Deep disinfection and tubular smear layer removal with Er:YAG using photon-induced photoacoustic streaming (PIPS) contra laser-activated irrigation (LAI) technics

Jaana Sippus^{1,2} · Norbert Gutknecht^{3,4,5}

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Abstract

Purpose This in vitro laboratory study assessed the efficacy of the laser in deep disinfection and smear layer removal with 2940-nm erbium:yttrium aluminum garnet (Er:YAG) laser. The purpose was to evaluate the efficacy of a conical and stripped Er:YAG tip using PIPS (photon-induced photo acoustic streaming) in root canals compared with end firing Preciso tip using LAI (laser-activated irrigation).

Methods Thirty extracted single-rooted upper teeth were divided in three groups for smear layer removal: using PIPS and Preciso with the third as the control group. After irradiation methods with different erbium tips, the roots were longitudinally split for SEM observation. The root canals were then scanned separately in each specimen in all three thirds—coronal, middle, and apical. The remaining smear layer was evaluated with the Hülsmann score (Hülsmann et al., J Endod 23:301–306, 1997).

Results In the coronal third of the canal, both the PIPS and the Preciso group scored significantly better when equaled with the control group. In the middle third, the PIPS group got the smallest score, which was meaningfully different from that of the Preciso and the control groups. Preciso scored higher in the apical third, in comparison to the control group and PIPS group. Statistically significant alterations were found.

Conclusions This SEM study showed that Er:YAG used with PIPS and Preciso tips, which generate cavitation in the irrigant, did not enhance the removal of the smear layer from dentin tubules from the apical part of a straight root canal when used only with saline solution as irrigant.

Keywords Modified laser fibers · Endodontics · Shockwaves · Er:YAG · Dental laser

Introduction

The biggest issue in a failure of root canal treatment is still the failure in cleaning the canals. The primary predictor of long-

term success in endodontic therapy is to eradicate micro-organisms from an infected root canal prior to obturation. If all remnants of debris are not extirpated, this can ruin all further steps of obturation. The most common irrigation techniques apply manual irrigation with needles and cannulas, while machine-assisted techniques use sonic and ultrasonic systems. The problem with all file systems is smear layer production and debris leftovers in the root canal.

The use of 5.25% sodium hypochlorite irrigation alone is not effective for debris and smear layer removal [1–6]. Many studies have concluded that other irrigants such as 2% chlorhexidine gluconate and 17% EDTA (ethylenediaminetetraacetic acid) are ineffective with an only limited ability to reach the multi-complex root canal internal anatomic faces. A recent study evaluated a new file system with a continuous irrigation device for debris and smear layer removal. Therefore, there is a need to search for new methods to clean and disinfect dentinal walls with deep penetration, and these with chemical intervention and

✉ Jaana Sippus
Jaana.sippus@netikka.fi

Norbert Gutknecht
ngutknecht@ukaachen.de

¹ University of Turku, Turku, Finland

² Laseredu LTD, Hovioikeudenpuistikko 20 B, 65100 Vaasa, Finland

³ Department of Operative Dentistry, Periodontology and Pediatric Dentistry, University Hospital RWTH Aachen, Pauwelsstrasse 30, 52074 Aachen, Germany

⁴ Aachen Dental Laser Center, Aachen, Germany

⁵ The University of Hong Kong, Pokfulam, Hong Kong

solution activation. Still, these methods are not successful in satisfactory handling the problem with anastomosis, additional canals, multiple apical foramina, and lateral canals [7–20].

Recent studies have also reported how the use of an Er:YAG laser, used at very low energy (20 to 50 mJ, 10 to 15 Hz, with a 400-micron tip in the so-called PIPS technique), in combination with commonly used irrigants, resulted in a superior debris and smear layer removal and bacterial reduction, without thermal damage to the organic dentinal surface [14, 21, 22]. Using erbium laser energy with very short pulse durations (less than 150 ms) in an environment filled with liquid, a shock wave phenomenon (*photo-mechanical-acoustic effect*) can appear. A current study reported a direct bactericidal effect linked to this shock wave-like phenomenon; bacteria were observed to be eliminated up to 73% *when distilled water was activated by PIPS for 30 s in an ex vivo infected root canal* [23].

