Comparative Study of Dentin Surface Changes Following Nd:YAG and Er:YAG Lasers Irradiation and Implications for Hypersensitivity

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Purpose: Dentin hypersensitivity (DH) is one of the most common complications occurring after periodontal treatment. Various methods such as Nd:YAG and Er:YAG have been used to treat DH. Previous studies support the effectiveness of these lasers, but their effect on the tooth surface largely depends on certain parameters of the tooth surface. This study attempts to evaluate some changes of the dentin surface after Nd:YAG and Er:YAG laser irradiation by using SEM.

Materials and Methods: Fifteen freshly extracted mandibular molars were selected, and 4 specimens with known dimensions (1 x 2 x 2 mm) from the buccal surface and below CEJ of all the teeth were prepared to obtain a total of 60 specimens. These specimens were then divided into 4 groups. Group 1 (control) was not subjected to laser irradiation. Group 2 was subjected to Nd:YAG laser irradiation (0.5 W, 50 mJ, 10 Hz, 60 s). Group 3 was irradiated by Nd:YAG laser (1 W, 100 mJ, 10 Hz, 60 s). Group 4 was irradiated by Er:YAG laser (0.3 W, 100 mJ, 3 Hz, 60 s). After preparation and gold coating of specimens, they were observed under SEM. Finally, the number and diameter of dentinal tubules, craters, and microcracks were determined in different groups. Finally, the data were analyzed using ANOVA.

Results: The number of open tubules showed significant differences between the Nd:YAG (1 W) group and other groups ($p < 0.05$), but no significant differences were observed between the Nd:YAG (0.5 W), Er:YAG (0.3 W), and control groups. Tubule diameter showed significant differences across all groups ($p < 0.001$), except between the Nd:YAG (1 W) and Er:YAG groups. Craters and carbonization were only observed in some samples of the Er:YAG group. No microcracks were detected in the study groups.

Conclusion: The results of this study show that Nd:YAG and Er:YAG laser irradiation can cause thermal effects such as decreased dentinal tubule diameter or occlusion. According to this study, the Nd:YAG laser at 1 W power is more effective than the Nd:YAG at 0.5 W or Er:YAG in occluding tubules.

Keywords: dentin hypersensitivity, Nd:YAG laser, Er:YAG laser, dentinal tubule, scanning electron microscope (SEM).

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Dentin hypersensitivity (DH) has long been a common clinical problem in dental practice.[1] It is reported that 54% to 98% of all patients have some degree of dentin sensitivity following periodontal therapies.[2] DH can cause sharp and severe pain, patient discomfort, and reduced levels of coordination with regard to oral hygiene, which can jeopardize the outcome of periodontal treatment.[3,4] DH is closely related to the presence of open dentinal tubules on the exposed dentin surface, where the tubules are wider and more numerous than in nonsensitive areas.[5,6] These observations are consistent with the hypothesis that dentinal pain is mediated by a hydrodynamic mechanism. In the hydrodynamic sequence, a pain-provoking stimulus applied to dentin increases the flow of dentinal tubular fluid. In turn, this mechanically activates the nerves situated at the inner ends of the tubules or in the outer layers of the pulp.[7] The most frequent causes for exposure of dentin are attrition caused by occlusal disharmony, gingival recession following either a periodontal disease process or periodontal therapy, trauma from tooth brushing, and abfractive lesions.[8,9] To reduce DH severity, attempts have been made to seal the dentinal tubules or to alter their contents, and various agents and methods have been recommended for this purpose.[10]

Several studies using lasers, such as Nd:YAG and, recently, Er:YAG, have suggested laser as a suitable tool for successful reduction of DH.[11-16] The effectiveness of laser irradiation largely depends on the physical characteristics of the laser beam including wavelength, power (W), pulse duration, and energy density (J/cm^2).

Other factors involved include the optical properties of the irradiated tissue such as optical density, structure, and maximum absorption.[17,18] The Nd:YAG laser is poorly absorbed by hard dental tissue but penetrates deep into irradiated tissues. Er:YAG laser, however, is entirely absorbed in the superficial layers of dentin. In both cases, the photon energy is converted into thermal energy but with completely different results; while Nd:YAG laser mainly heats the dentin, Er:YAG laser removes tissue in a process of microexplosions.[19]

The objective of the present study was to evaluate, under a scanning electron microscope, the changes of dentin surfaces following Nd:YAG and Er:YAG irradiation and their association with laser characteristics.

