Laser Induced Explosive Vapor and Cavitation Resulting in Effective Irrigation of the Root Canal. Part 2: Evaluation of the Efficacy

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Background and Objectives: Limited information exists regarding the efficacy of laser activated irrigation (LAI) on removal of root canal debris. This study compares the efficacy of LAI for removal of debris in root canals as compared to conventional irrigation (CI) and passive ultrasonic irrigation (PUI).
Materials and Methods: A splitted tooth model was constructed with straight roots prepared to a 0.06 taper and an apical diameter of ISO 40. A vertical groove was cut in the canal wall at 2–6 mm to the end of the canal in one halve of the root canal wall and filled with dentinal debris. In group 1 root canals were irrigated with 2.5% NaOCl by hand (20 seconds) with the needle 1 mm short from the apical stop, in group 2 NaOCl was ultrasonically activated (20 seconds) with an Irrisafe tip 1 mm short from the apical stop, and in group 3 NaOCl was activated with an Er,Cr:YSGG laser (Z2 Endolase tip −200 μm fiber, four times for 5 seconds, 75 mJ, 20 Hz, stationary at 5 mm from the apical stop). The remaining quantity of dentin debris in the groove was evaluated using a scoring system.
Results: LAI resulted in significantly less debris than PUI ($P < 0.005$) and CI ($P < 0.0005$). PUI also showed significantly less debris than CI ($P < 0.005$).
Conclusion: Under the conditions of this study LAI is statistically significantly more effective in removing artificially placed dentin debris in a root canal as PUI and CI. Lasers Surg. Med. 41:520–523, 2009.
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Key words: absorption; endodontics; Er,Cr:YSGG; fiber optics; laser dentistry; root canal

INTRODUCTION

Laser applications at different wavelengths have been proposed as adjuvant to conventional endodontic cleaning procedures [1–4]. A considerable limitation, though, is the unidirectional emission of the laser beam. This implies that a laser fiber has to be moved with a spiral motion along the root canal walls and this in a number of sequences in order to expose the whole root canal wall to the laser beam [2,4]. The interaction with the root canal walls is based on [1] absorption in dentin, microorganisms and/or smear layer and [2] thermal effects such as evaporation and contraction of the smear layer, and thermal heating of microorganisms [1–4]. The use of erbium lasers at ablative settings also has the disadvantage that there is a risk for the creation of ledges, and hence a good cleaning and shaping result may become hypothecated [2,4]. With the Er,Cr:YSGG laser, however, it appears that the occurrence of ledges up to a canal curvature of $< 10°$ [5] and undesirable side-effects as carbonization is moderate and within limits regarded as safe [6–8].

Alternative approaches such as side firing tips are or limitedly investigated and have limited use due to their size [2] or are new and require further investigation before marketing [9,10]. Photo-activated disinfection relying on the use of photosensitizers does not contribute to smear layer removal and bacterial killing is limited and depending on the species present in the biofilm [11–14].

Laser activated irrigation (LAI) with an Er,Cr:YSGG laser has been introduced as a method for the activation of the irrigant [15]. The effect is based on cavitation: in a water environment the activation of the laser at ablative settings may result in the formation of large elliptical vapor bubbles which expand and implode. It was demonstrated that these vapor bubbles may cause a volumetric expansion of 1,600 times the original volume. This expansion is the mechanism causing high pressure. This pressure drives fluid out of the canal. When the bubble implodes after 100–200 μs an underpressure develops and sucks fluid back

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into the canal and induces secondary cavitation effects. Hence, the laser works as a fluid pump. Passive ultrasonic irrigation (PUI) is also based on the principle of cavitation and acoustic streaming [16].

It is now the question whether LAI is as efficient or more efficient than PUI. The aim of the present study was therefore to evaluate ex vivo the removal of artificially placed dentin debris in standardized root canals by active hand irrigation, PUI, and LAI.

MATERIALS AND METHODS

For the set-up of this study an experimental root canal model according to Lee et al. [17] was used. Seventy maxillary canines with straight roots were selected for this study. The outline of the root canal in these roots was radiographically verified on bucco-lingual and mesio-distal radiographs. The location of the apical foramen was verified by means of the coronal insertion of an ISO size 15 file through the apical foramen. The teeth were decapitated at 19 mm of the location of the apical foramen with a diamond disc (Horico, Berlin, Germany).

