Effect of Er:YAG laser-activated irrigation on dentine debris removal from different parts of the root canal system: An in vitro study

Wpływ lasera Er:YAG aktywującego przepłukiwanie na usuwanie zębiny z różnych części kanału korzeniowego – badania in vitro

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Abstract

Background. There is insufficient information available in the literature about the efficacy of laser-activated irrigation (LAI) in removing dentine debris at different coronal-apical levels of the root canal system (RCS).

Objectives. To evaluate the efficacy of erbium (LAI) in removing dentine debris from different coronal-apical levels of the RCS when compared to passive ultrasonic irrigation (PUI) and conventional irrigation (CI).

Material and methods. Forty-five single-rooted human teeth were split longitudinally into halves. In each sample, a standardized groove was cut 2–6 mm from the apex along the canal wall of the 1st half, and another standardized groove was cut 10–14 mm from the apex along the canal wall of the 2nd half. Each groove was filled with dentine debris mixed with sodium hypochlorite (NaOCl) 5.25%. The samples were assigned to 3 experimental groups according to the irrigant activation techniques (n = 15); (a) CI group, (b) PUI group and (c) LAI group. The amount of the remaining dentine debris was identified and scored using a stereomicroscope.

Results. Laser-activated irrigation removed significantly more debris than PUI and CI systems. The efficacy of dentine debris removal was not affected by the root canal third within all groups.

Conclusions. Erbium LAI enhances dentine debris removal from the artificial irregularities in the RCS.

Key words: conventional irrigation, dentine debris removal, laser-activated irrigation, passive ultrasonic irrigation, root canal system

Słowa kluczowe: konwencjonalna irygacja, usuwanie zębiny, irygacja aktywowana wiązką laserową, pasywna irygacja za pomocą ultradźwięków, system kanału korzeniowego

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Chemo-mechanical preparation, including shaping and cleaning of the root canal system (RCS), is an essential step in successful endodontic treatment.¹ Cleaning depends on using an irrigant solution to chemically dissolve the tissues and mechanically flush organic/inorganic debris out of the RCS.¹ It has been suggested that the flushing action of the irrigant solution could be more critical than its dissolvent capability for complete debridement of the complex RCS.² Conventional irrigation (CI) depends simply on a syringe and a needle to supply an irrigant solution to the root canal. In this protocol, the flushing action is not sufficient to remove organic/inorganic debris due to its limited distribution within the complex RCS.^{3,4} Therefore, several activation techniques have been suggested to increase the flushing action of irrigant solution and enhance its distribution within the root canal, including passive ultrasonic irrigation (PUI) and laser-activated irrigation (LAI).⁵

Passive ultrasonic irrigation depends on the acoustic streaming produced when an ultrasonically oscillating small file vibrates freely within the irrigant solution in the prepared root canal.⁶ Moreover, cavitation can occur during PUI. However, this specifically occurs at the tip of the oscillating file, requiring a large apical preparation and a high energy setting.⁷ Laser-activated irrigation improves the flushing action of the irrigant solution in the RCS, depending upon the cavitation effects, which includes the expansion and immediate implosion of the vapor bubble to induce a rapid movement of the intra-canal solution with profound shock waves and secondary cavitation bubbles.^{8–10} It has been shown that erbium lasers, such as the erbium-doped yttrium aluminum garnet (Er:YAG) laser, exhibit the highest absorption in water, which promotes their use in the LAI technique.¹¹

It has been suggested that erbium LAI may enhance debris removal from root canal irregularities.^{12–14} Laser-activated irrigation is performed using a plain fiber tip inserted within the root canal 5 mm away from the apex which, in turn, may exhibit undesirable side effects such as carbonization, cracking¹⁵ and apical extrusion.^{15,16} Therefore, using the fiber tip in the pulp chamber instead of inserting it within the canal is advocated.^{17–22} However, the use of the fiber tip in the pulp chamber without inserting it into the root canal may decrease the irrigant efficiency. Therefore, the objective of this study was to investigate the efficacy of LAI with a conical fiber tip (Xpulse® 400/14; Fotona, Ljubljana, Slovenia) in dentine debris removal from different root canal levels when held in the pulp chamber, in comparison with both PUI and CI. The 2 null hypotheses investigated in this study were that LAI exhibited a similar efficiency in dentine debris removal to that of PUI and CI, and that the efficacy of dentine debris removal was not affected by different root canal levels.

