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Evaluation of Dentin Tubule Occlusion Using Diode Laser and Shield Force Plus: A Comparative Study

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Abstract

Introduction: Dentin Hypersensivity is a dental short _lasting sharp pain originating from exposed dentin. This study investigated the level of dentinal tubule occlusion using a diode laser, the desensitizing agent Shield Force Plus, and the combined application of both treatments.

Methods: Forty-five human premolar teeth, extracted due to orthodontic treatment plans or periodontal issues and confirmed to be free of caries, were collected for this study. The samples were sectioned to expose the outer third of the coronal dentin, and a rectangular area measuring 8 by 3 mm was delineated on each sample. The teeth were then allocated to five groups (n = 9 per group): a negative control group (smear layer), a positive control group (smear layer removed), a group treated with the diode laser, a group treated with Shield Force Plus, and a group that received both the diode laser (wavelength 980 nm) and Shield Force Plus treatment. Imaging of the specimens was conducted using scanning electron microscopy at a 2000x magnification.

Results: The group with the highest mean percentage of open dentinal tubules was the positive control group, which had an average of 10.52%. In contrast, the diode laser combined with the Shield Force Plus group exhibited the lowest average at 0.22%. The comparison revealed a significant difference between the laser group and the positive control group ($P < 0.001$), as well as between the Shield Force Plus group and the positive control ($P < 0.001$). No significant differences were found in dentinal tubule occlusion when comparing the effects of the diode laser, Shield Force Plus, and their combination ($P > 0.05$).

Conclusion: All three methods—diode laser application, Shield Force Plus, and their simultaneous use—effectively occluded dentinal tubules; however, none demonstrated superiority.

Keywords: Dentin, Shield force plus, Diode laser, Dentin hypersensitivity

Introduction

Dentin hypersensitivity is a common issue faced in dental practices, typically manifesting as a brief, sharp pain.[1-4] This condition presents as a short-lasting sharp pain originating from exposed dentin, in the absence of any other identifiable dental disorder. This pain is typically triggered by external factors such as temperature changes, physical contact, osmotic shifts, or chemical agents.[5] The primary cause of dentin hypersensitivity is gingival recession, which leads to the exposure of root surfaces, loss of cementum, and damage to the smear layer, often due to dental abrasion.[6] Gingival recession frequently arises from prolonged damage resulting from aggressive tooth brushing or the use of abrasive toothpaste.[6,7] Other less common causes include acid erosion—often linked to gastroesophageal reflux disease or excessive consumption of acidic foods and beverages—and periodontal root planning.[7] Additionally, tooth whitening (or bleaching) can significantly contribute to dentin hypersensitivity.[6] Currently, the hydrodynamic theory explains the mechanism behind dentin hypersensitivity.[8] The hydrodynamic theory suggests that external physical and chemical stimuli lead to shifts in fluid within the dentinal tubules, which in turn activate nerve endings in the odontoblastic layer and pulp, producing a pain response.[9,10] The prevalence of dentin hypersensitivity among patients ranges from 4% to 57% and can be easily diagnosed through routine examinations.[11,12] This condition is more common in patients with periodontal disease, with prevalence rates between 60% and 98%.[13] The cervical buccal areas of teeth, particularly canines and first premolars, are often the most affected,[14,15] especially in regions experiencing periodontal attachment loss.[7] Common treatments provided in dental offices include fluoride varnishes, potassium oxalate, and dental adhesives.[16,17]

The application of laser technology has introduced innovative strategies for managing dentin hypersensitivity.[9,18-20] Lasers employed for this purpose are typically categorized into two main types: low-level lasers such as helium-neon (He-Ne) and gallium-aluminum-arsenide (GaAlAs or diode) lasers, and medium-level lasers including CO_2, Nd:YAG, and erbium-based lasers (Er:YAG and Er,Cr:YSGG).[21] Among these, diode lasers—available in various wavelengths and settings—are widely used and have demonstrated promising outcomes in multiple studies.[22-24] However, an optimal wavelength for dentin hypersensitivity treatment

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has not yet been definitively established. Diode lasers are utilized in different therapeutic protocols to either induce photobiomodulation for alleviating pain and inflammation[25,26] or achieve dentinal tubule occlusion by thermally altering the dentin surface. Laser treatment may be applied directly to the sensitive area or indirectly following the application of desensitizing agents including sodium fluoride or stannous fluoride, which can enhance the occlusive effect via thermal interaction with the laser. Recently, the GaAlAs diode laser has shown promising results in clinical studies for treating dentin hypersensitivity. The diode laser can melt dentin and occlude the dentinal tubules. When these tubules are blocked, the movement of fluid within them decreases, ultimately reducing sensitivity.[19,20,27]

