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BRIEF REPORT

Comparison of dentin root canal permeability and morphology after irradiation with Nd:YAG, Er:YAG, and diode lasers

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Abstract The aim of this study was to compare the effects of Nd:YAG, Er:YAG, and diode lasers on the morphology and permeability of root canal walls. The three laser wavelengths mentioned interact differently with dentin and therefore it is possible that the permeability changes caused will determine different indications during endodontic treatment. Twenty-eight human single-rooted teeth were instrumented up to ISO 40 and divided into four groups: group C, control (GC), non-laser irradiated; group N (GN), irradiated with Nd:YAG laser; group E (GE), with Er:YAG laser and group D (GD) with diode laser. After that, the roots were filled with a 2% methylene blue dye, divided into two halves and then photographed. The images were analyzed using Image J software and the percentage of dye penetration in the cervical, middle, and apical root thirds were calculated. Additional scanning electron microscopy (SEM) analyses were also performed. The analysis of variance (ANOVA) showed significant permeability differences between all groups in the middle and cervical thirds ($p<0.05$). The Tukey test showed that in the cervical third, GN presented means of dye penetration statistically significantly lower than all of the other groups. In the middle third, GE and GD showed statistically higher dye penetration means than GC and GN. SEM analysis showed melted surfaces for GN, clean wall surfaces with open dentinal tubules for GE, and mostly obliterated dentinal tubules for GD. Er:YAG (2,094 nm) laser and diode laser (808 nm) root canal irradiation increase dentinal permeability and Nd:YAG (1,064 nm) laser decreases dentin permeability, within the studied parameters.

Keywords Endodontics · Root canal dentin · Laser dentistry · Morphology · Ultrastructure

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Introduction

The adequate cleaning of the root canal is based on the removal of organic and inorganic debris, followed by proper filling in order to seal it off from the surrounding oral tissues. A number of studies have demonstrated that the conventional technique of root canal preparation produces a considerable amount of smear layer and remaining pulp tissue that can be deposited on the dentinal walls and obliterate the dentinal tubules [1]. It thus reduces dentinal permeability and hinders penetration of intracanal medicaments into dentin, even when chemical irrigation is used in conjunction with mechanical instrumentation [2].

Over the last few years, many researchers have investigated the potential application of different types of lasers in endodontic therapy. Laser irradiation in the root canal is capable of vaporizing soft tissue, fusing, or glazing hard tissue and eliminating microorganisms [3–10]. In the endodontic field, up to now the ability of the lasers to decontaminate the root canal walls has been the most investigated one [11–14]. Nevertheless, as different wavelengths promote different tissue interactions, not only the effectiveness of decontamination but also the alterations in root canal morphology and permeability are important for determining a correct indication. As these two topics have not yet been clarified in the literature, the purpose of this pilot study was to evaluate in vitro the effect of Nd:YAG, Er:YAG, and diode lasers on dentin root canal wall permeability and morphology.

Materials and methods

This study was conducted after approval from the Ethics Committee of the University of São Paulo, Brazil (Protocol # 158/2008). Twenty-eight extracted human single-rooted teeth were used in this pilot study. Chemical-surgical preparation was carried out 1 mm short of the apical foramen using K-files up to ISO 40 and sodium hypochlorite 1%. After this, the teeth were randomly divided into four groups of four teeth each, according to the type of laser used.

Laser irradiation

The laser devices used are described below and a complete description of the laser parameters is given in Table 1. All irradiations were performed without water cooling and root canals were dried with sterile paper points before irradiation.

Group C: non-irradiated (control)

Group E: specimens were irradiated with an Er:YAG laser; Key-laser II, (KaVo, Germany); using a 50/28 fiber (470 μm in diameter) with the handpiece number 2055.

Group N: specimens were irradiated with an Nd:YAG laser; Pulse master 1000 IQ (American Dental Technologies, USA) using a 320-μm fiber.

Group D: specimens were irradiated with a diode laser (ZAP Lasers, USA), using a 200-μm fiber in continuous-wave mode operation.