Morphological effects of laser light on the dentinal surface

Lasers do not have only positive outcomes; the laser thermal effect can damage the dentinal walls. Many studies have examined the laser-induced morphological effects on root canal walls as a method of cleaning and reduction of bacteria. Both the near-infrared and the mid-infrared lasers generate typical thermal effects when they are used on a dry tissue [19]. Near-infrared lasers cause morphological changes of the dentinal wall; the smear layer is only partially removed, and the dentinal tubules are mostly closed as a result of melting of the inorganic dentinal structures. Mid-infrared lasers entirely vaporize the smear layer, but also generate a superficial thermal phenomenon on the dentin [13]. When used in dry mode in narrow and/or curved canals, these lasers can produce over-enlarging of the coronal section, apical transportation, perforation, and root canal ledging [18]. This is why current studies are seeking for non-thermal laser bacterial reduction methods such as photo-activated disinfection (PAD) or LAI [25].

Effects of laser light on irrigants

Studies on laser-activated irrigation stated that pulsed erbium lasers could cause a movement of fluids at high speed through a cavitation effect. The expansion (via thermal effect) and consecutive vapor bubble implosion within irrigant solutions generate a secondary cavitation effect on the intracanal liquids [25, 26]. The pulsed erbium lasers' force on the irrigants within the root canal system created a clean and debrided dentin surface [26, 27]. A certain type of laser activation of irrigants (PIPS) uses deficient energy (ranging from 50 to 20 mJ) at 10 to 15 Hz delivered with very short pulses (50 ms) to produce a more intense shock wave than cavitation. The outcome is parallel to the previously described effect with LAI [18, 25, 28–34].

When PIPS is used to activate 17% EDTA, a superior removal of smear layer and debris is obtained when compared to hand irrigation [18, 28]. When PIPS is used to activate 6% sodium hypochlorite, an effective bacterial reduction in the endodontic system through three-dimensional streaming of fluids is obtained [13, 25, 30–34]. The shape of the tip influences the direction and quantity of emission of the laser energy. Old-style laser tips are straight and end firing with no lateral emission. Latest tip models are tapered or both tapered and stripped so that most of the energy is delivered laterally, not so much frontally [25].

Materials and methods

Background and objectives

There is still insufficient evidence concerning the initiation of explosive vapor and cavitation bubbles in irrigants used in root canal treatments. There is also a discussion whether the fiber should be moved in the irrigation solution or could be kept still. There is even a lack of safe power settings for using cavitation inside the root canal. This study compares the cleaning effects of the fluid movements and the cavitation mechanism caused by PIPS and Preciso tip with Er:YAG laser.

Sample preparation

Thirty extracted teeth were collected. All teeth were stored in saline solution at a temperature of 21 °C.

Root canal treatment

This study followed a protocol by Prof. Gutknecht and Prof. Franzén.

Teeth used for this split root model study were upper incisors, canines, and premolars because they have large canals, which make longitudinal splitting easier to minimize breakage of roots before SEM. The primary access was made with a regular diamond drill (Horico) since most of the teeth had old amalgam fillings. All teeth were instrumented traditionally for exposing pulp chamber and providing access to root canals. Apical foramina were located with ISO size 15 files (Hedstroem; Micro-Mega) through the apical foramen and canal lengths verified 1 mm from the apex. To avoid rinsing through the apical foramen, teeth were then mounted in dental putty for traditional root canal treatment. The preparation was made with Wave One NiTi primary no. 0.25 and large no. 0.40 files.

Upper incisors were prepared up to ISO 90, canines up to ISO 70, and premolars up to ISO 60. After completing the enlargement, they were rinsed by physiological delusion. No irrigant like EDTA or NaOCl was used as this study focuses on the laser tips' ability to remove the smear layer.

The samples were then randomly put into 3 groups:

- 1) PIPS
- 2) Preciso
- 3) Control

Laser irradiation

Treatment protocol used was fabric protocol for Lightwalker Er:YAG by Fotona:

- 1) PIPS was used with 20 mJ, 15 Hz, 0.3 W, and 50 μ s (SSP) for 30 s with NaCl without the use of EDTA and NaOCl; this was done twice holding the tip only in pulp chamber close to the canal orifices.
- 2) Preciso was performed 40 mJ, 12 Hz, 0.45 W, and 100 μ s (MSP) withdrawn with helical motion four times in 5–8 s each cycle, beginning 1 mm from the apex. This was done also only with NaCl.
- 3) Control group was not lased but rinsed with NaCl solution between each ISO file size.