Shield Force Plus is a light-cured desensitizing agent with a resin base designed to alleviate dentin hypersensitivity both before and after dental procedures, according to the manufacturer, Tokuyama. Unlike bonding materials, its application is straightforward and does not require rubbing or rinsing afterward. The formulation includes phosphate monomers, bisphenol A-glycidyl methacrylate, triethylene glycol dimethacrylate, and 2-hydroxyethyl methacrylate. According to the manufacturer, when the resin tags extend as deep as 50 micrometers into the dentinal surface, they effectively block the tubules, leading to a prompt reduction in hypersensitivity.[28] Shield Force Plus alleviates dentin hypersensitivity through a mechanism known as the double-block effect. In practice, once the material is applied to the hypersensitive region, a chemical reaction occurs between the 3D-SR adhesive monomer and the calcium present in the tooth structure. The resulting compound deposits both within the dentinal tubules and on the treated surface. As air-drying eliminates the solvent and moisture, a thin protective film is formed that effectively seals the tubules, thereby producing a noticeable reduction in sensitivity.[29]

Given the high prevalence of dentin hypersensitivity and the increasing demand for effective solutions, there is a significant need to understand the varying results from studies that use lasers and desensitizing agents on sensitive teeth. Additionally, there is a lack of research exploring the simultaneous application of Shield Force Plus and laser therapy. Therefore, the primary objective of this study was to evaluate the degree of dentinal tubule occlusion achieved through the separate and combined use of Shield Force Plus and a diode laser.

Materials and Methods

Adhering to ethical considerations, we collected a total of 45 human premolar teeth,[30] which had been extracted due to orthodontic treatment plans or periodontal issues. The teeth were preserved in a 0.1% thymol solution to prevent microbial growth until the study began. The dental samples were initially mounted in acrylic and then sectioned using a cutting device (Pressi-T201A, France) to remove the buccal enamel, thereby exposing the outer third of the coronal dentin.

A grinding machine from Dorsa Company created a smear layer, equipped with sandpaper of 100, 400, and 1000 grit. The dentin surfaces were ground using each type of sandpaper for 60 seconds, progressing from the coarse to the fine grit. After this, all samples, except those in the negative control group, were immersed in 6% citric acid (Kimia Pars Company, Iran) for 180 seconds to expose the dentin tubules. A rectangular area measuring 8 mm by 3 mm was marked transversely on the cervical third of each sample to indicate the treatment area and imaging location.

The dental samples were divided into five groups (n = 9) as follows:

- Group 1: Negative control. Teeth with a smear layer underwent no surface preparation.
- Group 2: Positive control. Teeth with a smear layer were treated with 6% citric acid to expose dentin tubules without any subsequent treatment.
- Group 3: Diode laser. Teeth in this group were subjected to diode laser irradiation at a wavelength of 980 nm (Simpler, Doctor Smile; Italy) with a fiber size of 300 micrometers (according to the Supplementary section). A handpiece with a diameter of 1cm and an energy density ($Energy\ density = \frac{Power * Irradiation\ time}{\pi r^2}$, r is the radius of the handpiece) of 25.48 J/cm^2, in a sweeping motion, was irradiated on 9 teeth with 1 W/CW power for 20 seconds without contact, perpendicular to the tooth surface at a distance of 1 mm to prevent contaminating the dentin and burning the dentine surface.[31] We swept the laser tip throughout the area until each spot was irradiated only once (Table 1 and Supplementary file 1).
- Group 4: Shield Force Plus. One drop of the agent was placed in a special container and applied to the tooth surface for 10 seconds. This was followed by a gentle air spray for 5 seconds and a strong air spray for an

Table 1. Laser Diode 980 nm Parameters

Parameter	Quantity
Manufacturer	Doctor Smile
Model identifier/certification code	SIMPLER / LA7D0001.3
Wavelength (nm)	980
Pulse mode	CW
Fiber size (μm)	300
Handpiece diameter (cm)	1
Energy density (J/cm^2)	25.48
Area radiated (cm^2)	24
Power (w)	1
Exposure duration (s)	20
Application technique	Sweeping motion
number of treatment sessions	1

additional 5 seconds, after which it was light-cured for 10 seconds.

