Ultrastructural Analysis of Root Canal Dentine Irradiated with 980-nm Diode Laser Energy at Different Parameters


Abstract

Objective: The purpose of this in vitro study was to investigate using the scanning electron microscope (SEM) the ultrastructural morphological changes of the radicular dentine surface after irradiation with 980-nm diode laser energy at different parameters and angles of incidence.

Background Data: There have been limited reports on the effects of diode laser irradiation at 980 nm on radicular dentin morphology.

Materials and Methods: Seventy-two maxillary canines were sectioned and roots were biomechanically prepared using K3 rotary instruments. The teeth were irrigated with 2 mL of distilled water between files and final irrigation was performed with 10 mL of distilled water. The teeth were then randomly divided into five groups (n = 8 each) according to their diode laser parameters: Group 1: no irradiation (control); group 2: 1.5 W/continuous wave (CW) emission (the manufacturer’s parameters); group 3: 1.5 W/100 Hz; group 4: 3 W/CW; and group 5: 3 W/100 Hz. Laser energy was applied with helicoid movements (parallel to the canal walls) for 20 sec. Eight additional teeth for each group were endodontically prepared and split longitudinally and irradiation was applied perpendicularly to the root surface.

Results: Statistical analysis showed no difference between the root canal thirds irradiated with the 980-nm diode laser, and similar results between the parameters 1.5 W/CW and 3 W/100 Hz (p > 0.05).

Conclusion: When considering different output powers and delivery modes our results showed that changes varied from smear layer removal to dentine fusion.

Introduction

With the introduction of lasers to the fields of conservative dentistry, endodontic treatment was enriched by a multitude of new treatment methods that improved the chances for a successful treatment outcome. Lasers were shown to be feasible and effective tools for cleaning and disinfecting the root canal system, particularly because they helped to overcome the problem of insufficient depth of penetration of commonly used disinfecting agents.1

The most commonly used lasers for this purpose are Er:YAG, Nd:YAG, and CO2, and they have the capacity to alter the morphology of root canal dentine walls and remove the smear layer,2-4 reduce bacteria,5,6 seal the apical foramen,7,8 and increase or decrease dentine permeability.9,10

Among the new lasers with a wide range of characteristics now available in various fields of dentistry, the diode wavelength of 810 nm has been complemented by a diode device emitting at 980 nm. Although high-intensity diode lasers are relatively new in dentistry, there are many interesting characteristics that make them quite popular among dentists. Their low cost, small size, and ease of application in the oral cavity due to fiber delivery are important characteristics that favor their use in clinical practice and encourage new studies.1,5 According to Meister et al.,11 the generation of high-power laser radiation with small tips opens up new fields of application.

To date, the potential application of 980-nm diode laser energy in endodontics has seldom been addressed. The literature shows only three studies on the use of 980-nm laser devices for the treatment of root canals. Gutknecht et al.3 affirmed that while standard chemical solutions can reduce mi-
croorganisms up to 100 μm, the diode laser is effective up to 500 μm; Schoop et al.1 evaluated the effects of 980-nm diode and 532-nm KTP laser systems, focusing on their antibacterial effect in deep layers of dentin and their impact on the root canal dentin; Wang et al.,12 evaluated the rise in temperature of root surfaces during and immediately after diode laser irradiation, and observed morphological changes in root canal walls, and evaluated apical leakage after irradiation and obturation. However, these studies did not examine the potential of different parameters of this device.

It is important to consider that the effect of lasers on biological tissues, such as dentine or enamel, depends on various parameters, including wavelength, emission mode, energy density, pulse repetition rate, potency, tissue water content, air/water spray cooling, and irradiation direction.13 Thus, the purpose of this in vitro study was to investigate the ultrastructural changes of root canal dentine after irradiation with 980-nm diode laser energy at different parameters using the scanning electron microscope (SEM).

**Materials and Methods**

The crowns of 72 human maxillary canines were sectioned at the cementoenamel junction by means of a diamond bur and the root length was standardized at 17 mm. The crowns were discarded and the roots were measured with a #10 file (Dentsply-Maillefer, Ballaigues, Switzerland) until the tip was visible at the apical foramina.

Biomechanical preparation was performed using the K3 system (SybronEndo, Orange, CA, USA), activated by an electric motor (Endo Plus; Driller, Sao Paulo, SP, Brazil) at 350 rpm. The cervical third was prepared with a #2 LA Axxess bur (#35/.06; SybronEndo) and a #25/.12 instrument, followed by a #25/.08 instrument at the middle third and #30/.02, #35/.02, #35/.04, and #40/.02 instruments at the apical third. During the biomechanical preparation, the teeth were irrigated with 2 mL of distilled water between files. Final irrigation with 10 mL of distilled and deionized water was performed after final instrumentation to remove excess dentine chips. The canals were dried with paper points.

