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Effects of a 532 nm Q-Switched Nanosecond Pulsed Laser on Dentin

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The purpose of this study was to determine whether a nanosecond-pulsed, frequency-doubled Nd:YAG laser emitting at 532 nm can be used as an alternative to mechanical methods of root canal treatment or as an adjunct to conventional endodontic preparation. Laser parameters whose thermal effects did not exceed safety thresholds for adjacent periodontal tissues were selected in a preliminary study. In 27 extracted human teeth, root canals were irradiated for 30 to 60 s at fluences of 2 to 2.2 J/cm², and 10 Hz. Samples were observed using SEM. Laser irradiation could achieve smear layer removal after minimal manual preparation. However, results were inhomogeneous, and at higher energy densities thermal damage was observed, especially in the fully manually prepared samples. Nanosecond-pulsed irradiation at 532 nm can achieve complete smear layer removal. However, mechanisms must be developed to monitor laser effects and avoid potential damage to collateral structures.

The effects of various lasers on dentin and potential applications of laser techniques in the preparation of the root canal system have been investigated in a number of in vitro studies that achieved varying degrees of success. After irradiation with an air and water-cooled experimental Nd:YAG laser, Levy et al. (1) observed the presence of sealed dentinal tubules and an improved debridement of laser-treated root canals as compared with results of conventional techniques. Dederich et al. (2) reported melting and recrystallization of root canal wall dentin after Nd:YAG irradiation. Goodis et al. (3) suggested that lasers can serve as an adjunct in root canal preparation. In a comparative study assessing Nd:YAG laser treatment and conventional methods of cleansing and shaping of the root canals, they found that the laser removed smear layer and occasionally altered the morphology of dentin walls. Pini et al. (4) observed that XeCl excimer laser irradiation delivered into the root canal through optical fibers can achieve effective and selective removal of infected dentin with minimum ablation of healthy dentin. On the other hand, Frentzen et al. (5) reported that at energy densities of 80 to 120 mJ/pulse XeCl lasers were unable to remove dentin or pulpal tissues in the root canals of

human extracted teeth. Following the application of pulsed 9.6 μm CO₂ laser irradiation (12 J/cm²) delivered into the root canals with AgCl fibers, Onal et al. (6) observed fused areas of hydroxyapatite and open dentin tubules. Slayton et al. (7) found that low fluence 10.6 μm CO₂ laser treatment (2 J/cm²) caused a melted appearance of the smear layer with no apparent damage to the underlying dentin.

More recently, a frequency doubled YAG laser was evaluated for structural and functional effects on root canal dentin. Machida et al. (8) demonstrated that the potassium titanyl phosphate (KTP) laser (532 nm) can be used to remove debris and smear layer from root canal walls without exceeding the thermal safety threshold for periodontal tissue injury. In a study using the same laser, Tewfik et al. (9) observed varying results within individual root canals exposed to the same laser parameters. They reported areas of undisturbed smear layer, patchy zones of smear layer, vaporized smear layer, and some increase in dentinal tubule diameter.

Conventional biomechanical preparation of the root canal system involves the use of hand and rotary instruments with chemical irrigation, which results in the formation of a smear layer on the dentin surface of the root canal. The removal of smear layer which consists of dentinal shavings, organic tissue remnants, and micro-organisms is considered a major factor during root canal treatment, because its presence may interfere with the goal of achieving an aseptic and hermetic seal of the obturated root canal space.

The purpose of this study was to determine whether a frequency doubled Nd:YAG laser can be used either as an alternative to conventional mechanical methods of root canal treatment or merely as an adjunct to conventional methods of endodontic cleansing and shaping. Laser parameters whose thermal effects did not exceed temperature safety thresholds for adjacent periodontal tissues (5°C) were selected in a preliminary study. Based on these parameters, the effects of irradiation with a pulsed laser emitting at 532 nm were evaluated on dentin. Unlike the long pulsed KTP laser delivered with optical fibers used in the studies by Machida and by Tewfik, this study will evaluate a short pulsed (10⁻⁹ seconds) laser emitting through an articulated arm.