Irrespective of the type of laser, irradiation was delivered by introducing the fiber-optic cable along the entire length of the root canal, irradiating all along the dentin wall from the apical to cervical region, with helicoidal movements at a speed of 2 mm per second, according to the methodology of Gutknecht et al. [13]. This procedure was repeated three times and the samples were kept at room temperature for 20 s between each irradiation, to prevent the temperature rise from exceeding the accepted allowance [15, 16].

Permeability test

After sealing the apical foramina with utility wax, the teeth had their crowns sectioned at the enamel-cementum limit and the roots were made impermeable externally with ethyl cyanoacrylate.

The specimens were filled with 2% methylene blue dye with the aid of an insulin injection syringe [17]. After concluding this stage, they were kept in a relative humidity chamber containing cotton wool and distilled water for 24 h, so that total dye penetration occurred. When this time had elapsed, they were rinsed under running water, the root canals were dried with absorbent paper cones, and the samples were sectioned longitudinally to measure the dye penetration along the root canal length (Fig. 1).

Evaluation method

Both of the halves were photographed with a digital camera (D70, Nikon, Japan) at 6-Megapixel resolution and the images were divided into three parts: cervical, middle, and apical, using the Adobe Photoshop (6.0 version) software. For the permeability evaluation, the software Image J (version 1.41, NIH, USA) was used. The total area and the dye-penetrated area of the two root halves of each root third were measured using the analyze tool of the software and were expressed in square pixels. The values obtained from both halves were summed to give the final values of

Table 1 Description of the irradiation parameters in each group

Group	Wavelength (nm)	Pulse duration (μs)	Pulse energy (mJ)	Frequency (Hz)	Power (W)	Energy density (J/cm^2)
(GC) Control	-	-	-	-	-	-
(GE) Er:YAG	2,940	150–250	100	15	1.5	26.5
(GN) Nd:YAG	1,064	100	100	15	1.5	124.3
(GD) Diode	808	c.w.	250	c.w.	2.5	———

* Energy density values at the end of the fiber. The power emitted at the end of the fiber was measured with a power meter (Fieldmaster, Coherent Inc., USA)

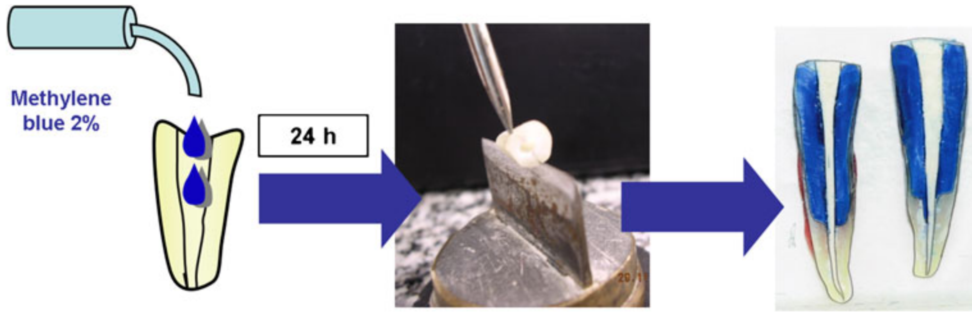

Fig. 1 Experimental sequence. **a** Methylene blue 2% application. **b** Longitudinal section of the roots. **c** Pictures of the two root halves obtained showing penetration of the dye mostly in the middle and cervical thirds

each specimen (Fig. 2). The dye-penetrated area was then multiplied by 100% and divided by the root third area, resulting in the percentage of dye penetration in each root third (Eq. 1). The dye-penetration analysis was performed by an investigator blind to the study groups.

$$\text{Percentage dye penetration in root canal} = \frac{\text{dye} - \text{penetrated area} \times 100\%}{\text{total root third area}} \quad (1)$$

SEM investigation

Additionally, morphological investigation was performed using 12 samples prepared in the same way as described above. After laser irradiation, they were split longitudinally into two halves, dehydrated with a graded series of ethanol, gold sputtered, mounted on metal stubs, and observed by a scanning electronic microscope (Jeol 6100, Jeol Ltd, Japan).