Time was controlled by a stopwatch to keep exact timing during the treatments.

After instrumented and lased root canals, the teeth were stored in saline and 1% thymol before being split longitudinally for SEM evaluation. The coronal part was cut off along dento-enamel junction with a diamond disc (Horico, Germany).

Specimens were fixed in 3% glutaraldehyde-buffer solution, dehydrated in a graded ethanol series, and air-dried. Finally, five teeth from each group were selected under microscope examination for SEM.

As dentin canal walls, dentinal tubule openings, and extensions of root canals accumulate dentin debris during instrumentation, the removal of this material is to be evaluated under large magnification.

All samples were sputtered with gold palladium. They were all examined under conventional high vacuum in SEM.

SEM analysis

After irradiation methods with different erbium tips, the roots were longitudinally split for SEM observation. The root canals were then scanned separately in each specimen in all three thirds—coronal (3 mm from canal orifice), middle, and apical (3 mm from apical opening). An evaluation was made to record the presence of smear layer on the surface of the root canal walls based on the following score described by Hulsmann et al. [3]:

Score 1: dentinal tubules completely open

Score 2: more than 50% of dentinal tubules open

Score 3: less than 50% of dentinal tubules open

Score 4: almost all dentinal tubules covered with smear layer

Results

The mean score and *P* value for the removal of smear layer are presented in Tables 1 and 2.

The control group exposed a very even, smear layer in the canal wall, in all segments. In the other two groups, the coronal third of root canal showed a reduced amount of dentin chips and pulp remnants (debris), layering the internal wall of the root. Samples from both PIPS and Preciso groups seemed to have fewer residues in the middle part of the root canal than the control group. In the apical area, the cleaning effect was incomplete in almost all specimens. PIPS group had better results in some specimen at the middle third with an area of open dentin tubules (Fig. 1, Fig. 2), and Preciso group showed the same result in the apical third of some specimen.

Result scores for smear layer removal are reviewed in Fig. 3. Generally, the PIPS group score seems lower, with statistically significant difference compared with other groups ($p < 0.05$).

In the coronal third of the canal, the PIPS group scored significantly better when equaled with the Preciso group (Fig. 3, $p < 0.05$, Tukey HSD test). In the middle third, the PIPS group got the smallest score, which was meaningfully different from that of the Preciso and control groups (Fig. 3, $p < 0.05$, Tukey HSD test). Preciso scored higher in the apical third, in comparison to the PIPS group. Statistically significant alterations were found.

In the PIPS group, the reduction of smear layer score was notably diverse from the coronal to the middle (Fig. 3, $p < 0.05$, Tukey HSD test). The decontamination efficiency diminished from the coronal to the apical portion of the canal in Preciso group. For the Preciso group, the scores in the coronal and middle third revealed a significant difference compared with the control group, both being kept at a middle level. A significantly higher score was found for the apical third (Fig. 3, $p < 0.05$, Tukey HSD test).

Conventional treatment

SEM evaluation shows clearly that conventional root canal therapy with saline, as rinsing aid, is not sufficient in smear

Table 1 Quantitative analysis of smear layer removal

Group	Coronal	Middle	Apical	Overall
PIPS	3.50 $\pm$ 1.20	2.78 $\pm$ 0.58	4.22 $\pm$ 0.43	3.50 $\pm$ 0.96
Preciso	3.60 $\pm$ 0.56	3.48 $\pm$ 0.76	4.30 $\pm$ 0.63	3.79 $\pm$ 0.68
Control	3.51 $\pm$ 0.76	3.80 $\pm$ 0.67	3.34 $\pm$ 1.02	3.55 $\pm$ 0.79

Figures above indicate mean $\pm$ SD (standard deviation)

Table 2 Data

Group	N	DATA Mean	SE	SD
PIPS	5	3.50	0.25	0.96
Preciso	5	3.79	0.18	0.68
Control	5	3.55	0.20	0.79

Figures above indicate mean, standard error (SE) of mean, and standard deviation (SD)

layer removal. In almost all parts of the root canal, a visible layer of debris was covering the surface, and no tubules were open.