- Group 5: In this group, Shield Force Plus was applied to the tooth as in Group 4, followed by diode laser application as performed in group 3.[32]

The samples were prepared for imaging with a scanning electron microscope (SEM). First, they were dried at 70 °C using a heater. Next, a 10-nanometer layer of gold was applied to the samples, and they were imaged at a magnification of 2000x using the SEM. The resulting SEM images were evaluated with Adobe Photoshop 2022 (version 23.5.1.724). In each image, five circles with a diameter of 20 µm (at 2000x magnification) were randomly selected from the four corners and the center. The open cross-sectional area of the dentinal tubules was assessed based on pixel units, and the average percentage of open dentinal tubules was calculated.

For data analysis, R software (version 4.1.1) was used. The degree of open dentinal tubules was analyzed to explore its relationship with three different treatment methods. To analyze the data, the non-parametric Kruskal–Wallis test was applied, and post-hoc comparisons were subsequently performed using the least significant difference (LSD) method. A significance level of less than 0.05 was considered statistically significant.

Results

The mean and standard deviation of the percentage of open dentinal tubules in each group are shown in Table 1. The raw data collected from measuring the open dentinal tubules in the study groups showed statistically significant results using the non-parametric Kruskal-Wallis test ($P<0.05$). The positive control group recorded the highest average percentage of open dentinal tubules at 10.52%, while the diode laser group combined with Shield Force Plus exhibited the lowest percentage at 0.22% (Figure 1 and Table 2).

The samples were ultimately prepared for imaging using the SEM and examined under the microscope. The SEM images, captured at a magnification of 2000x, were labeled A to E as follows (Figure 2): A. The negative control group, where dentinal tubules were observed without removing the smear layer; B. The positive control group, where dentinal tubules were observed after the smear layer was removed; C. Dentinal tubules in the laser treatment group; D. Dentinal tubules in the Shield Force Plus group; and E. Dentinal tubules in the group treated with both diode

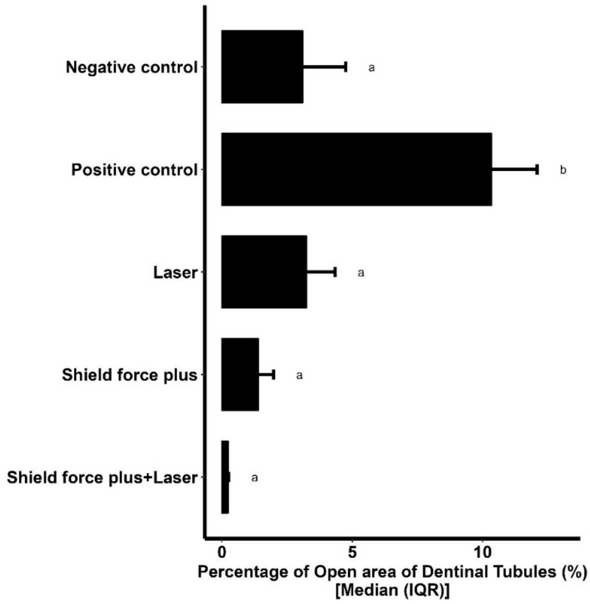

Figure 1. Percentage of Open Dentinal Tubules in the Treatment and Control Groups

Table 2. Mean (Interquartile Range) of the Percentage of Open Dentinal Tubules, Along With the Results of the Kruskal-Wallis Test

Groups	Shield Force Plus + Laser (n = 9)	Shield Force Plus (n = 9)	Laser (n = 9)	Positive control (n = 9)	Negative control (n = 9)	*P* value (Kruskal-Wallis Test)
Mean	0.22 (0.11, 0.26)a	1.07 (0.71, 1.98)a	3.53 (2.99, 4.34)a	10.52 (5.93, 12.09)b	4.49 (1.12, 4.75)a	<0.05

a and b are shown in Figure 1.