Results

The analysis of variance (ANOVA) demonstrated that there were significant differences among all groups in the middle and in the cervical root thirds ($p<0.05$) and that there were no differences in the apical third. The post-hoc Tukey test showed that in the cervical third, GN (Nd:YAG) had lower dye penetration means with statistical significance, when compared to the others, and in the middle third, GD (Diode) and GE (Er:YAG) showed higher dye penetration means with statistical significance, when compared to GN (Nd:

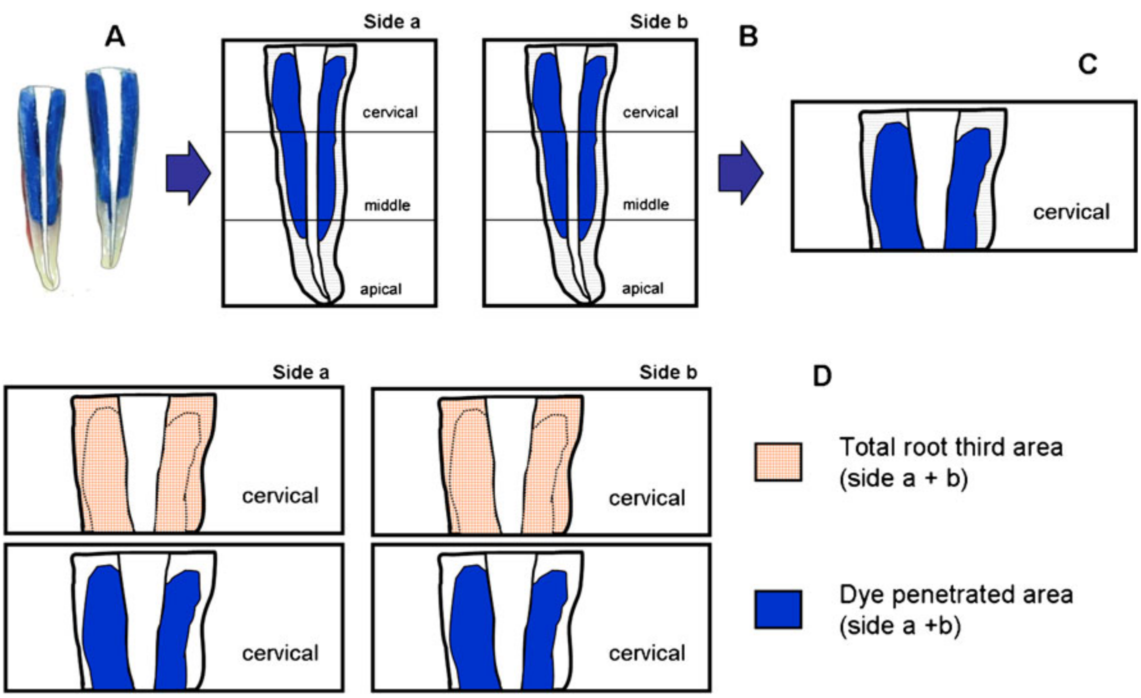

Fig. 2 Description of the measurement process. **a** Image of a dye-penetrated root canal longitudinally spited. **b** Schematic illustration showing the division of the two halves (sides a and b) into three thirds. **c** Example of the image of cervical third. **d** Analysis of the total area and the dye-penetrated area of the images obtained from the cervical third of both root halves. The areas were measured using Image J software and for each sample the total values were obtained by summing the values obtained in each half. Percentage of dye penetration was calculated in relation to the total root third area

Table 2 Means of percentage of dye penetration and standard deviations (SD) in each group for each of the three root thirds

	Control		Er:YAG		Nd:YAG		Diode	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cervical third	70.2%	13.9	83.0%	20.9	36.0%[a]	15.6	56.8%	11.8
Middle third	61.9%	20.4	82.6%[a]	5.0	56.0%	17.2	82.5%[a]	16.4
Apical third	7.7%	13.0	25.0%	11.2	20.7%	17.8	19.2%	12.7

[a] Statistically significant difference between the groups in each root third

YAG) and GC (control). Means and standard deviations are shown in Table 2 and the results of the morphological analysis are presented in Fig. 3.