MATERIALS AND METHODS

Preliminary Study

In a preliminary study, nine freshly extracted single rooted human teeth were bisected longitudinally using a low speed dia-

TABLE 1. Laser parameters used for SEM evaluation of dentin

Fluence (J/cm ²)	Duration (seconds)	Energy density (J/cm ²)	Frequency
2.0	30	60	10 Hz
2.0	60	120	10 Hz
2.2	30	66	10 Hz

mond saw (Isomet; Buehler Ltd., Lake Bluff, IL) with water as lubricant. A total of 18 root canal halves were used. These were stored in demineralized water with 0.01% (w/v) thymol. The narrowest portion of the root canal was selected visually. This area of the root canal was demarcated, and the dentin portion was irradiated at a fluence between 0.5 to 8.8 J/cm², a pulse repetition rate of 10 Hz, and a 1.5 mm beam diameter spot size. Temperature measurements were recorded using an IR camera (Inframetrics model 600, with a scan speed of 60 Hz) before, during, and after laser exposure to determine root canal surface temperature changes. Based on these preliminary results, the laser parameters used for the main study were selected. These are depicted in Table 1.

Sample Preparation

Twenty-seven extracted, single rooted human teeth were selected. Attached soft tissue and calculus were removed with a scaler and the crowns were sectioned horizontally at the cemento-enamel junction. The 27 roots were prepared in three different ways: nine samples remained untreated; nine root canals were minimally prepared; nine root canals were fully prepared. Manual preparation of the root canals for the minimally prepared group was performed using #10 and #15 files. Only gross root canal tissue contents and debris were removed during the procedure. In the fully prepared group, root canals were enlarged from file size #10 to #45. In both minimally and fully prepared groups, 5 ml of 2.5% NaOCl was used for irrigation after each filing. The working length of the root canals was determined visually for each tooth to 1 mm short of the apex. After preparing the root canals, the 27 roots were carefully sectioned longitudinally to obtain one complete half root canal at the expense of the other half. These 27 root halves were then laser-treated at the parameters listed in Table 1.

Laser Treatment and Scanning Electron Microscopy (SEM)

The laser used in this study was the Q-Switched 532 nm nano-second pulsed Medlite Laser (Continuum Biomedical, Inc., Livermore, CA). Upon completion of the irradiation procedures, the specimens underwent dehydration in a graded series of aqueous ethanol (30, 50, 70, 90, 100% ethanol) for 10 min at each concentration, samples were mounted on stubs using colloidal silver liquid (Ted Pella, CA) and gold coated on a PAC-1 Pelco advanced coater 9500 (Ted Pella, CA). Micrographs of the root canal wall were taken on a Phillips 515 (Mohawk, NJ) SEM.

RESULTS

Temperature measurements obtained during the preliminary study are depicted in Figure 1.

Maximum Temperature Rise At Selected Laser Parameters

Fig 1. Maximum temperature increases at the laser parameters selected for this investigation.

Fig 2. Scanning electron micrograph of dentin after minimal manual preparation, laser irradiation at a fluence of 2 J/cm², irradiation duration 30 s (×625, reference bar = 100 μm).

Main Study

The morphology of coronal and root dentin in the group that did not receive any prior endodontic preparation was consistently unaffected by laser treatment even at the highest energy densities used. The pulp tissue, however, overlying the dentin and directly in contact with the laser was detached from the canal wall at lower energy densities and evaporated at higher energy densities.

At a fluence of 2.0 J/cm² and an exposure time of 30 s, minimal preparation of the pulp chamber or root canal combined with laser treatment resulted in localized effects when observed under the SEM (Fig. 2). Patchy removal of approximately 20% to 35% of the smear layer was observed, without any surface changes in the exposed pulp chamber and root canal dentinal structures.

After an irradiation time of 60 s, more extensive and consistent removal of the smear layer was observed. This was limited to the irradiation site and caused no discernible structural changes in the

FIG 3. Scanning electron micrograph of dentin after minimal manual preparation, laser irradiation at a fluence of 2 J/cm², irradiation duration 60 s ($\times 625$, reference bar = 100 μ m).

FIG 4. Scanning electron micrograph of dentin after full manual preparation, laser irradiation at a fluence of 2 J/cm², irradiation duration 30 s ($\times 625$, reference bar = 100 μ m).

dentinal walls themselves. The areas of more marked smear layer removal and dentinal tubule exposure are depicted in Figure 3.

