Morphological Analysis of Root Canal Walls After Er:YAG and Nd:YAG Laser Irradiation: A Preliminary SEM Investigation

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Purpose: To evaluate the effect of laser irradiation (Nd:YAG and Er:YAG) after conventional endodontic treatment on the cleaness of root canal walls.

Materials and Methods: The roots of 9 extracted single-rooted human teeth were conventionally prepared and randomly divided into 3 groups (n = 3 per group): 1. control, not irradiated; 2. Nd:YAG laser irradiation (100 mJ; 1.5 W; 15 Hz, 124.4 J/cm^2); 3. Er:YAG laser irradiation (120 mJ, 15 Hz, 1.8 W, 108.7 J/cm^2). The teeth were irradiated 3 times with rotational movements in the apical-coronal direction, at a speed of 2 mm of root canal per second. The teeth were bisected longitudinally and prepared for scanning electron microscopy (SEM).

Results: Independent of the experimental group, both clean and smear-layer-covered areas were observed in the same sample and the same root canal third. The samples treated with Er:YAG laser mostly presented clean areas. The Nd:YAG laser apparently removed less smear layer than the Er:YAG laser, and left areas completely covered by debris and smear layer. The control root canal walls predominantly exhibited areas covered by smear layer.

Conclusion: Complete cleaning of root canal walls with Nd:YAG and Er:YAG laser radiation with the power settings used here was not possible. Although the cleaning capacity of laser could improve conventional endodontic treatment, there is still a need to develop devices which can irradiate root canal walls in their entirety.

Key words: Er:YAG laser, Nd:YAG laser, root canal, scanning electron microscopy.

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The success of endodontic treatment depends on the comprehensive cleaning and decontamination of the root canal system.[1] However, many studies have demonstrated that canal preparation techniques produce a considerable amount of smear layer, remaining pulp tissue, and inorganic dentin debris.[1,2] This smear layer is responsible for the leakage between the canal walls and the filling material after root canal obturation. Until now, endodontic treatment has been based on the use of chemical irrigating solutions in conjunction with mechanical instrumentation to remove smear layer. However, endodontic treatment is sometimes still unsuccessful.[1,3-5] For this reason, researchers are looking for new techniques to shape and clean the dentin walls completely.

Laser applications have been investigated in several areas in dentistry since the ruby laser was developed by Maiman.[6] The potential application of lasers in endodontology has been explored by a number of investigators.[7-12] The Nd:YAG laser[13-16] and the Er:YAG laser

[1,17-19] have been introduced as complementary tools in root canal preparation, because they are able to efficiently remove debris or smear layer. Additionally, these lasers have considerable antibacterial activity.[8,20-23] The aim of this study was to evaluate the effect of laser irradiation (Nd:YAG and Er:YAG) after conventional endodontic treatment on the cleaness of root canal walls in their entirety.

MATERIALS AND METHODS

Sample Preparation

After the approval of the Ethics Committee of the University of Sao Paulo, 9 freshly extracted single-rooted human teeth were used. The teeth were cleaned by removing all visible calculus and by root planing with a Gracey curette. The working length was determined by radiographs, 1.0 mm from the apical foramen.

The root canal was cleaned and shaped up to an ISO #40 K-file according to the working length. The cervical and middle thirds of all canals were debrided with Gates-Glidden drills (Takanazawa, Japan) to standardize access to the middle and apical thirds of the canals. Copious irrigation with 0.5% NaOCl solution was alternately performed between each file and the Gates-Glidden drills. The root canals were then dried with paper points.

Experimental Groups and Laser Irradiation

After the endodontic procedures, the teeth were randomly divided into 3 groups (n = 3 each) as follows:

- Group 1 (control): no additional treatment
- Group 2: The teeth were irradiated with Nd:YAG laser (Pulse Master 1000 IQ; American Dental Technologies, Corpus Christi, TX, USA), 1.064 μm wavelength, 100 ms pulse width, through an optic fiber of 320 μm diameter. The parameters used were: 100 mJ, 1.5 W, 15 Hz and energy density of 124.4 J/cm^2. Each canal was irradiated 3 times with 10 s intervals. The irradiations (2 mm of root canal per second) were performed with rotational movements in the apical-coronal direction.[9]
- Group 3: The teeth were irradiated with Er:YAG laser (Key-Laser 3, [1243]; KaVo, Biberach, Germany), 2.940 μm wavelength, 250 ms pulse width, through handpiece number 2062, with an optic fiber of 375 μm diameter under air cooling. The parameters used were: 120 mJ, 15 Hz, 1.8 W and an energy density of 108.7 J/cm^2. Each canal was irradiated 3 times with 10 s intervals. The irradiations (2 mm of root canal per second) were performed with rotational movements in the apical-coronal direction according to manufacturer's instructions.