Discussion

The results of this study showed that among the three wavelengths studied, Er:YAG showed the highest increase in dentin permeability. This finding was confirmed by the micromorphological analysis that showed the dentinal smear layer had been removed and dentinal tubules were wide open after irradiation with this laser. The other two lasers studied, the Nd:YAG and the diode, presented low permeability means, but the lowest was caused by the Nd:YAG. Especially in the cervical and middle thirds Nd:YAG means were even statistically significant lower than the control.

The increase of permeability yielded by Er:YAG laser could be of benefit by allowing a free passage of medications and solutions through the dentinal tubules, promoting a more effective cleanliness and disinfection. On

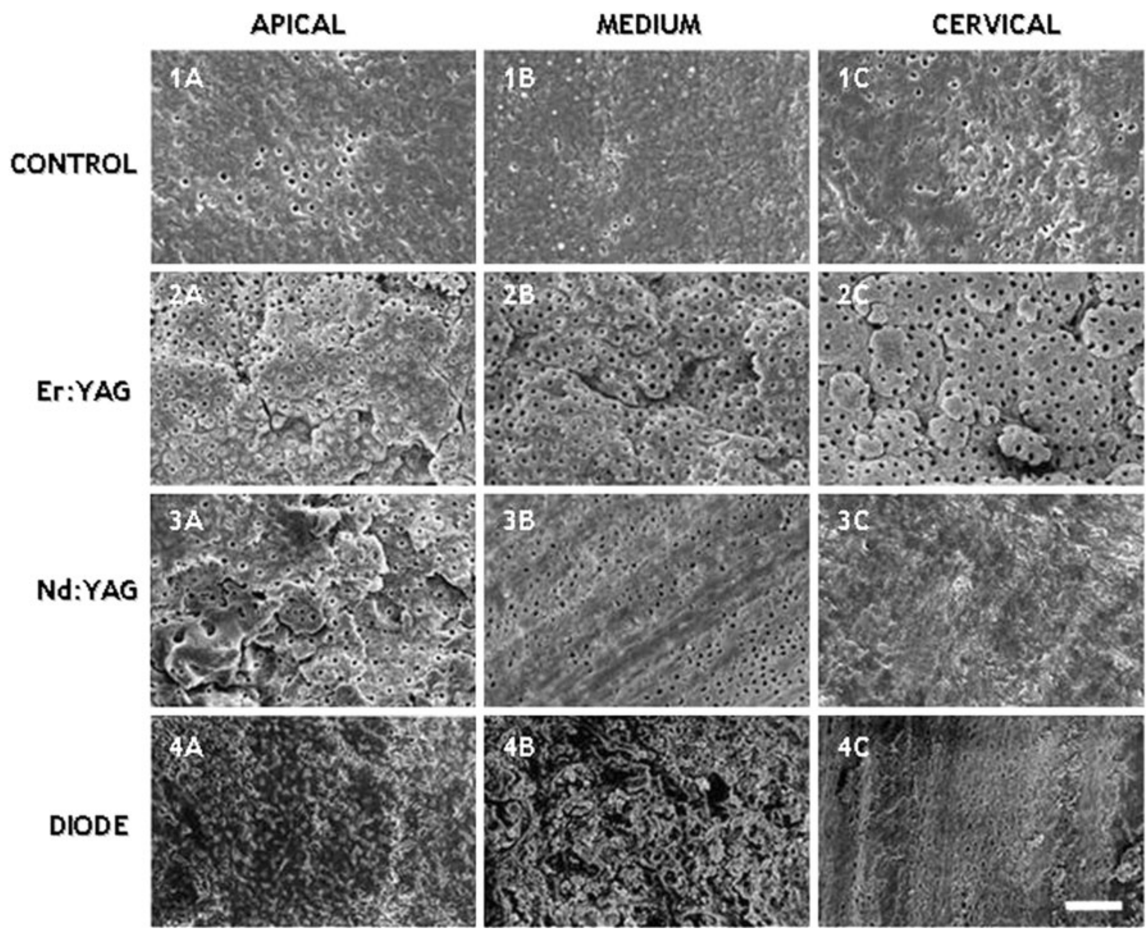

Fig. 3 Scanning electron micrographs showing morphological characteristics representatives from all experimental groups divided into the three thirds (cervical, middle, and apical). **1a, 1b, 1c** Micrographs of the control group (GC) showing presence of smear layer and obliterated dentinal tubules entrance. **2a, 2b, 2c** Er:YAG group (GE) showing removed dentinal smear layer and widely opened dentinal tubules. **3a, 3b, 3c** Nd:YAG group (GN), showing surfaces with melting and recrystallization areas. **4a, 4b, 4c**. Diode laser group (GD) showing presence of smear layer and mostly obliterated dentinal tubules. Original magnification was 1000 X

the other hand, the decrease in permeability produced by Nd:YAG and the diode lasers would be interesting at the end of treatment, by promoting almost complete occlusion of dentinal tubules before root canal filling.

Our findings as regards Er:YAG and Nd:YAG lasers match those of Takeda et al. [18] in which the Er:YAG laser produced root canal surfaces free of the smear layer and with evident dentinal tubules, while all the root canal surfaces irradiated with a Nd:YAG laser presented melted, fused, and recrystallized aspects. The present diode laser results are in accordance with Costa Ribeiro et al. [16] which showed in the diode-laser-treated group (λ=810 nm) signs of fusion and partially opened dentinal tubules. Nevertheless, opposite results were observed by Wang et al. (2005) [19] after irradiation with a 980-nm diode laser (GaAlAs) with two times more power than in the present study. It must be observed that this higher smear layer removal was also accompanied by a mean temperature increase of 8°C at the root surface and with the conditions used in our study only 3.3°C temperature increase has been observed [16]. Considering that a temperature increase of 10°C can cause damage to the surrounding tissues [20], being far from this threshold increases the safety of the therapy.

