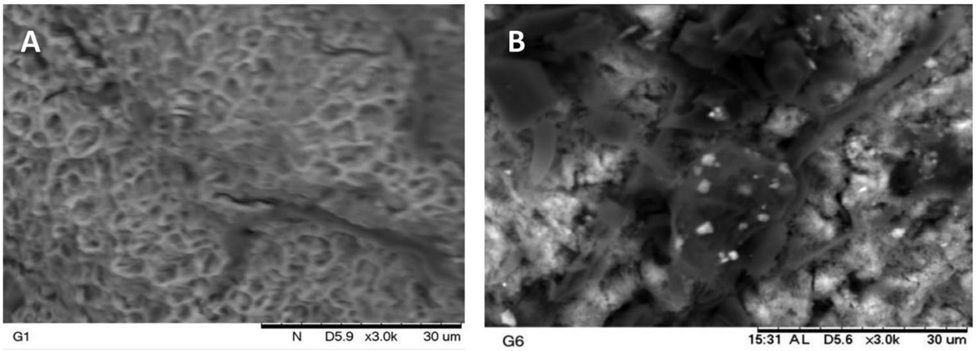


Fig. 3 Dentin surface with obliteration of dentinal tubules with presence of cracks observed in samples from Group 1, after irradiation with 808 nm diode laser without photoinitiator (**A**); fusion of the dentinal surface with fusion of dentinal tubules with inclusion of photoinitiator particles. Samples from Group 6, after irradiation with high-power 976 nm diode laser with photoinitiator (**B**).

SEM analysis of samples from Group 1, which exhibited the greatest increase in temperature variation according to thermocouple readings, showed cracks in the dentinal tubules. These samples, irradiated with the 808 nm wavelength laser at 1 W power for two 30-second irradiation phases (with a 30-second interval between phases), displayed significant temperature increases (Fig. 3A).

In SEM evaluation of the samples irradiated with 1 W of power, two 30-second irradiation phases with a 30-second interval between them, and using photoinitiator, irregular fusion of the dentinal tubules was observed, with photoinitiator particles present between the tubules. This can be seen in Fig. 3B for Group 6.

The SEM results indicated that lasers with wavelengths of 808 nm (with photoinitiator) and 940 nm, 976 nm, and 980 nm (both with and without photoinitiator) at 1 W power did not show cracks on the dentin surface. Instead, melting and recrystallization of the surface occurred, leading to obliteration of the dentinal tubules.

Discussion

Dentin hypersensitivity (DH) is caused by various factors that leave dentinal tubules exposed to the oral environment, leading to pain [1, 2, 24]. Numerous studies advocate the use of lasers with different wavelengths for the treatment of DH, with the most widely used being the Nd laser, with a wavelength of 1064 nm [25–28]. This laser is particularly effective due to its affinity for water and hydroxyapatite, which helps prevent temperature increases within the pulp chamber. However, the high cost of this laser makes diode lasers a more economical alternative.

One advantage of diode lasers is their ability to obliterate dentinal tubules through fusion, forming a superficial layer known as “melting” [29–31]. The main concern with high-power diode lasers is the increase in intrapulpal temperature, which, in theory, could lead to pulpal necrosis if the temperature rise exceeds 5.5ºC [32]. Additionally, if temperature control is insufficient, cracks and areas of dentin carbonization may occur, as reported by Kreisler et al. [32–34].

After statistical analysis, both null hypotheses were rejected, as both the diode laser wavelength and the use of a photoinitiator significantly influenced intrapulpal temperature variations. The 808 nm wavelength induced the greatest temperature variation, followed by 940 nm, 976 nm, and 980 nm. Moreover, the inclusion of a photoinitiator resulted in temperature variations that followed the same pattern, although these variations were statistically smaller compared to those observed without the photoinitiator.

The morphological analysis in this study, conducted using SEM, was qualitative. We observed dentin fusion and closure of the dentinal tubules in samples irradiated with high-power diode lasers, with no cracks around the tubules, except in Group 1. These findings are consistent with those reported by Umana et al. [35] and Gutknecht et al. [27]. Umana et al. [35] investigated the effects of a 980 nm diode laser at two power settings, 0.8 W and 1 W, in continuous mode using SEM. They observed a reduction in tubule diameter and complete obliteration of the tubules. However, at 2 W, they noted areas of dentin destruction in the SEM images, concluding that 0.8 W and 1 W in continuous mode were sufficient to obliterate the dentinal tubules. These results are in agreement with those of Gutknecht et al. [27].

In samples from Group 1, irradiated with the 808 nm diode laser under the parameters used in this study and without the application of a photoinitiator, cracks were observed at the level of the dentinal tubules (Fig. 3A). This can be attributed to the wavelength of this laser, which exhibits low absorption by water and high absorption by pigmented tissues (in this case, hemoglobin from the dental pulp) [36, 37]. This led to a considerable increase in both superficial and intrapulpal temperature, exceeding 5.5ºC. These findings are consistent with studies by Gutknecht et al. [27] and Kreisler et al. [33], who also associated this dentinal destruction with uncontrolled temperature increases on the surface. However, further research is required to develop parameters for the use of the 808 nm diode laser without a photoinitiator in order to avoid intrapulpal temperature rise and adverse effects, such as cracks on the dentin surface.