Scanning Electron Microscopy

The root canal walls were analyzed by scanning electron microscopy. After treatment, the teeth were fixed in 2.5% glutaraldehyde in 0.1 M phosphate buffer for 24 h at room temperature. The crown was separated from the root with a steel disk; for this reason the root canal entrance was plugged with wax to protect the canal walls from the debris produced by the disk. Then the root was bisected longitudinally using a custom-made morse. The specimens were dehydrated in ascending grades of ethanol and submitted to chemical drying in hexamethyl disilazane (HMDS) (Electron Microscopy Sciences, Fort Washington, PA, USA). Specimens were then sputter coated with gold (Sputtering SCD050, Bal-Tec, Balzers, Liechtenstein). Scanning electron microscopy was carried out with a LEO scanning electron microscope (Leo, Cambridge, UK). Electron micrographs were taken from the three thirds of the root canal walls of each tooth (n = 18 per experimental group) at 1000X magnification.

RESULTS

Independent of the experimental group, both clean and smear-layer-covered areas could be observed in the same sample and the same root canal third. Conventionally treated root canal dentin served as the control (Group1) (Fig 1). These samples mostly presented surfaces either totally or partially covered by smear layer (Figs 1A, B, D, F). The areas with smear layer were most commonly located in the apical third of the root canal (Fig 1B). Clean areas were also observed, but with less frequency (Figs 1C, E). These areas showed dentinal tubules intermingled with smear layer (Fig 1A) or open dentinal tubules (Figs 1C, E).

The root canal surfaces of teeth treated with Nd:YAG laser (Group 2) are illustrated in Fig 2. In some areas, these surfaces presented the typical morphology of melted dentin with both globular and glassy appearances (Fig 2A). These areas were free of smear layer and presented open dentinal tubules interspersed with areas covered by melted mineral globules having a

