The Photoacoustic Efficacy of an Er:YAG Laser with Radial and Stripped Tips on Root Canal Dentin Walls: An SEM Evaluation

Enrico E. DiVito, DDS, Scottsdale, Arizona, United States; Mark P. Colonna, DDS, Whitefish, Montana, United States; Giovanni Olivi, MD, DDS, University of Genoa, Rome, Italy

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Enrico E. DiVito, DDS

Mark P. Colonna, DDS

Giovanni Olivi, MD, DDS

ABSTRACT

The aim of this *in vitro* study was to investigate, by scanning electron microscopy (SEM) analysis, the debriding ability of an Er:YAG laser system equipped with a new tapered and stripped tip of 400-micron diameter and auxiliary irrigating solutions after mechanical preparation. Fifty extracted human teeth were endodontically prepared with both hand and rotary instrumentation and conventional chemical irrigation (5.25% sodium hypochlorite). Following mechanical instrumentation with irrigation, different flushing protocols were used. Group A: 20 seconds Er:YAG laser irradiation in saline solution, wet canal; Group B: 20 seconds Er:YAG laser irradiation in 17% EDTA, wet canal; Group C: 40 seconds Er:YAG laser irradiation in 17% EDTA, wet canal. Laser settings were the same for all the groups: 20 mJ, 10 Hz, 0.2 W, 50-microsecond pulse duration, and water spray off; the tip was placed stationary superior to the coronal opening of the canal. Group D: 60 seconds of saline solution irrigation without laser activation was used as control group. SEM evaluation at the apical third showed that standardized instrumentation, followed by a final Er:YAG laser irradiation in EDTA-wetted canals, resulted in more debriding and cleaning of root canal surfaces in comparison with Er:YAG laser irradiation in saline solution or saline solution alone.

INTRODUCTION

The Er:YAG laser, emitting at 2940 nm, can be a valuable tool for root canal debridement and improved pathogen reduction during endodontic treatment. The ability to successfully negotiate and remove the smear layer and bacteria continues to be a challenge for nonsurgical endodontic treatment in root canal systems. Current instrumentation techniques use both hand and ultrasonic irrigation in an attempt to debride and decontaminate the root canal system, and there are studies with conflicting results regarding the successful and/or complete removal of the smear layer, bacteria, and biofilm from inside the root canal system.[1-6] Many irrigants such as chlorhexidine, 5.25% sodium hypochlorite, 10% citric acid, and 17% ethylenediaminetetraacetic acid (EDTA) have been used, and studies have shown some variation in their ability to remove all of the microorganisms and smear layer within the intraradicular canal space,[7-10] but one report indicates that activation (by manual-dynamic, automated-dynamic, and sonic means) of those irrigants increases their effectiveness.[11]

Researchers continue to seek alternative methods to more effectively debride and penetrate into the dentinal walls of root canal systems. The Er:YAG laser system used in this study has U.S. Food and Drug Administration (FDA) clearance for debriding, cleaning, and enlarging the root canal system.[12] Many studies have evaluated the effects of lasers on root canal walls. Those laser procedures were performed with end-firing tips that were withdrawn with a helical motion in 5 to 10 seconds each cycle, beginning 1 mm from the apex. The canals were tested both dry and wet according to different protocols. Different energy outputs ranging from 75 to 100 mJ at different repetition rates were also used. With previous traditional laser techniques, the irradiated dentin showed both clean and debrided surfaces, with little to no smear layer and opened tubules. However, the surfaces treated when dry showed serious thermal damage.[13-18]

Figure 1: Stereo microscope image of root dentin surface irradiated with traditional end-firing tip in a dry canal, showing the presence of charring and ledging, expression of serious thermal damage. Er:YAG laser at 75 mJ, 15 Hz, 1.1 W, and 300-micron end-firing tip

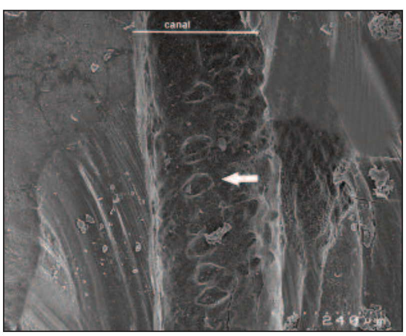


Figure 2: SEM image of the canal and surrounding dentin. The arrow indicates one of the 'hot spots' striking up the middle third of the canal walls during the withdrawal of the end-firing tip from the apex. Er:YAG laser at 75 mJ, 15 Hz, 1.1 W, 300-micron end-firing tip