The roots were embedded in self-curing acrylic resin (Ostron100, GC, Tokyo, Japan) and split longitudinally through the canal in mesio-distal direction (the previously taken radiographs helped as an indicator for a good separation in two root halves) using an ultrathin diamond saw. To remove the imprint of the root canal, both halves were grinded with sandpaper and copiously rinsed with saline in a syringe. The two blocks were reassembled with four cupper screws. The roots were prepared with K-files (Denstply Maillefer, Ballaigues, Switzerland) and ProFile rotaries (Denstply Maillefer) up to a length of 18 mm, size 40, and taper 0.06 in order to make standardized root canals.

The coronal 3 mm of the canals were enlarged by a round bur with a diameter of 2.3 mm (Komet, Düsseldorf, Germany—340.202.001.001.023—American size 8) and simulating the pulp chamber (Fig. 1). After preparation of the canals and the coronal chambers, the blocks were opened and both root halves were copiously rinsed with air–water spray for 2 minutes and then dried.

The standardization of the root canal outline was checked: pictures of the canals (3,040×2,040 pix) were taken, the diameter of five randomly chosen models was measured at 2, 6, and 10 mm from the apical end of the canal using image analysis software (Sigmascan Pro Image Analysis Version 5.0, SPSS, Inc., Chicago, IL) [18]. At 2 mm, the average canal diameter was found to be 0.52 ± 0.02 mm (diameter of the ProFile rotary is 0.52 mm), at 6 mm this was 0.76 ± 0.02 mm (0.76), and at 10 mm this was 1.00 ± 0.02 mm (1.00). These measurements confirmed the uniformity of the canal shapes and hence the standardization.

The working portion of a hand spreader (A60, Denstply Maillefer) was removed and the end of the shank sharpened to V shaped. Using this modified hand spreader, a standard groove 4 mm in length was created in the wall of one-half of each root canal, 2–6 mm from the apex, to simulate uninstrumented canal extensions. This groove was 0.5 mm deep and 0.2 mm wide (Fig. 1).

Dentin debris was produced by grinding dentin with round burs from the pulpal to cementum side of a number of other teeth that had been split longitudinally. The dentin debris was mixed with 2.5% NaOCl during 5 minutes before use; a wet sand-like mixture was prepared. Using a paper point, the grooves and depressions were then filled with debris [17]. The two halves of each tooth were again secured with the cupper miniscrews. A total of 60 blocks were used for the experiment and randomly divided in three groups of 20 models.

Three irrigation protocols were investigated: conventional irrigation (CI) with 2.5% NaOCl, PUI, and LAI, the irrigation time was 20 seconds for each experimental group. In group 1 ($n = 20$) hand irrigation with 4 ml 2.5% NaOCl was performed with a 10 ml syringe (Terumo, Leuven, Belgium) and a 27 gauge endodontic needle (Monoject, Sherwood Medical, St Louis, MO), the needle was inserted 1 mm short of the working length and moved slowly over a distance of 4 mm up and down in the apical half of the root canal. In group 2 ($n = 20$) a stainless steel non-cutting wire (#20) (Irrisafe, Satelec, Acteongroup, Mérignac, France) was used, driven by an ultrasonic device (Suprasson Pmax Newtron, Satelec, Acteongroup) at power setting "blue 4" (frequency 30 KHz, displacement amplitude ca. 30 μm according to the manufacturer). The tip of the Irrisafe was kept at 1 mm from the apical stop. After this procedure the canal was flushed with 2 ml 2.5% NaOCl with a syringe and an 27 gauge endodontic needle (Monoject). In group 3 ($n = 20$) the NaOCl was activated by laser irradiation (Er,Cr:YSGG laser, Waterlase Millenium, Biolase, San Clemente, CA, USA) using an endodontic fiber (Z2, Endolase tip, Biolase) with a diameter of 200 μm and 25 mm length, with pulse energies of 75 mJ at 20 Hz. The fiber was kept away from the most apical preparation at a distance of 5 mm and then kept stationary during a 5 seconds time period. A mark was put on the fiber with a black marker at 13 mm in order to put the fiber in the root canal at this length. This protocol was repeated four times, without removing the tip from the root canal. At the end of this procedure, the canal was flushed with 2 ml 2.5% NaOCl using a syringe with endodontic needle.