MATERIALS AND METHODS

An in-vitro experiment was designed along the lines recommended in the literature. Given that 4 groups were included in the study, the sample size was determined according to a degree of freedom equal to 1.96. Therefore, 15 freshly extracted impacted third molars from 20-year-olds with large mesiodistal areas on root surfaces were selected for this research. However, in such young teeth, the dentin tubule size is larger than dentin tubule size in erupted teeth in older people.

Four specimens with the dimensions of 1 x 2 x 2 mm were prepared from each tooth by disk cutting. The thickness of specimens prepared was 1 mm, as mentioned elsewhere in the literature.[20] The cementum layer was not removed. The opposite pulpal side of dentin was selected for this study. As the diameter of dentinal tubules increase toward the pulp, the thickness of specimens was prepared as small as 1 mm, although the thinness may blur the actual thermal reaction, because absorption of Er:YAG and penetration of Nd:YAG lasers sometimes goes deeper than 1 mm; thus, the efficacy of laser may be reduced.

EDTA and hypochlorite were applied on the surfaces to remove the smear layer, by immersing for 5 min in 17% EDTA (pH = 7.8) and then in hypochlorite for another 5 min. Finally, all the samples were washed in 5 ml distilled water.[21]

A simple randomizing method using blind selection was used to divide these individual specimens into 4 different groups. The first group was left as control without any laser treatment. The Nd:YAG laser at 0.5 W (50 mJ, 10 Hz, 60 s, 2 times) was employed for irradiating the second group, and the third group was subjected to a laser of 1 W (100 mJ, 10 Hz, 60 s, 2 times).[11] The diameter of output beam was about 300 µm. The last group was treated with Er:YAG at 100 mJ, 3 Hz, for 60 s twice, with water coolant used.[15] The pulse duration selected was about 700 to 1000 µs (VLP mode) and the output beam diameter was about 900 µm.

A Fidelis plus laser system (Fotona; Ljubljana, Slovenia) was used. The pulpal side of dentin was laser irradiated in specimens in all the laser groups. The specimens were held by dark lockable pincers, and then were placed on flat stone. The distance between laser fiber or tip and tooth root surface was kept at 2 mm in all the experiments by means of 3 orthodontic wires. The beam was perpendicular to the dentin surface.

For SEM imaging (XL-30, Philips; Eindhoven, The Netherlands), a magnification of 100X was used for microcracks and crater form, and a magnification of 1500X for dentinal tubule changes.

For evaluating the diameter of dentinal tubules, a digitized caliper was used to measure all tubule orifices in every field. Average values of diameters were reported.

Using a fixed scale in all the images, the real sizes were extracted and used for statistical analysis. Open tubules were counted to evaluate their closure by laser irradiation. In addition, the presence of craters at a magnification of 100X was documented as a possible side effect.

Table 1 Indices of diameter of dentinal tubules in different groups (n=15)

	Diameter of dentinal tubules				
Groups	Mean	SD	Differences range	Max(µm)	Min(µm)
Control	5.1	0.6	1.9	6.2	4.3
0.5W Nd:YAG	3.4	0.7	2	4.2	2.4
1 W Nd:YAG	0.4	2	1.1	2.4	1.3
Er:YAG	0.3	1.8	0.9	2.1	1.2

Microcracks were counted and reported if seen at 100X in any field that showed such a feature. The data were finally analyzed using ANOVA and SPSS software.

RESULTS

Scanning electron microscopy of the specimens showed that the diameters of dentinal tubules diminished in all laser groups compared to those in the control group ($p < 0.001$). However, the Er:YAG and Nd:YAG (1 W) groups did not show any significant differences in this study ($p = 0.775$) (Table 1; Figs 1 to 4).