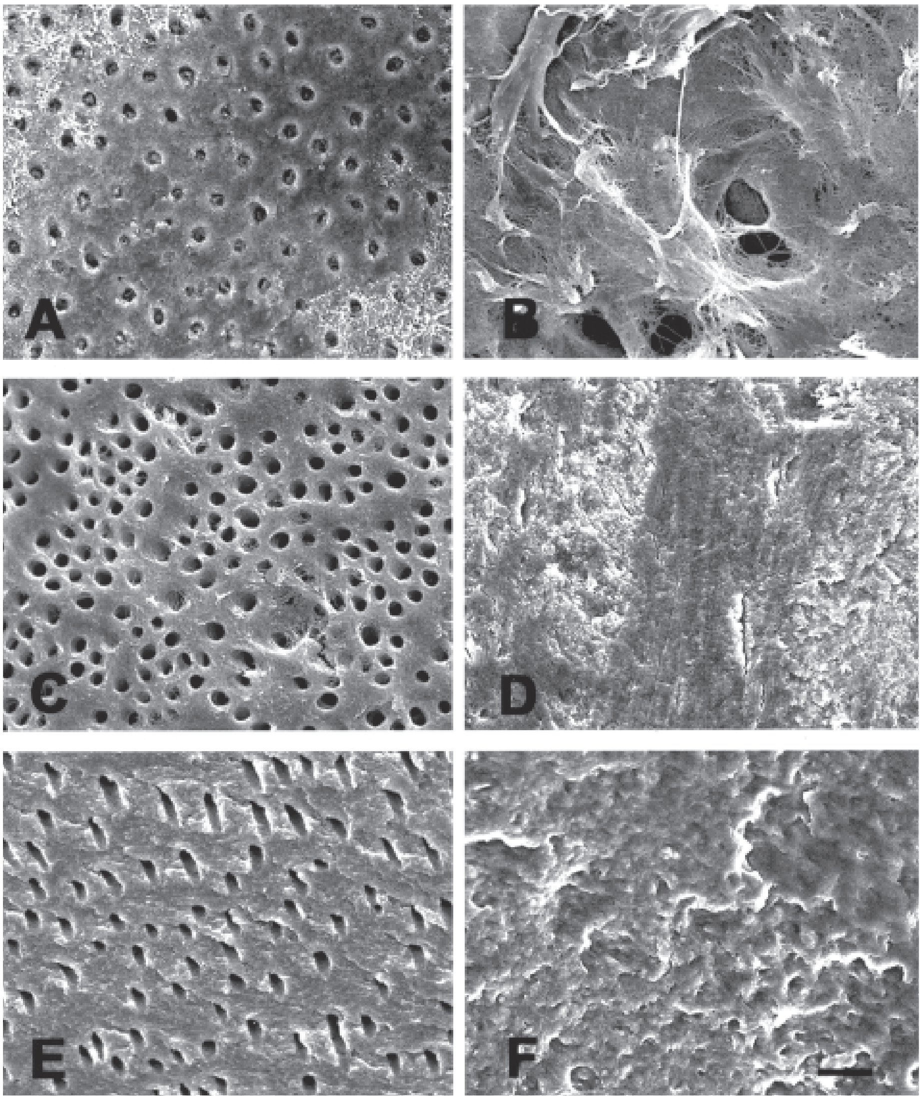

Fig 1 Scanning electronmicrographs of root canal dentin from control samples. The apical third of the root canal is represented by A and B images. The middle third is represented by C and D and the cervical third by E and F. Observe that the same third simultaneously depicts clean (A, C and E) and debris-covered (B, D and F) areas. The clean areas show little to no smear layer, and open dentinal tubules, whereas the noncleaned areas consist of variable quantities of organic material, eg, collagen fibers, or smear layer (bar = 10 µm; original magnification 1000X).

cracked appearance, and dentinal tubules sealed by fusion of dentin and deposits of mineral components on root canal walls (Fig 2A). Other clean areas were observed on different areas of the root canal wall (Figs 2C, E). These areas were characterized by open dentinal tubules, either free of smear layer (Fig 2C) or partially covered by smear layer (Fig 2E). Areas fully covered by smear layer could be observed in all three thirds of the root canal (Figs 2B, D, F). In the apical third, this smear layer was more often seen than in the other thirds of the root canal (Fig 2B).

The samples treated with Er:YAG laser mostly showed clean areas in all root canal thirds (Figs 3A, C, D, E). These areas were characterized by open dentinal tubules in a globular arrangement of the dentin surface. Other areas presented partial smear layer with open tubules (Fig 3D) or heavy smear layer, which closed the dentinal tubules completely (Figs 3B, F).

DISCUSSION

Successful endodontology relies to a great extent on complete cleaning of the root canal. Infected dentin and pulpal tissue can endanger therapy outcomes. Conventional root canal treatment aims at the removal of the infected pulp and dentin layers using mechanical techniques and bactericidal irrigants. Several studies indicate that these techniques are only partially successful.[1,3-5] Thus, there is a constant search for comple-