After irrigation the canals were carefully dried with paper points size 35. Subsequently the two halves were unlocked and the amount of remaining debris in the artificial grooves was evaluated. Digital images of the groove were taken before and after the irrigation protocols at 40× magnification. These images were scored by two dentists and double blind, and scores were attributed according to the following scoring system: score 0: the groove is empty, score 1: less than half of the groove is filled with dentin debris, score 2: more than half of the groove is filled with dentin debris, score 3: the groove is completely filled with dentin debris. The differences in dentin debris scores between the different groups were analyzed by means of the Kruskal–Wallis and Mann–Whitney U tests (level of significance was set at $\alpha = 0.05$).

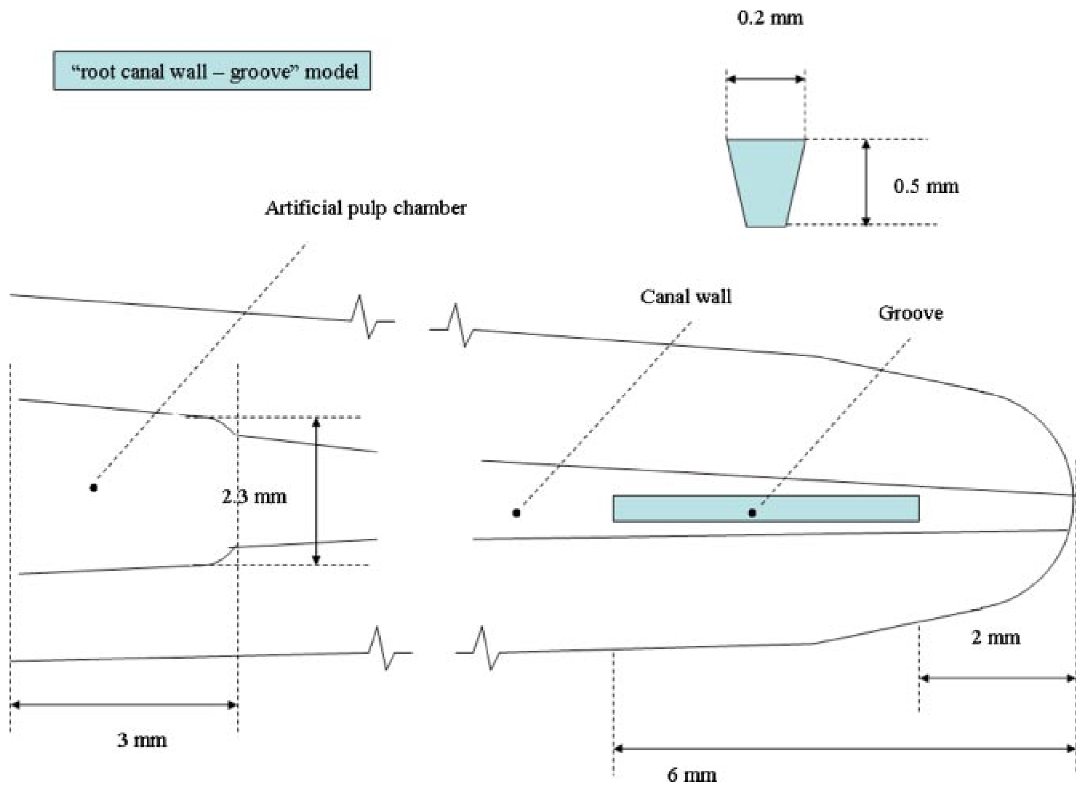

Fig. 1. Schematic representation of the specimen preparation. On one half of the instrumented root canal a groove was cut 2–6 mm from the apex. In the coronal 3 mm an artificial pulp chamber was prepared over a length of 3 mm (diameter 2.3 mm). [Figure can be viewed in color online via www.interscience.wiley.com.]

RESULTS

Table 1 shows the debris scores before and after irrigation. Statistically significant differences between groups were found (Kruskal–Wallis test, $P < 0.0001$). The debris scores in group 3 were statistically significantly lower than group 2 ($P < 0.005$) and group 1 ($P < 0.0001$), in group 2 this was also statistically significantly lower than in group 1 ($P < 0.0001$).