The authors performed experiments using end-firing tips with similar parameters to the above studies and found that same damage as shown in Figure 1. Likewise, they also discovered ledging, apex transportation or perforation, charring, and presence of untreated surfaces (Figures 2-3). Microscopically, the typical erbium laser ablation pattern is commonly seen in traditional laser-irradiated root canal surfaces,

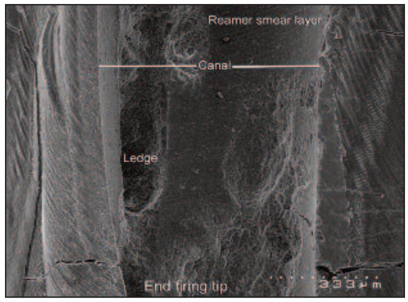


Figure 3: SEM image shows presence of little smear layer, ledging, hot spots on the dentin middle third of the root canal, all aspects of thermal ablation, in addition to areas of untreated canal surfaces. Er:YAG laser at 75 mJ, 15 Hz, 1.1 W, 300-micron end-firing tip

with more ablation in the intertubular area richer in water than in the more mineralized peritubular area (Figures 4-5). These aspects are related to the interaction of erbium laser energy with water in dentin surfaces and are closely linked to several parameters used.[19-20] A recent *in vitro* study investigated the ability of both Er:YAG and Er,Cr:YSGG (at 2780 nm) lasers equipped with conical-shaped, radially firing tips and plain tips for removing smear layer from the apical third of the root canal system.[21] The results showed a laser activation of EDTA and a better performance of conical fibers compared to plain fibers for improving the action of EDTA in dissolving smear layer. Another study confirmed the efficacy of these newly designed radial-firing tips using both erbium laser wavelengths as an additional value to the root canal treatment.[22] The results of these studies confirmed that the laser interaction on root dentin walls is dependent on energy and power used, irradiation period, pulse durations, and whether the canals where wet or dry. Tip design as well as placement and motion in the canal also showed variation in interaction with root dentin.

OBJECTIVE

The aim of this study was to investigate and evaluate the ability and

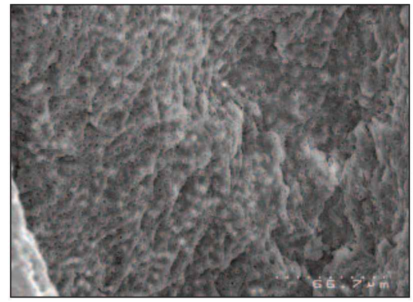


Figure 4: SEM image of the coronal 5 mm of the canal showing the typical Er:YAG laser irradiation pattern, with the classic flakey dentin surface, absence of smear layer, and aspects of more ablation in the intertubular compared to the peritubular rings of dentin. This is due to the higher water content of the intertubular dentin. Er:YAG laser at 75 mJ,15 Hz, 1.1 W, 300-micron end-firing tip

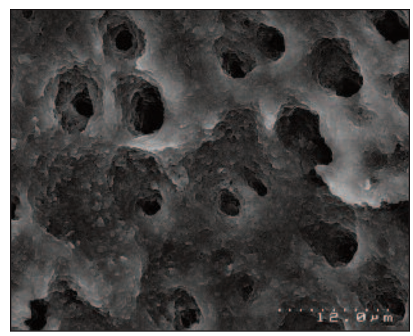


Figure 5: SEM image at higher magnification of Er:YAG laser-ablated dentin at 75 mJ, 15 Hz, 1.1 W, with 300-micron end-firing tip. The absence of visible collagen fibrils in the intertubular dentin is consistent with vaporization via photothermal energy

effectiveness of an Er:YAG laser equipped with a newly designed tapered and stripped tip to debride and remove the smear layer from the root canal dentin surfaces after traditional chemomechanical instrumentation (Figures 6-7). To reduce the thermal effects on the irradiated surface, very short pulse duration (50 microseconds) and low energy output (20 mJ at the panel display) at 10 Hz were used with irrigants in the root canal. A tapered and stripped lateral-emitting tip was used, positioned stationary superior to the canal orifice to minimize the above-cited collateral damages seen in the canals with the end-firing tips.

MATERIALS AND METHODS

Sample Preparation

Fifty (50) freshly extracted premolar teeth, stored in saline solution at 21°C, were used for this study.

Root Canal Treatment

Traditional mechanical techniques were used to open the access cavities and to expose the pulp chambers and canals. The teeth were then instrumented with two different methods:

- Twenty-five teeth were prepared to size #30 at the apex by using a K-File #30 hand file (Lexicon™, DENTSPLY Tulsa Dental, Tulsa, Okla., USA).
- The remaining 25 teeth were prepared to size #30 at the apex by using NiTi rotary instrumentation (Profile® GT™, Dentsply Tulsa Dental), size 30/06.