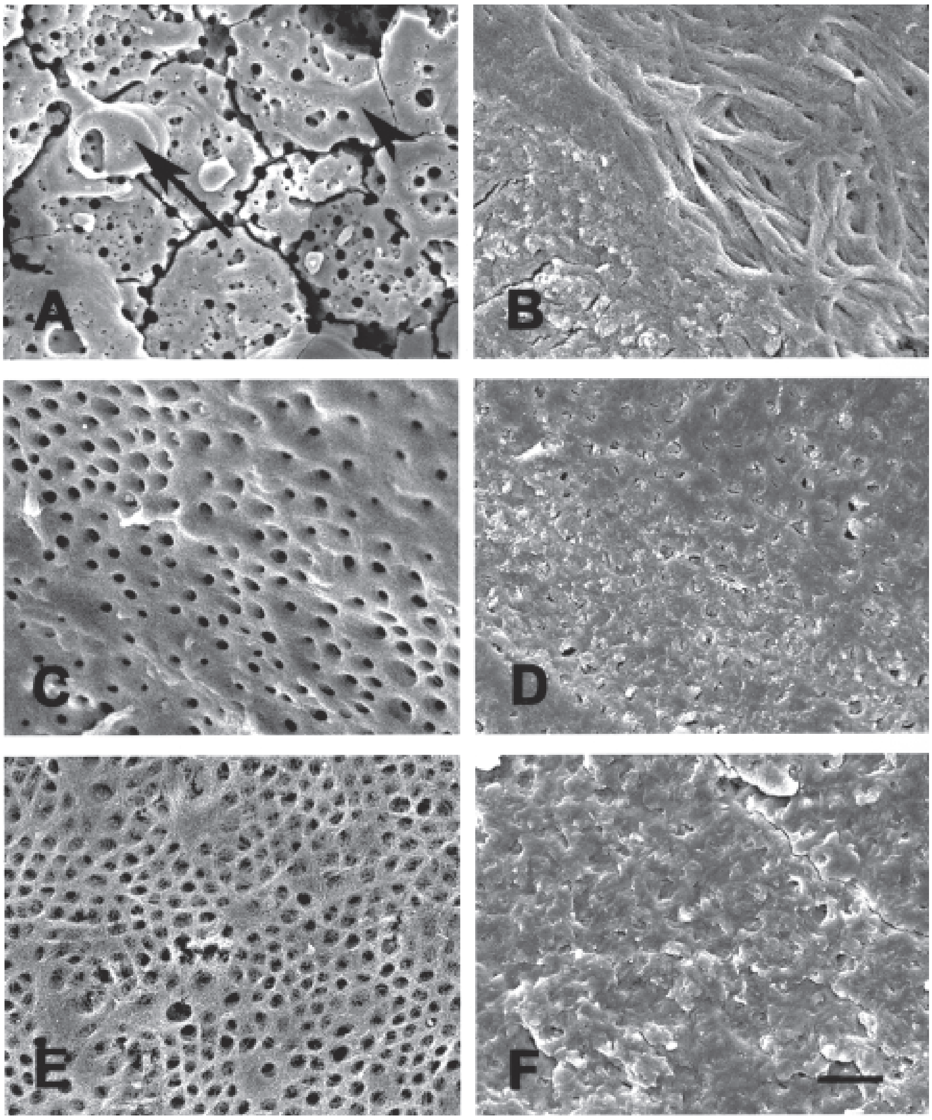

Fig 2 Scanning electronmicrographs of root canal dentin of samples treated by Nd:YAG laser. The apical third of the root canal is represented by A and B images. The middle third is represented by C and D and the cervical third by E and F. Observe that the same third simultaneously depicts clean (A, C and E) and noncleaned (B, D and F) areas. The typical morphology of melted dentin with both globular (arrows) and glassy surfaces (arrowheads) can be observed (A). Other clean areas show either open dentinal tubules (C) or open tubules intermingled with variable amounts of smear layer (E) (bar = 10 µm; original magnification 1000X).

mentary procedures to conventional root canal treatment in order to improve dentin wall cleaning. The properties of high intensity lasers made them a logical choice for this purpose.

Er:YAG and Nd:YAG lasers were chosen for the present study because, among other reasons, they have an antibacterial effect in vitro against several bacteria. For instance, Nd:YAG laser is effective against Enterococcus faecalis, Escherichia coli,[8,21] Streptococcus aureus,[23] Streptococcus sanguis, Prevotella intermedia,[22] and Streptococcus mutans,[20] and Er:YAG laser is effective against Escherichia coli, Streptococcus aureus,[23] Prevotella buccae, Peptostreptococcus micros, and Porphyromonas assacharolyticus.[17]

The samples treated with the Er:YAG laser mostly presented clean areas, whereas the control root canal walls predominantly exhibited areas covered by smear layer. These results can be explained by the absorption of the Er:YAG laser wavelength in water and hydroxyapatite. Emitting at 2,940 nm, this laser acts through photoablation, so that water contained in dental hard tissue evaporates instantaneously and thereby ablates the surrounding tissue with minimal thermal side effects.[24]

It is already known that the Er:YAG laser is effective in removing debris and smear layer from root canal walls.[1] However, some dentin walls were still covered by smear layer. This means that the optical fiber did