Forty teeth were randomly divided into five groups of eight teeth each for laser irradiation with a 980-nm diode laser system (SIROlaser 2.2; Sirona Dental Systems GmbH, Bensheim, Germany): group 1: no laser irradiation; group 2: 1.5 W and continuous wave emission (CW); group 3: 1.5 W and pulsed wave emission (100 Hz); group 4: 3 W and CW; and group 5: 3 W and 100 Hz.

For laser application, a 200-μm fiberoptic tip was introduced up to the apical region; the laser was activated and gently withdrawn from the root canal to the coronary region with a helicoid movement and re-introduced to the apex for a total laser irradiation cycle of 20 sec (the cycle time established by the manufacturer).

The remaining 32 teeth were split longitudinally with a diamond disk (KG Sorensen, Barueri, SP, Brazil) and low-speed motor (Dabi Atlante, Ribeirão Preto, SP, Brazil) and laser irradiation was applied perpendicularly to the entire root canal surface at a distance of 1 mm, using the same pa-

**FIG. 1.** Photomicrograph of dentine instrumented with distilled and deionized water (control group) that shows a heavy, loose smear layer (original magnification 1500×).
rameters described above, for 20 sec. This angle of application was chosen to show the maximal effects of this new laser wavelength on root canal dentine.

Preparation for scanning electron microscopy

The pulp chambers of the parallel irradiation specimens were closed with Blu Tack (Bostik Ltda, Leicester, England), which is a non-oily adhesive mass that does not leave residue. A diamond disk turning at low speed was used to make a longitudinal sulcus along the buccal and palatal surfaces of the tooth, taking care not to reach the root canal. The teeth were fractured longitudinally with a bi-tapered chisel and a surgical hammer, exposing the entire root canal.

The fragments were placed in an Eppendorf tube with 2.5% buffered glutaraldehyde and 0.1 M sodium cacodylate (pH 7.4; Merck KGaA, Darmstadt, Germany) at 4°C for 12 h, washed with distilled and deionized water for 3 min, immersed in distilled and deionized water for 1 h (the water was changed every 20 min), and then dehydrated in an ascending ethanol series (Labsynth Ltda., Diadema, SP, Brazil): 25% (20 min), 50% (20 min), 75% (20 min), 95% (30 min), and 100% (60 min). After dehydration, the specimens were placed in a dehumidifier for 10 min for final drying.

The specimens were then fixed on stubs with double-faced carbon tape, covered with a gold-platinum layer (30 μm; Bal-Tec SCD 005, Zurich, Switzerland) and placed in a vacuum apparatus (SDC 050; Bal-Tec RG, Balzers, Liechtenstein).

The dentin surfaces were examined with a scanning electron microscope (XL30 FEG; Philips, Eindhoven, The

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>1</td>
<td>Heavy smear layer covering the specimen; no tubule orifices; no visible melting</td>
</tr>
<tr>
<td>2</td>
<td>Modified organic matrix layer with an amorphous form; no tubules visible; no visible melting</td>
</tr>
<tr>
<td>3</td>
<td>Modified organic matrix layer with an amorphous form; tubules visible but not completely opened; no visible melting</td>
</tr>
<tr>
<td>4</td>
<td>Little or no modified organic matrix layer covering the specimen; most tubules were visible; opened, sparse lava-like melting and a scaly surface</td>
</tr>
<tr>
<td>5</td>
<td>Little modified organic matrix layer covering the specimen; some visible and opened tubules; lava-like melting</td>
</tr>
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FIG. 2. Photomicrographs of root canal walls irradiated with 980-nm diode laser energy perpendicularly to the dentine at (A) 1.5 W/CW; (B) 1.5 W/100 Hz; (C) 3 W/CW; and (D) 3 W/100 Hz. Arrows indicate modified organic matrix and circles indicate opened dentine tubules. Arrowhead indicates a partially opened dentine tubule and the asterisk indicates a scaly surface (original magnification 1500× and 4000×).
Netherlands) operating at 20 kV. A standardized series of photomicrographs were taken at different magnifications in the scanning electron mode (SE), backscatter mode (BSE), or MIX mode. To select the representative illustrations of each group, photomicrographs were taken at 2 mm, 8 mm, and 15 mm from the apex representing the apical, middle, and cervical regions, respectively.

The photographs were evaluated in a double-blind study by three examiners who were previously calibrated by one of this paper’s authors who did not participate in the taking of or the examination of the photomicrographs. To guide examiners during morphological and ultrastructural analyses, scores were established based on the dentine characteristics of the non-irradiated group (Fig. 1), and the ultrastructural changes found for the perpendicularly irradiated group (Fig. 2 and Table 1).

Statistical analyses were performed using the Mann-Whitney and Kruskal-Wallis tests and a value of $p < 0.05$ was considered significant.

### Results

Scores attributed to the specimen photomicrographs obtained for the analysis of the parallel irradiation are reported in Table 2. Photomicrographs showing these results are represented in Fig. 3.

Statistical analysis with the Mann-Whitney test showed more intense results for perpendicular irradiation ($p < 0.01$) than for parallel irradiation.