Material and methods

Sample preparation

Forty-five caries-free, single-rooted human teeth, extracted from patients aged 18–30 years, were collected. The teeth were radiographed to verify the presence of only 1 canal without any resorptions or calcifications. Then, they were stored in saline solution at room temperature until use. The teeth were accessed and the working length (WL) was determined by inserting a size 10 file into the canal until the tip of the file was just visible at the apical foramen, and then deducting 1 mm. Then, they were cut with a diamond disc under water coolant to standardize the working length at 19 mm.

The canals were shaped with Protaper® universal rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) up to F2 (size 25) and irrigated with 2 mL of 5.25% sodium hypochlorite (NaOCl) after each instrument was used. A diamond bur with a diameter of 2.3 mm was used to enlarge the coronal 3 mm of each tooth in order to simulate and standardize the pulp chamber.¹²

Each sample was partly embedded in a putty impression material (Zetaplus®; Zhermack, Badia Polesine, Italy) to obtain a matrix, allowing the reassembly of the tooth halves for irrigation test after splitting (Fig. 1A).³

Fig. 1. A – a set matrix of putty impression material for tooth reassembling; B – grooves cut in the root surfaces; C – tooth was split into halves; D – split tooth reassembled for irrigation tests

Each tooth was grooved longitudinally with a diamond disc (Jota AG, Rüthi, Switzerland) along the outer surface of the root, avoiding penetration into the canal, to split it longitudinally into halves using a small chisel (Fig. 1B, 1C).

For each sample, a standardized groove (4 mm in length, 0.2 mm in width, 0.5 mm in depth) was cut 2–6 mm away from the apex on the canal wall of the 1st half and a similar groove was cut 10–14 mm away from the apex on the canal wall of the 2nd half (Fig. 2). This helps in stimulating the un-instrumented canal irregularities in the apical and coronal third, respectively.^{4,23} The dentine of other split teeth was grounded by round bur to produce dentine debris. Each groove was filled with this debris after mixing it with 5.25% NaOCl 5 min before use. A digital baseline image for each half containing the groove was taken before the irrigation procedure using a digital camera (Nikon D80; Nikon Co, Tokyo, Japan) and a stereomicroscope (Meiji Techno D80; Saitama, Japan) at $\times 20$ magnification. The halves of each sample were reassembled using sticky wax and putty impression material (Fig. 1D).

Irrigation protocols

The specimens were randomly divided into 3 experimental groups (n = 15) according to the irrigant activation techniques; (a) CI group, (b) PUI group and (c) Er:YAG LAI group. The CI was performed with 5.25% NaOCl, delivered with a 10 mL syringe through a 30-gauge side-vented needle (NaviTip®; Ultradent Products Inc, South Jordan, USA) at a rate of 0.1 mL/s. The needle was inserted 1 mm coronal to the working length and moved slowly up and down over a distance of 4 mm in the apical third of the canal. The open side of the needle always faced the canal half with the apical groove.³ A total of 6 mL of the solution was delivered over 60 s.

Fig. 3. A 14 mm long and conical 400 μ m fiber tip (Xpulse 400/14; Fotona, Ljubljana, Slovenia) used in the study

Passive ultrasonic irrigation was conducted with a 15# K/21 mm file (Irri-Safe®; Satelec, Acteon Group, Norwich, UK) driven by an ultrasonic device (Satelec). After the root canal was filled with 5.25% NaOCl, the ultrasonically-activated file was inserted 1 mm coronal to the WL and the ultrasonic activation cycle was done for 20 s at a power setting of 25%. Then the canal was rinsed with 2 mL of 5.25% NaOCl using a syringe and a needle, and the irrigant solution underwent a 2nd ultrasonic activation cycle for 20 s. This sequence was repeated 3 times, resulting in a total irrigation volume of 6 mL and total activation time of 1 min.²⁴