Table 3. Pairwise Comparisons of the Groups

Groups	Difference	*P* value	LCL	UCL
Shield Force Plus + laser vs shield force plus	-1.1577778	0.880	-4.680605	2.3650499
Shield force plus + laser vs laser	-3.0111111	0.125	-6.533939	0.5117165
Shield force plus + laser vs positive control	-10.0977778	0.000*	-13.620605	-6.5749501
Shield force plus + laser vs negative control	-2.8600000	0.160	-6.382828	0.6628276
Shield force plus vs laser	-1.8533333	0.566	-5.376161	1.6694943
Shield force plus vs positive control	-8.9400000	0.000*	-12.462828	-5.4171724
Shield force plus vs negative control	-1.7022222	0.643	-5.225050	1.8206054
Laser vs positive control	-7.0866667	0.000*	-10.609494	-3.5638390
Laser vs negative control	0.1511111	0.999	-3.371717	3.6739387
Positive control vs negative control	7.2377778	0.000*	3.714950	10.7606054

LCL, Lower control limit; UCL, upper control limit
*$P<0.001$

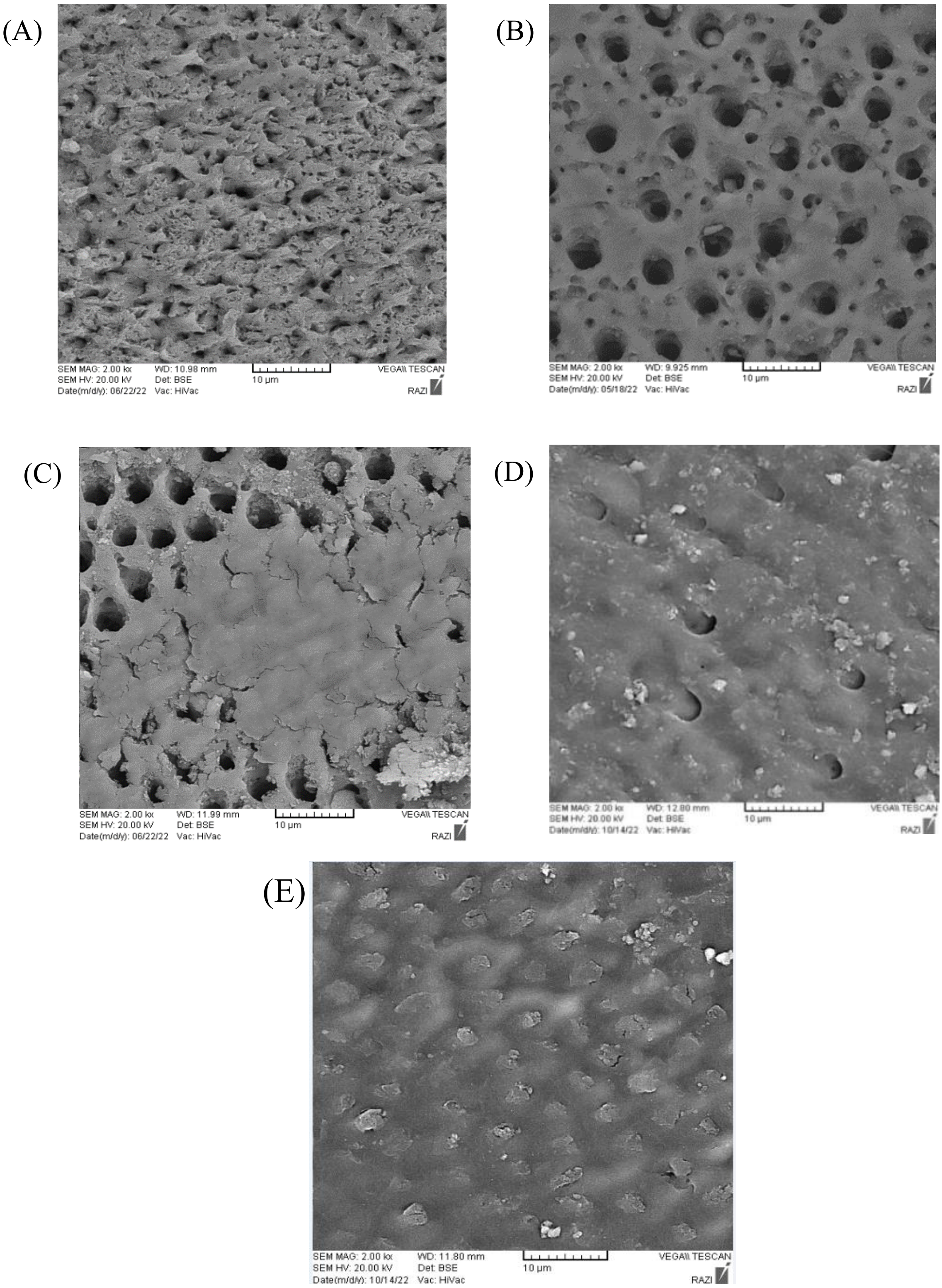

Figure 2. SEM Images of Dentin Surface (A: negative control, B: positive control, C: diode laser, D: Shield Force Plus, E: combination of diode laser and Shield Force Plus)

laser and Shield Force Plus.