As shown in Table 2, there were no statistically significant differences in the mean number of open dentinal tubules between the Nd:YAG (0.5 W) and the Er:YAG ($p = 0.391$), between control and Er:YAG ($p = 0.058$), between the Nd:YAG (0.5 W) and control ($p = 0.719$). In contrast, significant differences were observed between the Nd:YAG (1 W) group and control or Nd:YAG (0.5 W) ($p < 0.001$) and between the Nd:YAG (1 W) group and Er:YAG ($p = 0.003$).

Furthermore, evaluation of irradiated specimens showed that laser side-effects such as craters and carbonization were only detected in the Er:YAG group (Fig 5). However, no evidence of microcracking was found in any of the groups studied.

DISCUSSION

Conventional treatment methods for dentin hypersensitivity have the great disadvantage of having to be repeated regularly to achieve a continuous relief from pain, because acids contained in food or aggressive tooth brushing cause gradual removal of precipitates and superficial coatings. The use of lasers might open up new dimensions in the treatment of dentin hypersensitivity.[22]

The lasers used for the treatment of dentin hypersensitivity are divided into two groups: low-output power lasers (He-Ne and GaAlAs), and middle-output power lasers (Nd:YAG, Er:YAG and CO_2).[22] The mechanism of Nd:YAG laser effects on dentin hypersensitivity is thought to be the laser-induced occlusion or narrowing of dentinal tubules, as well as direct nerve analgesia. For the Er:YAG laser, it is suggested that a deposition of insoluble salts in the exposed tubules is responsible for an obturation of the dentin tubules.[22]

In this study, the effects of Nd:YAG and Er:YAG laser irradiation were evaluated on some structural features of dentin, like changes in number and diameter of dentinal tubules and certain side-effects, including craters and microcracks. The relations between these changes and suggested parameters were also investigated. As shown in Tables 1 and 2, changes in dentinal tubules diameters were significant ($p < 0.001$) in the Nd:YAG and Er:YAG laser irradiated groups compared to the control group. Furthermore, the number of open dentinal tubules in the Nd:YAG laser irradiated group (1 W) was significantly lower ($p < 0.001$) than that in the control and Er:YAG, Nd:YAG (0.5 W) laser irradiated groups. Changes in tubule diameters and number of occluded dentinal tubules by laser irradiation were similar to the findings of Lan[23,24] and Magalheas.[25]

According to the results of this study, Nd:YAG laser (0.5 W) caused in most cases a decrease in dentinal tubule diameter, while the Nd:YAG laser (1 W) additionally caused tubule occlusion and disappearance (Figs 1 to 3). As reported in previous studies, this occlusion of dentinal tubules would directly result in

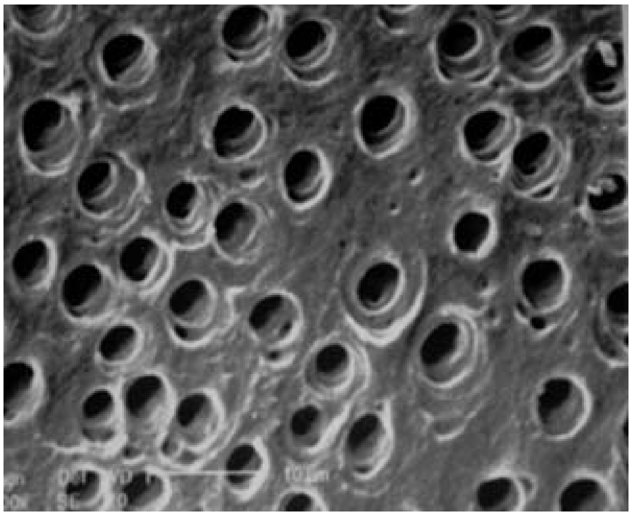

Fig 1 Control specimen (not irradiated) (magnification 1500X).