In the fully prepared groups, laser effects at fluences of 2.0 J/cm² after 30 s of irradiation were seen on the smear layer and on dentinal structures. In Figure 4, evaporation of 40% to 50% of the smear layer is evidenced; other portions of the smear layer appeared melted and adherent to dentin. The dentinal tubules were exposed in areas not covered by smear layer. Similar observations were made in samples irradiated for a longer time of 60 s. However, laser effects were more uniform.

At a fluence of 2.2 J/cm² after irradiation for 30 s, laser treatment of minimally hand-prepared root canals and pulp chambers resulted in approximately 80% to 90% reduction of smear layer, however, with patchy alterations in the morphology of the underlying dentinal structures in approximately 10–20% of the irradiated surface area (Fig. 5 A and B).

The same irradiation parameters applied to the fully prepared groups produced a definite crater on the dentinal wall (Fig. 6 A). At

high magnification (Fig. 6 B), a very clean surface with complete removal of the smear layer and exposed dentinal tubules can be observed in 50% of irradiated areas. Thermal damage (Fig. 6 C) and less effective smear layer removal (Fig. 6 D) are seen in other areas of the same samples.

DISCUSSION

Only combinations of fluence and irradiation time that would not cause a rise in temperature of surrounding periodontal tissues beyond the level of biological tolerance (5°C) were selected from our preliminary study. Temperature measurements were conducted in the narrowest portion of the root canals to measure maximum heating and thus to provide the most conservative temperature ranges for irradiation. Nevertheless, using parameters identified in the preliminary investigations, structural changes were still observed in dentin at some of the laser parameters used in this study. Consistent with the results of other investigations, treatment in this study varied from "no effects" to "disruption of the smear layer" to "surface alterations in dentin structures," depending on the laser type and radiation energy applied (1–6, 10, 11).

The presence of overlying pulp tissue, tissue remnants, and smear layer are factors that influence laser effects on dentinal structures. In the presence of substantial pulp tissue, debris, and smear layer (minimally prepared groups), dentin walls remained unaltered even after a long exposure time of 60 s at a fluence of 2.0 J/cm². Similar results were reported by Goodis et al. (3) using the Nd:YAG (1.06 μ m) laser in root canals, which had undergone only initial cleaning and shaping of the apical portion with files #10 to #20 and chemical irrigation with 5 ml of 2.5% NaOCl between files and laser probes. These authors were generally able to remove remaining smear layer and tissue remnants after hand instrumentation using laser application and constant movement of the laser probe within the root canal space also produced occasional alterations in the morphology of the dentinal walls. In this investigation, the steady application of a laser at a wavelength of 532 nm at a fluence of 2.2 J/cm² for 30 s in minimally prepared root canals or pulp chambers resulted in the optimal removal of smear layer. At this energy density, the dentinal walls remained unaltered and a cleansing effect was achieved with little or no prior instrumentation. In the fully prepared groups, however, the same energy density that achieved a moderately clean dentinal surface in the minimally prepared group produced a totally clean surface accompanied by morphological changes in the dentinal structures. Because NaOCl is known to be an effective agent in the removal of organic tissue, one might conclude that it aided in the cleansing of the dentinal walls in this sample group of our study (12–15). However, some studies have shown that NaOCl appears to have no effect in removing smear layer when compared with samples not treated with NaOCl (3). The 532 nm nanosecond pulsed laser was also effective in removing soft tissue and smear layer on the surface of dentinal walls as evidenced by the unclean surfaces of nonirradiated areas. Laser interaction occurred between the soft tissue and the water it contains. Damage is more readily observed at the higher energy densities in fully prepared groups because in the presence of less soft tissue, the laser will also interact with the dentin underlying it.

In both minimally and fully prepared groups, the number of exposed dentinal tubules was related to the extent of smear layer removal. The importance of removing the smear layer is based on research findings showing that such layers contain microorganisms

FIG 5. A. Scanning electron micrograph of dentin after minimal manual preparation, laser irradiation at a fluence of 2.2 J/cm^2 , irradiation duration 30 s ($\times 625$, reference bar = $100 \mu\text{m}$). B. Scanning electron micrograph of dentin after minimal manual preparation, laser irradiation at a fluence of 2.2 J/cm^2 , irradiation duration 30 s ($\times 600$, reference bar = $100 \mu\text{m}$).