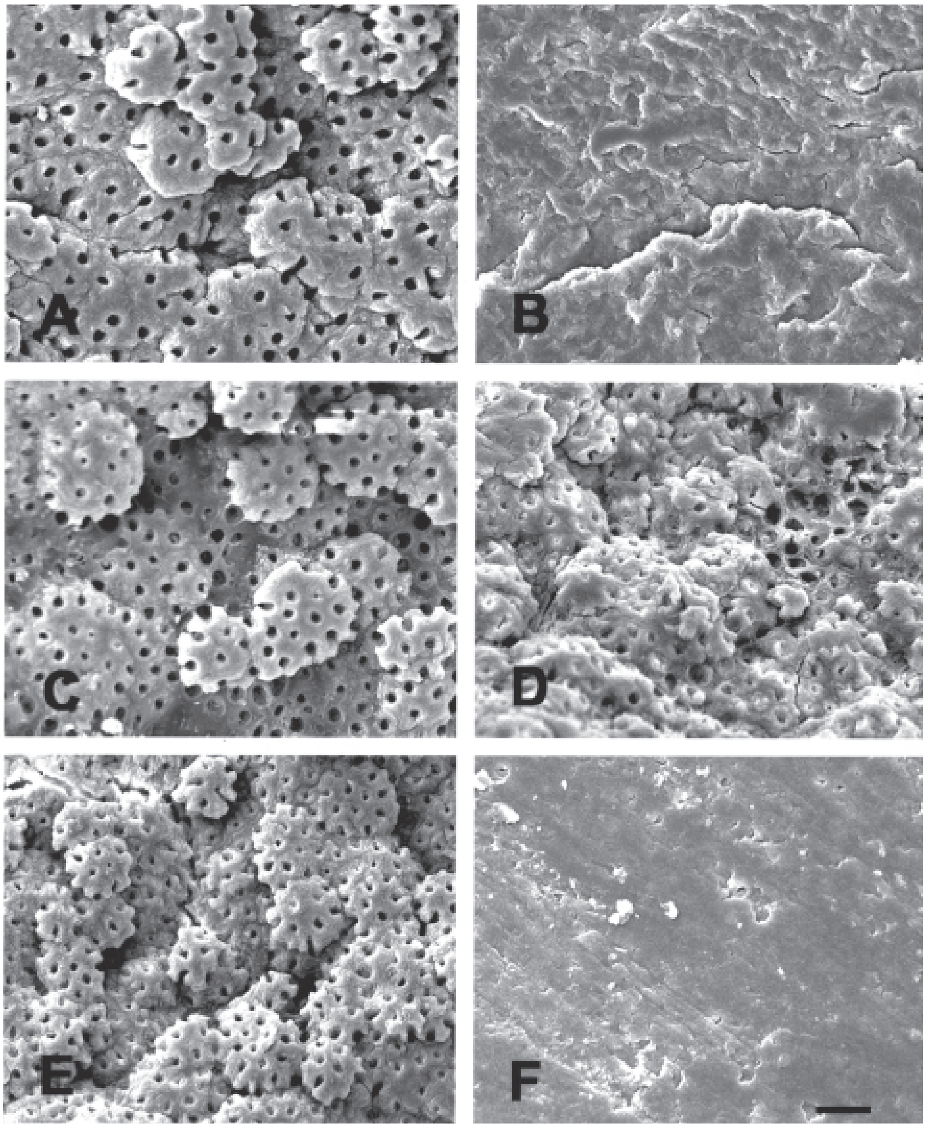

Fig 3 Scanning electron micrograph of root canal dentin of samples treated by Er:YAG laser. The apical third of the root canal is represented by A and B images. The middle third is represented by C and D and the cervical third by E and F. Observe that the same third simultaneously depicts clean (A, C and E) and noncleaned (B, D and F) areas. The clean areas are always free of smear layer showing open dentinal tubules in a globular surface (A, C and E) (bar = 10 µm; original magnification 1000X).

not reach all the surfaces of the root canal walls. Results similar to those obtained with the Er:YAG laser were also observed using the Nd:YAG laser. This laser apparently removed less smear layer than the Er:YAG laser, and also left areas completely covered by debris and smear layer. In agreement with our results on the cleanliness of root canal walls after Er:YAG laser application, Takeda et al[19] also found that Er:YAG laser irradiation was the most effective in removing the smear layer from the prepared root canal walls in vitro when compared with the effectiveness of argon and Nd:YAG laser.

Laser irradiation of one specific wavelength produces different effects on the same tissue at different parameters, and the same laser wavelength can produce varying effects in different tissues.[13] In the present study, melted areas were observed in the Nd:YAG laser group using 1.5 W and 10 Hz, similar to the findings of Gutknecht[11,12] and Harashima,[13] who stated that Nd:YAG laser causes melting of internal structures on the instrumented root canal walls at the parameters of 1.5 W, 15 Hz and 100 mJ or 2W and 20 Hz. On the other hand, the Er:YAG laser vaporized organic matrix[17,18] providing open dentinal tubules free of smear layer and debris at 1.8 W, 120 mJ and 15 Hz, similar to the results of Takeda,[1,19] who used 1 W, 100 mJ, and 10 Hz.

Morphological alterations on dentinal surfaces of treated root canals and the control group were observed through SEM. Independent of the experimental group, both clean and nonclean areas were observed on the same sample and the same root canal third. These results could be due to the laser irradiation technique used, where each canal was irradiated 3 times with rotational movements in the apical-coronal direction. The irradiation time was 2 mm of root canal per second, with 10 s intervals. These movements, although repetitive, were not enough to scan the entire root canal wall. It may be important to develop devices which can irradiate root canal walls in their entirety.

CONCLUSION

Complete cleaning of root canal walls with laser irradiation is still difficult. Although the cleaning capacity of laser improves conventional endodontic treatment, there is a need to develop devices to irradiate the root canal walls over their entire area.

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