The observed morphological changes promoted in the root canal walls by the different lasers are supported by the biophysical interaction principles. As dentin contains 47% of mineral matrix, 33% of organic matrix and 20% of water, by volume, the most effective interaction between the three lasers tested occurs with the 2,940 nm. The Er:YAG wavelength is highly absorbed in water (800 cm^{-1}), and therefore tissue removal through thermo-mechanical ablation may occur [21, 22]. On the contrary, the two other wavelengths (λ=1,064 and 810 nm) are neither well absorbed in water nor in the mineral matrix and on top of it, in the interaction with dentin, scattering is more predominant than absorption [23]. Therefore deeper penetration in the tissue can be expected and rather thermal effects, like melting and fusion, than removal of smear layer are observed with these two lasers.

As dentinal tubules are the major channels for fluid flow across the dentin and the bacteria adhered to the canal walls are often not affected by conventional chemo-mechanical instrumentation, the increase in dentin permeability may facilitate the penetration of chemical solutions and improve the treatment success rate. Thus, the increase in dentin permeability promoted by Er:YAG laser is of interest before the application of root canal medication, due to the possibility of increasing its effectiveness. On the other hand, before final canal filling, and in cases in which one-visit endodontic treatment is planned, irradiation with a Nd:YAG laser seems to be more interesting. The irradiation produces a melted surface and decreases dentin permeability, which can reduce bacterial penetration into the canal space or into the canal wall after filling [24].

Finally, it is important to say that all the lasers studied have been reported to have a high potential for eliminating *Enterococcus faecalis* and other microorganisms from the main root canal walls [11–13, 25]. Nevertheless, among them, only the Nd:YAG laser can achieve a high degree of decontamination, even in deeper dentin layers (far from the main canal). Therefore, considering that none of the lasers tested were able to increase permeability in the apical root third, in the case of teeth already presenting periapical lesions, the Nd:YAG seems to be more indicated.

Conclusions

Based on the results of this pilot study, it can be concluded that in the cervical and middle root thirds:

- Er:YAG laser at 1.5 W and 15 Hz and diode laser at 2.5 W (c.w.) are useful for increasing dentin permeability.
- Nd:YAG laser at 1.5 W and 15 Hz is useful for decreasing dentin permeability.
- The three types of laser appear to have interesting applications as adjuvant to endodontic treatment.

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