The Kruskal-Wallis test showed no statistically significant difference between the different parts of the root canal (cervical, middle, and apical), and significant differences between the different parameters ($p < 0.01$) for parallel irradiation, except between groups 1 (1.5 W/CW) and 5 (3 W/100 Hz; $p > 0.05$).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Score 1.5 W/CW</th>
<th>1.5 W/100 Hz</th>
<th>3 W/CW</th>
<th>3 W/100 Hz</th>
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<tr>
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<td>5</td>
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See Table 1 for definition of the scores.

[FIG. 3. Photomicrographs of root canal walls irradiated with 980-nm diode laser energy parallel to the dentine at (A) 1.5 W/CW; (B) 1.5 W/100 Hz; (C) 3 W/CW; and (D) 3 W/100 Hz. Arrows indicate modified organic matrix and the circle indicates opened dentine tubules. The arrowhead indicates partially opened dentine tubules (original magnification 1500×).]
Discussion

There are still very few studies in the literature that address the new 980-nm wavelength diode laser, hence the present study evaluated the morphological alterations produced by irradiation of root canal walls by the 980-nm diode laser in two circumstances: a hypothetical situation in which the laser beam strikes the surface at a perpendicular angle, in order to determine the maximum effects of this laser on the dentine walls and guide examiners during evaluation; and in a situation seen in clinical practice, in which the laser is delivered through an optic fiber inside the root canal (parallel irradiation). Scanning electron microscope analysis was used to verify ultrastructural changes of the irradiated dentine because it allows qualitative and quantitative evaluation of the morphological aspects. The results were analyzed by three double-blind calibrated examiners to guarantee the fidelity of the results.

In contrast to Wang et al.,12 who irrigated the root canals during biomechanical preparation with 5% NaOCl and 3% hydrogen peroxide, in our study endodontic treatment was performed solely with water as an irrigant because water is unlikely to induce changes in the chemical or mechanical properties of the root canal dentine and smear layer,13 and thus only the morphological changes induced by laser irradiation of the dentine structure would be observed. According to a recent study of Marending et al.,17 when using NaOCl, there is severe alteration of the peripheral dentine matrix, reduction of elastic modulus and flexural strength, and altered intertubular dentine permeability due to the dissolution of organic dentine components. Therefore the use of any chemically active irrigant may produce false results.

Our results show that when 980-nm diode laser energy was applied parallel to the root canal walls, the morphological changes induced varied according to the laser parameters used: no significant changes were seen for 1.5 W/100 Hz, a modified organic matrix layer with an amorphous form and tubule visibility were seen for 1.5 W/CW and 3 W/100 Hz, and sparse lava-like formations with opened tubules were seen for 3 W/CW. Removal of the smear layer is an important step in the process of root canal therapy, because the smear layer occludes the dentinal tubules, and as reported by Shahravan et al.,18 the smear layer may also harbor bacteria and bacterial products. The slight alterations seen on the dentine surfaces in the parallel-irradiated groups can probably be explained by the comment by Schoop et al.,1 who wrote “in contrast to higher wavelengths like those of the Er:YAG and the Er,Cr:YSGG lasers, the radiation of diode lasers is poorly absorbed by hard dental tissues themselves and thus allows propagation, scattering, or diffused transmission of the laser light through dentin.”

Our results also showed that there was a significant loss of efficacy for parallel irradiation compared to perpendicular irradiation. This limitation is found in most lasers used to enhance root canal therapy.3 Since an optical fiber is used to deliver the laser energy inside the root canal, irradiation is limited to the fiber tip, and little or no energy is dispersed laterally. Part of the absorbed energy might have been dissipated along the canal, producing uneven dispersal of energy throughout the root canal. Thus, the affected areas of the root canal dentine appear to be inconsistent and discontinuous. Although alternative delivery systems are being tested,19–21 they are not currently available. Thus only the findings of the parallel-irradiated samples were subjected to statistical analysis because they more closely reflect what would occur in an actual clinical situation.

The similar morphological changes found for the 1.5 W/CW group (parameters established by the manufacturer) and the 3 W/100 Hz group suggest that further studies to assess the temperature changes seen with these parameters should be performed before conclusive statements are made. Ever since the findings of Moritz et al.,22 it has been well known that the duration of laser exposure and pauses during the application of laser treatment of root canals are important to allow cooling of the surface and to less temperature increase. Excessively high temperatures in the root canal may injure the periodontal ligament.

Understanding the physics, emission characteristics, and ultrastructural changes that the available wavelengths induce in intracanal dentine is important in aiding the dental professional in selecting the proper laser device to fulfill the needs of each clinical situation encountered during root canal therapy, and thereby improve outcomes.

Conclusion

It can be concluded that 980-nm diode laser irradiation of root canal dentine induced similar morphological changes in dentine at the parameters of 1.5 W/CW and 3 W/100 Hz. The changes seen for all the studied laser parameters ranged from smear layer removal to dentine fusion.

References


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