(16) that can result in subsequent reinfection in a canal not completely sealed after treatment. On the other hand, some studies suggest that the presence of smear layer covering dentin tubules in root canals reduces permeability and therefore reenhances resistance against leakage and bacterial penetration following restoration (17).

The application of a fluence of 2.0 J/cm^2 over 30 to 60 s in the fully prepared group resulted in the removal of a considerable amount of the smear layer. Longer exposure times produced greater smear layer removal and concomitant damage as well. Although some residual smear layer was visible on the surface of the dentinal walls, it appeared melted and adherent to the openings of the dentinal tubules. Such a melted smear layer could be important in reducing the permeability of dentin and possibly preventing reinfection of root canals in the clinical situation. Tewfik et al. (9) suggest that the presence or absence of a smear layer is a deciding factor in determining whether there is to be a change in the permeability of irradiated dentin surfaces. Using a KTP/532 nm laser on smeared dentin resulted in decreased dentin permeability regardless of the energy level (1–5 W for 0.2–1.0 s) used (9). However, after EDTA/NaOCl treatment of dentin surfaces, they found significant increases in permeability after KTP irradiation (9). Using a thermally cooled pulsed Nd:YAG laser, Miserendino et al. (18) reported leakage patterns to be dependent on the presence of a glass-like material that coated the canal wall surface. They also observed areas of melted and recrystallized dentin that did not by themselves decrease permeability. The different results obtained in these investigations are difficult to compare as the laser systems and irradiation procedures in these studies differed greatly.

The melted appearance of the smear layer after irradiation at a fluence of 2.0 J/cm^2 over a longer exposure time of 60 s in fully prepared groups suggests that loss of water and organic content by evaporation resulted in a more condensed and more packed smear layer. Although permeability measurements were not performed in this study, the altered smear layer might fuse or adhere to the underlying dentin surface, thus covering underlying dentinal tubules. Despite these possibilities, there exists no study to date that has conclusively shown how the presence, absence, or modification of the smear layer may affect the overall success of endodontic treatment.

In a study by Tewfik et al. (9), laser irradiation was performed parallel to the canal through a fiber, with the result that a variable distance between the irradiation source and the canal wall in an asymmetric root canal produced more than one surface pattern within the same root canal despite the consistent energy density used. The closer the fiber tip to the canal walls, the greater the evaporation of water and/or organic content of the smear layer observed. In this study, laser irradiation was directed at right angles to the dentin. Therefore, more consistent results were observed within the same root canal and in multiple specimens exposed to the same treatment. However, sufficient variability occurred within our results to raise concerns regarding clinical application of this technique until means of obtaining predictable and uniform results have been established.

In this study, laser parameters were selected in a preliminary study to be thermally tolerable to biological tissues. However, structural changes were still observed at the chosen parameters that related to the laser parameters used as well as the amount and nature of residues overlying the dentin. Moreover, the “real” transient temperature peaks produced by a nanosecond pulsed laser will have remained undetected by the thermal camera used in this study, which has a scan speed of 60 Hz. Limitations presented by existing infrared thermal cameras must be recognized and taken into consideration when determining safe laser energies for treatment procedures. More research is also required to determine which laser effects on dentinal walls provide optimal clinical results.

Presently, the 532 nm nanosecond pulsed laser cannot replace the conventional method of hand instrumentation in root canals and pulp chamber. Our results demonstrated that the 532 nm nanosecond pulsed laser is capable of complete removal of smear layer. However, modifications in this form of treatment must be made to avoid accompanying changes in the morphology of dentinal structures observed during irradiation.

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FIG 6. A. Scanning electron micrograph of dentin after full manual preparation, laser irradiation at a fluence of 2.2 J/cm², irradiation duration 30 s (×212, reference bar = 100 μm). B. Scanning electron micrograph of dentin after full manual preparation, laser irradiation at a fluence of 2.2 J/cm², irradiation duration 30 s (×845, reference bar = 100 μm). C. Scanning electron micrograph of dentin after full manual preparation, laser irradiation at a fluence of 2.2 J/cm², irradiation duration 30 s (×1010, reference bar = 10 μm). D. Scanning electron micrograph of dentin after full manual preparation, laser irradiation at a fluence of 2.2 J/cm², irradiation duration 30 s (×745, reference bar = 100 μm).

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