Irrigation of all the samples during preparation was accomplished using a combination of 2 ml root canal conditioner containing EDTA and carbamide peroxide (ProLube®, Dentsply Tulsa Dental), 2 ml of 5.5% sodium hypochlorite solution, and 2 ml of 17% EDTA. Each was introduced into the canal in the aforementioned order using a dual-ported 27-gauge needle (Appli-Vac™ and Vista-Probe™ irrigating tips, Vista Dental Products, Racine, Wis., USA) in a sterile syringe.

After instrumentation was completed, additional final irrigation was performed using two cycles, 30 seconds each, of irrigation with saline solution. Hand- and rotary-prepared teeth were randomly divided into four groups for the final laser irradiation with different protocols.

Laser Irradiation Method

A 2940-nm Er:YAG laser (Fidelis, Fotona d.d., Ljubljana, Slovenia) was used with a newly designed, 14-mm-long, 400-micron diameter tapered

Figure 6: Diagrammatic representation of the 400-micron tapered and stripped tip used for this laser study

Figure 7: Operative image shows the tip, positioned stationary and immersed in irrigant-filled chamber, at the orifice opening of the palatal (palatine) canal

tip; 4 mm of the polyamide sheath were stripped back from the end.

Laser settings were 10 Hz, 20 mJ, with 50 microseconds pulse duration, with air/water spray off.

Four groups were established, and each group had the same number of canals prepared by K and NiTi files:

- Group A (n = 12) was laser-irradiated for 20 sec in saline solution-wetted canal.
- Group B (n = 12) was laser-irradiated for 20 sec in 17% EDTA-wetted canal.
- Group C (n = 12) was laser-irradiated for 40 sec in 17% EDTA-wetted canal.
- Group D (n = 14) was not laser-irradiated, and served as the control group.

During laser irradiation, the root canals were continuously irrigated with 2 mL of the same fluid (saline solution or 17% EDTA) to maintain hydration and fluid levels using a 25-gauge needle (same manufacturer as above) in a sterile syringe, positioned above the laser tip in the coronal aspect of the access opening.

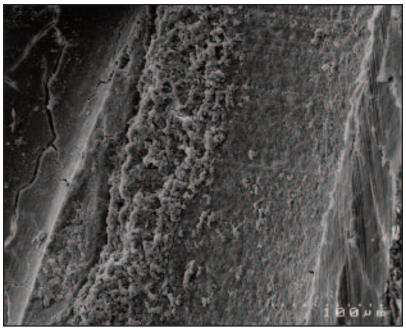
The prepared samples were then sectioned longitudinally and examined with a field emission electron microscope (F4000, Hitachi, Tokyo, Japan).

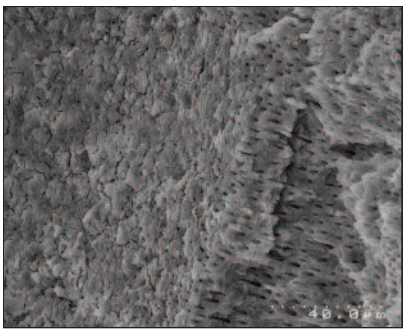
Temperature Measurements

Temperature variations were measured on the root surface of five samples for each laser group (for a total of 15 samples). A modified thermocouple measurement sensor of 1.5-mm diameter (TEL-11854 K-Type NiCr-Ni Immersion Sensor, TEL-Atomic Inc., Jackson, Mich., USA) was used. It was placed on the external root surface at 5 mm from the apex and attached with a silicon-based heat-conductive compound (Dow Corning® 340 Heat Sink Compound, Dow Corning Corp., Midland, Mich., USA). The temperature variations were monitored continuously during all the irradiation procedure periods (20 sec for Groups 2 and 3, and 40 sec for Group 4) using a digital thermometer (TEL-11853 Digital Quick Response Pocket Thermometer, TEL-Atomic Inc.).