Pairwise comparisons of the groups with a post hoc LSD test are presented in Table 3. A significant difference was observed between the laser and positive control groups ($P < 0.001$). A significant difference was also noted between the Shield Force Plus and positive control groups ($P < 0.001$). However, there was no statistically significant difference between the effects of the diode laser and Shield Force Plus and their combined use on dentinal tubule occlusion ($P > 0.05$).

Discussion

Dental professionals frequently encounter dentin hypersensitivity, which has remained one of the most prevalent clinical complaints. Various materials and methods have been used to address this problem; some have been effective, while others have not. Factors such as enamel wear, exposure of dental roots, cavities, cracks, tooth fractures, and recent fillings have contributed to the high prevalence of sensitivity within the community. Therefore, finding a long-term solution to this issue is essential.

Agarwal et al. demonstrated that dentin sensitivity is a painful condition affecting nearly 20% of the population.[33] According to a study by Moraschini et al, the cervical buccal areas of teeth, particularly canines and first premolars, are often impacted by dentin hypersensitivity.[15] Therefore, we used healthy extracted human premolar teeth in our study. Research by Gholami et al. found that Nd: YAG, Er: YAG, and CO2 lasers produced the smallest diameter of dentinal tubules and were most effective in sealing them.[34] However, these lasers' excessive cost, large size, and weight make their use relatively uncommon.

In 2006, Sipahi et al[35] stated that laser beams cause the evaporation of the water inside the dentinal tubules. This increase in volume causes microexplosions inside the dentinal tubules, which cause cracks in their walls. The sealing of dentinal tubules occurs due to the explosion and its products. In 2005, it was stated that a diode laser has incredibly good absorption in melanin and hemoglobin. It is also absorbed in water and hydroxyapatite to a small extent, and this low absorption can cause a change in the morphology of the dentine surface.[36]

Saluja et al. showed that morphological changes, such as cracks, fissures, and burning effects on dentin, were more pronounced with CO2 laser treatment than in other groups.[37] Given the adverse effects of the CO2 laser on dentin, its application for alleviating dentin hypersensitivity seems unjustifiable. In an in vivo investigation, the use of a 980 nm diode laser at 1 W power output, in conjunction with graphite paste, was shown to alleviate dentinal hypersensitivity effectively, without causing harm to the dental pulp.[38] Umana et al. indicated that diode lasers operating at 0.8 and 1 W in continuous wave mode had a superior ability to seal dentinal tubules. A power output of 2 W caused ablation and damage in certain dentin areas, while outputs of 1.6 and 2 W resulted in the melting of dentin, accompanied by fissures and loss of dentin.[39] According to the findings by Nair et al, the sequential application of sodium fluoride varnish followed by diode laser therapy demonstrated superior efficacy in managing dentin hypersensitivity compared to either intervention alone. Their study further reported that using a high-power diode laser (2 W) effectively reduced hypersensitivity by inducing thermal melting of the dentin's inorganic phase, leading to crystallization and fluid coagulation within the tubules, without causing notable structural changes to the pulp tissue or odontoblast layer.[40] According to the contradictory results in previous studies that suggest that a high intensity of 2 W may have harmful effects, we decided to use a power of 1 watt, which is safer. Also, in many studies, such as those by El Mobadder et al [38] and Umana et al,[39] it has been shown that a diode laser with a wavelength of 980 nm and a power of 1 W does not create any morphological problems in the dentinal tubules, has no destructive effect on the pulp, and has a good desensitizing effect.

Our study utilized a 980 nm diode laser at 1 W in continuous wave mode, which proved effective in occluding dentinal tubules. Raichur et al found that diode lasers were more effective than fluoride gels and potassium nitrate in reducing dentin hypersensitivity, providing more immediate relief than the other two gels.[41] Given the side effects of CO2 lasers on dentin, the rare use of Er: YAG and Nd: YAG lasers in dental offices, the effectiveness of diode lasers in occluding dentinal tubules in laboratory studies, and their ability to alleviate patient pain in clinical studies, we selected the diode laser for the present study. The main advantage of the diode laser that influenced our decision was its widespread application in dental practices. Its small size, affordability, portability, and efficacy in hard and soft tissues have made this type of laser the most widely used in dental offices. In contrast, the excessive cost of other laser devices has limited their adoption. Our study employed a 980 nm diode laser operating at 1 W with continuous wave irradiation. Our results indicated that, compared to the positive control group, the laser had a statistically significant impact, and the substantial occlusion of dentinal tubules was observed in SEM images.