DISCUSSION

The present model has been chosen for the study of the effectiveness of irrigation in removing dentin debris in artificial irregularities and extensions because it allows the comparison of the presence of debris before and after irrigation. In most studies, however, the amount of debris is only evaluated after preparation and irrigation. The latter studies also have in common that it is not clear how much debris is present before irrigation and therefore it is also impossible to establish how much is removed using the different irrigation procedures. The groove cut in the root canal wall is made in order to simulate uninstrumented extensions in the apical half.

Canines were used because they have wide canals [19,20] and hence the root can be more easily split in mesio-distal direction.

The results show that LAI with the Er,Cr:YSGG laser during four times 5 seconds is more effective in removing the compacted dentin plug from the artificial groove in the root canal wall than both other irrigation protocols (PUI, CI with an endoneedle). In this set-up, it was chosen to have an ultrasonic irrigation only over a 20 seconds time period, whereas van der Sluis et al. [21] advocate to ultrasonically activate the irrigant during three times 1 minute. When the results of that study are taken into account, the scores for PUI (3×1 minutes) appear to be comparable to that of the

TABLE 1. Dentin Debris Scores After Conventional Irrigation With 2.5% NaOCl, Passive Ultrasonic Irrigation and Laser Activated Irrigation

Score	0	1	2	3	N (total)
Conventional irrigation			4 (20%)	16 (80%)	20
Passive ultrasonic irrigation	6 (30%)	7 (35%)	7 (35%)		20
Laser activated irrigation	15 (75%)	5 (25%)			20

LAI with the Er,Cr:YSGG. This means that the activation time of the irrigant seems to be a determining factor for the effectiveness of PUI.

Blanken et al. [22] showed that at 75 mJ pulse energy the fiber of the Er,Cr:YSGG had to be kept stationary for at least six times 5 seconds or moved out of the canal for at least five times 5 seconds to be able to remove all the colored water out of an artificial root canal model with the same dimensions as the ones used here. The present results, however, show that already at four times 5 seconds activation of the irrigant with the 200 μm Er,Cr:YSGG endofiber at subablative settings of 75 mJ, cavitation effects are sufficient to remove a large dentin plug. This opens perspectives for the cleaning or detachment of smear plugs or smear layer in those areas that cannot be reached by root canal instruments and/or insufficiently by irrigation solutions.

It is known that the Er,Cr:YSGG fiber used with higher pulse energies in a root canal irrigant may result in the formation of bubbles as long as 4–5 mm [23] and also in the extrusion of fluid from the apex [9]. This is of clinical relevance since this might damage the vulnerable apical zone of a tooth where it is better to leave this zone intact. Matsuoka et al. [23] therefore suggest in a preliminary study that to prevent damage to the apical area, it is better to keep the 200 and 320 μm fibers 2 and 3 mm away from the anatomical apex. With the study of George and Walsh [9] in mind, showing that there was twice as much dye penetration through the apical constriction with the fiber tip at 4 mm than at 5 mm, a distance of 5 mm from the apical stop to the fiber tip was taken for the present evaluation. In this study, all apical stops were also controlled under magnification 40× (Pico Opmi, Zeiss, Oberkochen, Germany) by two dentists and no damage or widening of the unprepared last 1 mm up (from the apical stop to the outer surface of the root) was seen.

When the Er,Cr:YSGG laser is used with water spray coolant some collateral damage was evident when high energy levels were used. An explanation might be that due to the dimensions of the vapor bubbles at these higher energy levels there is no irrigant or water between fiber and canal wall to absorb the emitted energy. This energy is then absorbed by the hydroxyapatite in the root canal wall. Another explanation might also be root canal wall contact of the apex of the fiber. This problem was not encountered in the present study as the 200 μm fiber was inserted in a root canal with a 0.06 taper and a master apical preparation up to an ISO size 40 and at 5 mm from the most apical preparation. Also here no signs of carbonization or collateral ablative removal of root canal wall dentin due to exposure to the laser beam were detected by the two scoring dentists.

CONCLUSION

This study demonstrates that LAI with the Er,Cr:YSGG laser and a 200 μm fiber is more effective in removing artificially placed dentin debris from a root canal groove than conventional hand irrigation with 2.5% NaOCl or PUI with an Irrisafe tip when the irrigant is activated for 20 seconds.

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