After irradiation of the dentin surface, diode lasers produce a process of fusion and solidification of the involved minerals, as observed in the samples from Groups 2 through 10. This phenomenon has been evaluated in studies by Dilber et al. [38], who indicated that laser irradiation within wavelengths between 532 nm and 1064 nm on the dentin surface does not induce changes in the concentration of minerals such as Ca, Mg, K, Na, and P.

In a complementary study, Hossain et al. [39] concluded that the temperature increase caused by the high-power Er, Cr laser reduces the P and Ca ratio, resulting in surface recrystallization. This creates a more stable, less permeable dentin, corroborating the results observed in the groups analyzed in this study. Absorption is the most critical factor in the laser-tissue interaction process. This absorption leads to tissue ablation as a result of the vaporization of the irradiated tissue. For this process to be safe, the irradiated energy must be sufficient and delivered over a short time, preventing heat diffusion to adjacent tissues.

This tissue denaturation is closely linked to the increase in temperature, exposure time, and the thermal relaxation intervals necessary to prevent heat accumulation in the tissue between irradiation stages. The 30-second interval determined in this study for thermal relaxation between irradiations effectively helped control the intrapulpal temperature increase.

This finding is significant, as Gutknecht et al. [34] suggested a 10-second interval for diode laser irradiation at 1 to 1.5 W in continuous mode, and Ribeiro et al. [40] employed a 20-second interval between irradiations to prevent cumulative temperature effects. Both studies support the use of these intervals to avoid temperature-related pulpal damage, and our results, which employed a 30-second interval, confirm that this method prevents alterations in pulpal tissue as long as proper relaxation intervals are observed.

The use of a photoinitiator before diode laser irradiation increased tissue absorption on the dentin surface when using infrared wavelengths, which are capable of ablating dental tissues while preventing excessive heat penetration into deeper layers. The absorption of energy by superficial adjacent tissues reduces the risk of pulpal damage [21–23, 41].

In this study, the use of a carbon paste as a photoinitiator in several groups enhanced energy absorption at the dentin surface, resulting in lower intrapulpal and apical temperature increases due to the photothermal effect of the photoinitiators. This effect facilitated the obliteration of dentinal tubules through the fusion of hydroxyapatite present in dentin tissue, with less temperature increase compared to groups without photoinitiator use. These findings are supported by the study of Khoubrouypak et al. [42], who concluded that the combination of photoinitiator and diode laser effectively obliterates dentinal tubules while minimizing temperature variations within the pulp chamber.

In the samples irradiated with the parameters used in this study, except for Group 1, no destructive alterations such as surface dentin carbonization or cracks were observed in SEM analysis. These results are consistent with the in vitro study by Kreisler et al. [33], who concluded that 1 W of power did not produce destructive effects, although higher parameters did result in partial or total surface carbonization.

The penetration depth of laser wavelengths into tissues increases as the wavelength approaches the infrared spectrum (around 1200 nm). In general, lasers with wavelengths near 750 nm are associated with increased tissue temperatures due to absorption effects, resulting in alterations such as tissue vaporization [43].

According to Umana et al. [35], the obliteration of dentinal tubules by diode lasers follows a pattern similar to that of Nd lasers, where energy is absorbed by mineral components of dentin, such as phosphate and carbonate in hydroxyapatite. This thermal ablation of these components leads to the obliteration of dentinal tubules. Groups irradiated with 976 nm and 980 nm lasers showed lower temperature increases compared to those with wavelengths closer to 750 nm. However, it can be concluded that lasers closer to the Nd wavelength (1064 nm) produce less temperature increase because these lasers primarily interact with the mineral components of dentin located at the surface. Due to light diffusion properties, heat is absorbed at the surface, thereby preventing a significant rise in intrapulpal temperature.

In all high-power diode laser groups, except for the 808 nm group without photoinitiator, SEM analysis revealed obliteration of the exposed dentinal tubules without the presence of cracks, indicating no compromise to dentin structure. These findings, by Brännström's hydrodynamic theory, suggest that tubule obliteration reduces fluid flow within the dentinal tubules, explaining the absence of pain in the results. This could serve as a foundation for future research.

Conclusion

1. The evaluated parameters, except G1 (808 nm without photoinitiator), did not result in a temperature increase exceeding 5.5 °C. These parameters led to the fusion of dentin tissue, resulting in the obliteration of dentinal tubules, indicating that this treatment may be safe for managing dentin hypersensitivity (DH).
2. The use of a photoinitiator continues to be an effective strategy for minimizing temperature variations during irradiation.
3. Further studies are needed to investigate the 808 nm diode laser without a photoinitiator in order to determine the optimal irradiation parameters that prevent thermal damage to the tooth structure.

Author contributions C.G.B.R., C.P.E. conceived and designed the experiments. C.G.B.R., D.M.Z. performed the experiments. C.G.B.R., M.P.N.C.M., F.E.A.T., D.M.Z., C.P.E. analyzed data. C.G.B.R., M.P.N.C.M., F.E.A.T., C.P.E. wrote the manuscript. C.G.B.R., M.P.N.C.M., F.E.A.T., D.M.Z., C.P.E. critically reviewed the manuscript. All authors read and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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