Regarding the effect of Shield Force Plus, Chandra et al demonstrated in their experiments on sensitive teeth that the desensitizing agent Shield Force Plus completely occluded dentinal tubules, while Gluma only partially occluded them. As a result, Shield Force Plus exhibited greater efficacy.[42] Similarly, Salem et al showed that Shield Force Plus had a significantly greater effect on sealing tubules than sodium fluoride varnish.[43] In our study, Shield Force Plus effectively occluded dentinal tubules, showing statistically significant differences compared to the control group. Therefore, despite the limitations of the present laboratory study, Shield Force Plus proves to be effective in altering the micromorphology of the dentin surface, achieving either partial or complete occlusion of the dentinal tubules. This positions it as a promising biomimetic material for managing excessive dentin sensitivity.

Previous studies did not simultaneously explore the use of various lasers alongside the desensitizing agent Shield Force Plus. However, various studies have investigated the occlusive effect of the simultaneous use of various desensitizing agents and diode lasers on dentinal tubule occlusion. Some of these studies showed an additive effect of simultaneous use. For example, Umberto et al demonstrated that diode lasers can provide immediate relief from pain associated with dentin hypersensitivity, whether alone or combined with sodium fluoride gel. They also emphasized that these findings should be validated with larger patient samples and longer follow-up periods (e.g., 3 and 6 months) to confirm the long-term effects of the combined laser and treatment gel.[44] Femiano et al revealed that using a diode laser alongside 2% sodium fluoride significantly reduced dentin hypersensitivity immediately after treatment, as well as at 1-month and 6-month follow-up intervals. Combining these two agents produced a greater effect than using either alone.[45] Ghoneim et al found that diode lasers significantly enhanced immediate pain relief associated with dentin hypersensitivity and provided better occlusion of the dentinal tubules compared to the use of 1.23% sodium fluoride varnish and an 8% arginine-CaCO3 desensitizing agent applied alone.[46] Our results demonstrated no statistically significant changes in the combined effects of the diode laser and Shield Force Plus compared to either agent alone.

This study was done on extracted teeth in the laboratory in a limited time and without considering the side effects on patients in clinical investigations. Therefore, we recommend comparing the long-term durability and investigating the side effects of diode laser application, the Shield Force Plus desensitizing agent, and their combination in occluding dentinal tubules in laboratory and clinical investigations in future studies. We strongly recommend adding another group (applying laser first and then Shield Force Plus) to the groupings considered in this study.

We also faced some limitations during this study: Shield Force Plus was not readily available in the Iranian market, and further clinical investigations are needed to confirm the results obtained from this research regarding both the material and the laser.

Due to the time constraints for this article, we were only able to investigate a 1-W diode laser. We suggest that in future studies, one or two additional diode laser groups with different powers be investigated to compare their effect on dentinal tubule occlusion with that of a 1-W diode laser.

Conclusion

Based on the results of the present research, both methods—using the diode laser and Shield Force Plus—were effective in occluding dentinal tubules. In comparisons between the groups, no statistically significant differences were found in the effects of the diode laser, Shield Force Plus, or their combined application on dentinal tubule occlusion.

Authors' Contribution

Conceptualization: Samaneh Salehpour, Marjan Rahmani.
Data curation: Samaneh Salehpour, Marjan Rahmani.
Formal analysis: Samaneh Salehpour, Marjan Rahmani.
Investigation: Samaneh Salehpour, Marjan Rahmani.
Methodology: Samaneh Salehpour, Marjan Rahmani.
Project administration: Samaneh Salehpour, Marjan Rahmani.
Resources: Samaneh Salehpour, Marjan Rahmani.
Software: Samaneh Salehpour, Marjan Rahmani.
Supervision: Samaneh Salehpour, Marjan Rahmani.
Validation: Samaneh Salehpour, Marjan Rahmani.
Visualization: Samaneh Salehpour, Marjan Rahmani.
Writing–original draft: Samaneh Salehpour, Marjan Rahmani.
Writing–review & editing: Samaneh Salehpour, Marjan Rahmani.

Competing Interests

None to declare.

Ethical Approval

The study was approved by ethics committee of Qazvin University of Medical Sciences (IR.QUMS.REC.1401.242).

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Supplementary File

Supplementary file 1. Laser diode information

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