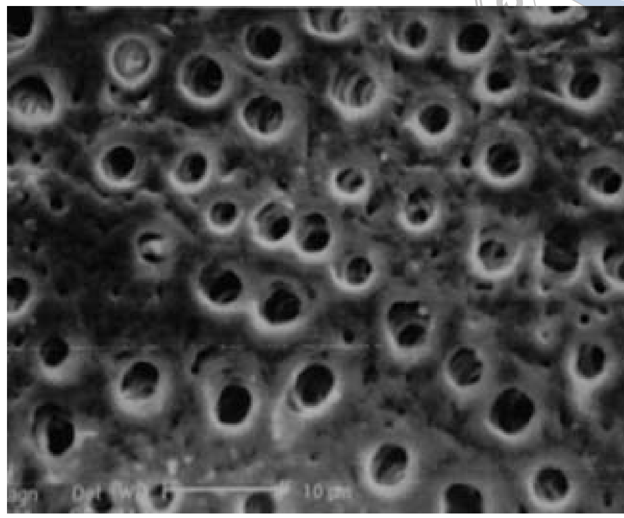

Fig 2 Nd:YAG (0.5 W) laser irradiated specimen (magnification 1500X).

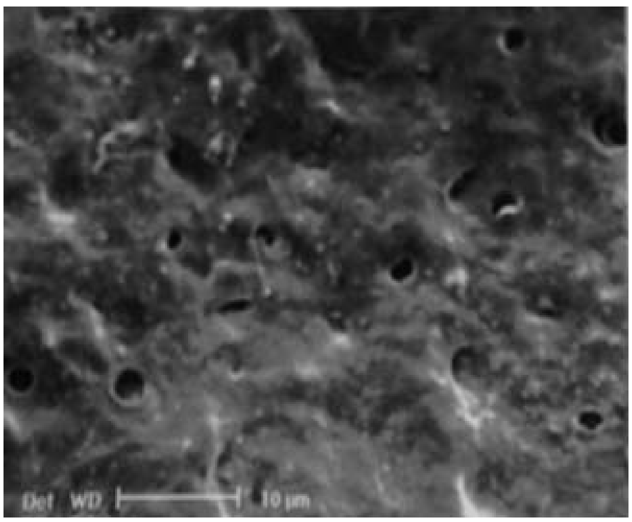

Fig 3 Nd:YAG (1 W) laser irradiated specimen (magnification 1500X).

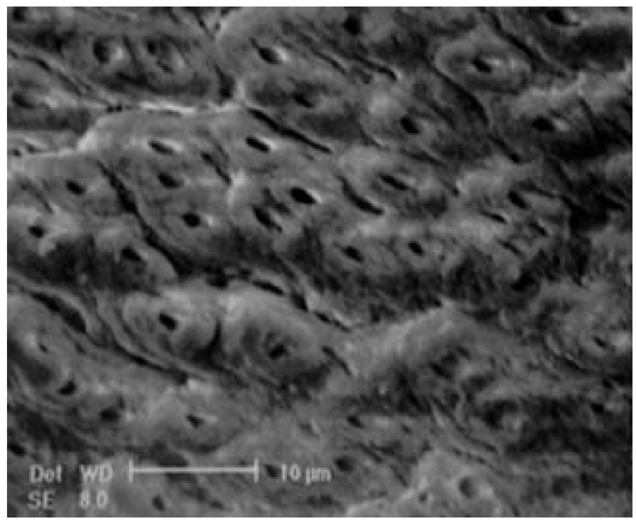

Fig 4 Er:YAG laser irradiated specimen (magnification 1500X).

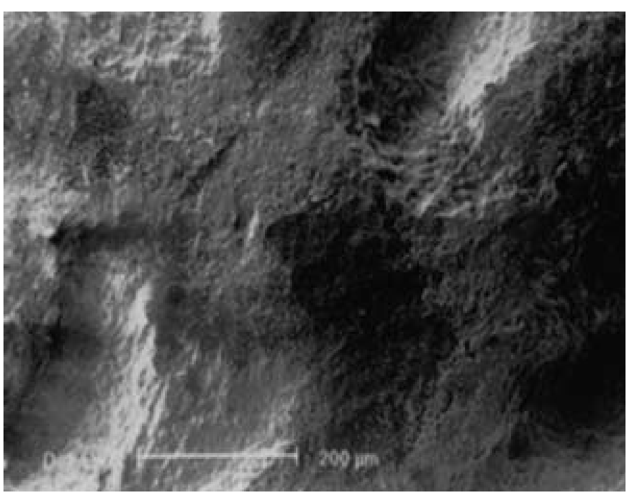

Fig 5 Craters due to Er:YAG irradiation (magnification 100X).