RESULTS

- The samples in Group A, treated with the Er:YAG laser and saline solution, showed partially clean surfaces and open tubules, with residual debris and thin smear layer remaining. (Note: There is no accompanying illustration included in this article.)
- The samples from Group D, with saline solution applied conventionally, demonstrated a noticeable smear layer and closed tubules (Figures 8-9).
- However, the Group B samples that incorporated the Er:YAG laser irradiation for 20 seconds, the tapered and stripped tip, and





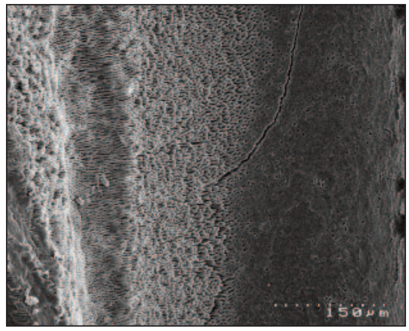
Figures 8-9: Group D sample: SEM images of the coronal third show adherent mechanical debris present in conventional mechanically instrumented canals, followed by rinsing with saline solution for 1 minute

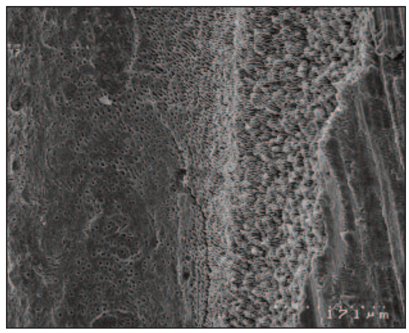
EDTA irrigation showed clean, open tubules with essentially no smear layer or debris remaining (Figures 10-11).

- In addition, the Group C samples with Er:YAG irradiation for 40 seconds, the tapered and stripped tip, and EDTA irrigation show the collagen fibers and internal hydroxyapatite matrices intact at increased SEM magnification at 20,000**x** (Figures 12-13).
- Temperature increases were observed at the root surface during laser irradiation. Groups A and B (20 seconds of laser exposure) exhibited a rise of 1.2°C, and Group C (40 seconds) showed a 1.5°C increase.

DISCUSSION

Currently used chemomechanical instrumentation still falls short of successfully removing the smear layer from inside the root canal system.[5] This was also confirmed





Figures 10-11: Group B sample: SEM images of the coronal third show clean surface after laser irradiation in 17% EDTA for 20 seconds and smear layer and debris removal from dentin tubules. The surface does not exhibit evidence of the application of thermal energy. Er:YAG laser at 20 mJ, 10 Hz, 0.2 W, 400-micron tapered and stripped tip

from the results seen in the control group of this study, when the laser technique was not employed.

This study introduced several modifications to the commonly used laser-assisted techniques and protocols, to reduce the thermal effect of laser radiation on dentinal walls.

The thermal and ablative effect of laser radiation on the root canal surface may be reduced using less ablative parameters. The dentin ablation threshold is currently known to be about 1 to 4 J/cm^2 for the Er:YAG laser.[23-24] Based on these values and using a 400-micron tip, this study utilized the higher but still valid threshold ablative energy value of 20 mJ (measured at the panel display), which is 4 J/cm^2. As mentioned above, this pulse energy is significantly below those reported in previous studies, but did not produce

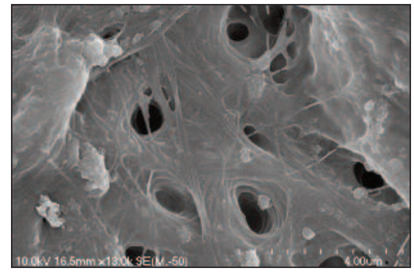


Figure 12: Group C: SEM image of apical third presents completely removed smear layer from the dentin tubules following laser radiation in 17% EDTA wetted canal for 40 seconds. There is no evidence of morphological thermal damage at 20 mJ, 10 Hz, 0.2 W, 400-micron tapered and stripped tip

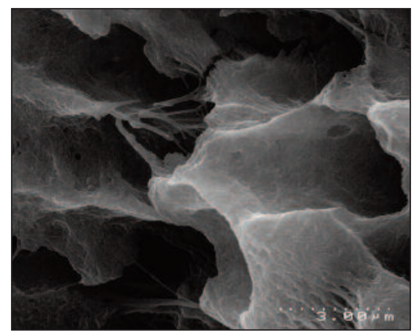


Figure 13: Group C: SEM image of middle third shows the collagen fibers and internal hydroxyapatite matrices left intact, indicating the absence of laser thermal energy, at 20 mJ, 10 Hz, 0.2 W, 400-micron tapered and stripped tip

the thermal damage. Furthermore, with the pulse duration of 50 microseconds, a peak power of 400 W per pulse was achieved.