Laser treatment

Both laser groups, PIPS and Preciso (Er:YAG laser), showed in some cases better results in cleaning efficiency than the conventional group. Dentin wall was only partially covered with smear layer, and dentinal tubules could be seen. Preciso was better in apical area in some cases, and PIPS was superior in some samples in the middle third of root canal. However, none of these laser tips was effective enough for high cleaning effect when used with saline (NaCl) as only irrigant.

Discussion

The model in this study focuses on the comparison of different tips used with Er:YAG laser in their efficiency of irrigation in removing dentin debris and smear layer from root canal system.

The generation of shock waves by dental lasers inside endodontic system can play a key role in smear layer removal. Likewise, smear layer removal can be achieved when water is

Fig. 1 PIPS group showed at the middle third an area of open dentin. Smear layer score 2–3

Fig. 2 Preciso presented in the middle part a result with smear layer score 3–4

activated in root canals using Preciso tip with erbium laser, producing the formation of vapor bubbles that expand and implode.

The PIPS fiber is inserted only in the orifice of the endodontic system without contact with the dentinal wall and kept unmoving during emission. When done traditionally, a spiral movement is needed in the irrigant, when the whole canal wall has to be exposed straight to the laser light. The risk of ledge creation at this point seemed to be higher with Preciso than PIPS. Nevertheless, apical extrusion of the irrigant when using the laser fibers in the root canal, consequently after laser activation, has been described at the present power settings. A previous study by George et al. [6] showed that there was twice as much dye penetration through the apical constriction with the fiber tip at 4 mm than at 5 mm. Therefore, a distance of 5 mm from the apical stop to the fiber tip was used for the present evaluation.

Additionally, placing the laser tip only in the canal orifice might be too remote for the fluid flow activation in the distant parts of the root canal system, affecting its apical bactericidal efficiency.

George et al. in an investigation of the ability of both the Er:YAG and Er,Cr:YSGG lasers equipped with conical-shaped radially firing tips and plain tips to remove the smear

Fig. 3 Quantitative evaluation results

layer from the apical third of the root canal 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. Sirtes et al. [11] reported that warming the sodium hypochlorite from 20 to 45 °C enhanced the killing efficacy of sodium hypochlorite. Stojicic et al. reported that the effect of agitation of irrigants on tissue solution was higher than that of temperature, and continuous agitation of sodium hypochlorite resulted in the fastest tissue dissolution. Therefore, different agitation techniques have been proposed to increase the effectiveness of irrigation solutions, involving hand agitation and sonic and ultrasonic devices. Additional studies have examined the ability of some laser wavelengths to activate the commonly used irrigant solutions inside the root canal. This laser-activated irrigation (LAI) technique has been shown to be statistically more successful in debris and smear layer removal in root canal system compared to conventional techniques (hand irrigation and passive ultrasonic irrigation) [12–17].

While the most outstanding property of Er:YAG application in endodontics has been its distant ability to eliminate bacteria, the vast anatomical variations in the root canals could restrict this kind of distant effect. One significant benefit of the PIPS system is that it requires only minimal root canal preparation. When the tip can be placed only in the pulp chamber, there is a minor need for enlarging the canal for irrigation than as in conventional technics.

Even though there is an option that Er:YAG laser wavelength having high absorption in water, activated in a small quantity of liquid, using the high peak power from the short pulse duration could result in a photomechanical phenomenon, this shock wave could eliminate bacteria and remove smear layer from the root canal. Nevertheless, the results of this study show that this kind of efficiency happened only in the coronal and middle thirds of the root canals. In comparison, from the coronal part to the apical part, the cleaning efficiency was weakening. The interesting thing is that in previous studies (DeVito, Olivi) [11], when combined with EDTA irrigation, Er:YAG laser irradiation revealed more successful removal of smear layer than with non-chelating saline. For best results to remove apical smear layer, PIPS technique with EDTA irrigant could be a rational combination.

The effect of pulsed Er:YAG to eliminate microorganisms is non-thermal, eliminating the unwanted effects of thermal energy. When Preciso tip allows easier access to the apical area, PIPS could be more successful when used in curved, narrow canals where other methods are restricted by anatomical form of root canal.

Conclusion

This SEM study showed that Er:YAG used with PIPS and Preciso tips, which generate cavitation in the irrigant, did not

enhance the removal of the smear layer from dentin tubules from the apical part of a straight root canal when used only with saline solution as irrigant.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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