Table 2 Number of open tubules, mean and SD in all groups (n=15)

	Numberof open tubules			
Group	Mean ± SD	Differences range	Maximum	Minimum
Control	51 ± 9	25	62	37
Nd:YAG 0.5 W	45 ± 8	22	57	35
Nd:YAG 1 W	17 ± 6	16	28	12
Er:YAG	37 ± 15	17	52	35

reduced dentin hypersensitivity.[26,27] Treatment effectiveness ranged from 52% to 100% when using Nd:YAG laser irradiation.[28]

Although minimal Nd:YAG laser power (0.3 W) for dentin desensitization has been suggested by some authors,[12,14,23,24] the results of this study showed that low-power (0.5 W) Nd:YAG laser did not cause complete occlusion of dentinal tubules. As a result, treatment effectiveness range may be low and/or inconsistent.[12] Others, such as Aranha et al,[29] have suggested the use of Nd:YAG laser at 1.5 W, 15 Hz to decrease dentin permeability. They have also reported that Nd:YAG laser at 1 W, 10 Hz decreases permeability with a smaller effect.[29]

It must be mentioned here that the distance between fiber tip and tooth surface is critical due to energy density and peak power of any pulse at the irradiated area.[30] Application of Nd:YAG laser at a distance of 6 mm from the surface by Aranha et al[29] and at 2 mm in our study as well as the light contact mode in other studies[12,14,23,24,31] may be claimed as a reason for the variations observed in treatment effectiveness.

According to the present study, application of Er:YAG laser (12 J/cm^2, 3 Hz) on the surface of dentin resulted in decreased dentinal tubule diameter compared to that in the control group. This finding is in agreement with the findings of Aranha et al,[29] who reported that application of Er:YAG laser caused decreased dentin permeability. In regard to some clinical studies, the use of Er:YAG laser to reduce dentin hypersensitivity is reported to be effective.[15,16] In some studies, the results are controversial. The Nd:YAG laser, Er:YAG laser, and GaAlAs low-level laser all reduce DH, but the reductions were not significantly different from those of a placebo[32] or positive controls.[33] In addition to these equivocal results, lasers represent a more expensive and complex treatment modality.[7]

In one study, application of Gluma desensitizer to Er:YAG-irradiated dentin increased the bond strength and durability of the self-etching priming adhesive used.[34] In another study, dentinal surfaces were exposed to acidic beverages, then treated with Nd:YAG laser and afterwards exposed to acidic beverages again. According to the results, irradiation with Nd:YAG laser produced obliteration of and reduction in the number of dentinal tubules, thus modifying the original structure.[31]

In some studies, the combined occluding effects of fluoride-containing dentin desensitizer and Nd:YAG laser irradiation burns the occluding agent into the dentinal tubules, thereby providing resistance to the effects of an acidic diet and brushing, and increasing the duration of the desensitizing effect.[20] In another study, the combination of Nd:YAG laser and 5% sodium fluoride varnish seemed to show an impressive efficacy, when compared to either treatment alone, in treating dentin hypersensitivity. The SEM findings seem to relate to the clinical findings in that reduction in number/patency of tubules was associated with improvement in treatment efficacy.[35]

In a study using 1% rhodamine B dye solution, effects of Er:YAG and Nd:YAG lasers on dentin permeability in root surfaces were evaluated. According to the results of this in vitro study, the Er:YAG laser at 60 mJ, 2 Hz, and the Nd:YAG laser at 1.5 W, 15 Hz are useful for decreasing dentin permeability.[29]

Furthermore, in some studies, craters and microcracks have been mentioned as possible side-effects following Nd:YAG and/or Er:YAG irradiation.[19,36] However, in this study, there were no craters in the Nd:YAG groups, while craters were observed in the Er:YAG group (Fig 5), as also reported by Majaron and Apel.[37,38] The craters may be caused by the density of the energy applied (higher than ablation threshold).

However, no evidence of microcracking was found in the study groups.

CONCLUSION

The results of this study show that Nd:YAG and Er:YAG laser irradiation can cause thermal effects such as decreased dentinal tubule diameter or their occlusion. Moreover, the Nd:YAG laser at 1 W, 10 Hz is more effective than the Nd:YAG (0.5 W) and Er:YAG in tubule occlusion.

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