According to a study by George and Walsh, the use of tapered and stripped laser tips showed greater lateral emissions and corresponding lower forward emissions than conventional blunt tips, thus reducing the thermal side effects of the end-firing tips. They also reported that two different erbium laser systems equipped with a radial fiber design elicited temperature increases less than 2.5°C during lasing, confirming the role of water irrigation in attenuating the thermal effects of each lasing cycle.[22]

Because of the high affinity of the Er:YAG laser for water and the very short pulse duration utilized in this laser protocol, the resultant high peak power of 400 W generated a cavitation and shock wave effect in the liquid. Since the volume of the liquid in the root canal is very small, this effect is amplified and improves the removal of the smear layer and residual tissue tags, which was confirmed by another study.[21] The authors speculate that this phenomenon is responsible for the removal of smear layer observed in group A, in which laser irradiation was combined with saline solution. Limited information exists at this time regarding the induction of mechanical effects due either to ultrasonic or laser stimulation, and other authors have described similar expanding and imploding vapor bubbles, shock waves, with secondary cavitation effects with fluid movements in endodontics as a result of the erbium laser (Er:YAG and Er,Cr:YSGG) thermal activation of irrigants, within the canal, termed laser-activated irrigation.[25-27] However, those studies utilized lasers equipped with different tips, and different parameters and techniques were employed. In this study, the tip was placed only within the coronal portion of the root canal system; and, with 20 mJ per pulse, the previously described harmful thermal effects[13-18] did not occur. The authors postulate that the smear layer and debris were not removed via thermal vaporization, but from the laser-activated coronal irrigation fluid. They use the acronym PIPS™ to describe this Photon-Induced Photoacoustic Streaming™.

The use of EDTA together with the described Er:YAG laser protocol produces a synergistic effect. This contributes to improved treatment efficacy when compared to the erbium laser-saline solution group (Group A) or the nonirradiated control group (Group D), leading to an efficient debriding of the root canal as seen in Groups B and C.

The SEM images verified also the minimally disruptive effects on dentin walls, and even on the hydroxyapatite and collagenous fiber matrices.

CONCLUSION

This SEM study demonstrated the effective ability of an Er:YAG laser equipped with a tapered and stripped tip, set at low energy and short pulse duration, to clean and debride the root canal system. This laser system and the technique used appeared to have no thermal effects on the dentinal walls by virtue of decreased energy settings and short pulse duration and by remote placement of the radial and stripped tip from the target site (at the orifice of the root canal). The dentin surface and its collagen and hydroxyapatite matrices were essentially undisturbed and clean. The use of the laser utilized in this study appeared to enhance the removal of the smear layer from dentin tubules when used with EDTA for both 20 and 40 seconds.

AUTHOR BIOGRAPHIES

Dr. Enrico DiVito has been in practice since 1980. He established and runs the Arizona Center for Laser Dentistry in Scottsdale, Arizona. He is always exploring potential uses for innovations in the field and holds a number of patents for dental products. He lectures nationally and internationally. Dr. DiVito is the founder and director of the state-accredited Arizona School of Dental Assisting. He also teaches as a clinical instructor at the Arizona School of Dentistry and Oral Health and is responsible for helping to create and implement their Department of Laser Dentistry. In 2007 he was awarded the Biolase Clinical Case of the Year. Dr. DiVito may be contacted by e-mail at edivito@azcld.com.

Disclosure: *Dr. DiVito receives honoraria from Lares Research for lectures on laser dentistry. He is also a shareholder in Medical Dental Advanced Technology Group, which has performed the research for PIPS™.*

Dr. Mark Colonna founded and operates the Montana Center for Laser Dentistry, his private practice and advanced laser training center. He is a pioneer in the development of techniques and instruments for dentistry without the use of drills. He lectures, teaches, and writes nationally and internationally about laser dentistry. Dr. Colonna holds many awards, including the Clinician of the Year Award from the World Congress of Minimally Invasive Dentistry. He has achieved Mastership status from the World Clinical Laser Institute. Dr. Colonna may be contacted by e-mail at doc@mtlaserdentistry.com.

Disclosure: *Dr. Colonna receives honoraria from Lares Research for lectures on laser dentistry. He is also a shareholder in Medical Dental Advanced Technology Group, which has performed the research for PIPS™.*

Dr. Giovanni Olivi is a Professor in Restorative and Endodontics at the University of Genoa Faculty of Dentistry, and a Board member of Scientific Committee of the University of Genoa “Laser in Dentistry” Master Course. He is a member of the Academy of Laser Dentistry and received Mastership from the ALD. Dr. Giovanni is the 2007 recipient of ALD’s Leon Goldman Award for Clinical Excellence. He is a co-author of the books *Pediatric Laser Dentistry* and *Lasers in Dental Traumatology.* Prof. Giovanni Olivi may be contacted by e-mail at olivi.g@tiscali.it.

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