Laser-activated irrigation was carried out using an Er:YAG laser with a wavelength of 2.940 nm (LightWalker® AT; Fotona, Ljubljana, Slovenia). A 14 mm long and conical 400 μ m fiber tip (Xpulse 400/14; Fotona, Ljubljana, Slovenia) was utilized (Fig. 3). The laser operating parameters were 40 mJ per pulse, 20 Hz and 50 μ s pulse duration.²⁵ The water and air on the laser system were turned off. After the root canal was filled with

Fig. 2. Schematic representations of the “root canal-groove” model: A – the apical and coronal grooves; B – a cross section of the model

5.25% NaOCl, the fiber was placed into the artificial pulp chamber and a laser activation cycle was conducted for 30 s simultaneously with irrigation of 3 mL NaOCl through the pulp chamber. After 30 s of resting time, another activation cycle was performed for another 30 s, resulting in a total irrigation volume of 6 mL and total activation time of 1 min.²⁶

Evaluation of dentine debris removal

The canal was carefully dried with paper points and the root halves of each sample were separated to evaluate dentine debris removal within the grooves. A 2nd digital image for each groove was taken at the same magnification as the baseline image. Two calibrated examiners, blinded to the experimental groups, assessed the presence/absence of dentine debris within the grooves. The reliability of the examiners was evaluated by repeating the assessment of the images after 1 week. A previously defined scoring system was used to evaluate the presence/absence of the dentine debris (Fig. 4): score 0 – the groove was empty; score 1 – less than half of the groove was filled with debris; score 2 – half or more of the groove was filled with debris; score 3 – the groove was completely filled with debris.⁴

Fig. 4. Representative images of the grooves according to the dentine debris removal score: A) score 0 – the groove is empty; B) score 1 – less than half of the groove is filled with debris; C) score 2 – more than half of the groove is filled with debris; D) score 3 – the groove is completely filled with debris

Table 1. Distribution of dentine debris scores for each irrigation technique

Irrigation technique	Location of the groove	Debris score [%]				
		0	1	2	3	n
CI	coronal	0 (0)	1 (6.7)	7 (46.7)	7 (46.7)	15
	apical	0 (0)	5 (33.3)	6 (40.0)	4 (26.7)	
PUI	coronal	6 (40.0)	8 (53.5)	1 (6.7)	0 (0)	15
	apical	6 (40.0)	7 (46.7)	2 (13.3)	0 (0)	
LAI	coronal	12 (80)	3 (20)	0 (0)	0 (0)	15
	apical	12 (80)	2 (13.3)	1 (6.7)	0 (0)	

Score 0 – the groove is empty. Score 1 – less than half of the groove is filled with debris. Score 2 – more than half of the groove is filled with debris. Score 3 – the groove is completely filled with debris.

LAI – laser-activated irrigation; n – number;

PUI – passive ultrasound irrigation; CI – conventional irrigation.

Statistical analysis

The intra-observer reproducibility and inter-observer agreement were tested using Cohen's kappa coefficient. Debris score data was analyzed using Kruskal-Wallis test and Mann-Whitney U test. The effect of the location of the groove on the debris removal was analyzed using the Mann-Whitney U test. All statistical analyses were performed at the 95% confidence level ($p = 0.05$) using SPSS Statistics 17 software (IBM, SPSS Inc., Chicago, USA).

Results

Kappa value for the inter-observer agreement was 0.921, and for the intra-observer reproducibility the Kappa values were 0.984 and 0.968 for the 1st and 2nd observer, respectively. Table 1 presents the debris score values according to the experimental groups in the coronal and apical grooves. A score of 3 was observed only within the CI group (7 grooves in the coronal group and 4 halves in the apical group). The highest values for score 0 were presented in the LAI group with 24 out of 30 halves.

There were significant differences between the 3 experimental groups in both apical and coronal grooves (Kruskal-Wallis test $p < 0.001$). Table 2 shows the results of the Mann-Whitney U test comparing debris scores

Table 2. Results of Mann-Whitney U test comparing debris scores between groups in both apical and coronal grooves. A p -value ≤ 0.05 was considered statistically significant

Location of the groove	Comparison	Mann-Whitney U test	p-value
Apical	LAI vs PUI	69.0	0.038*
	LAI vs CI	13.0	<0.001*
	PUI vs CI	33.5	0.001*
Coronal	LAI vs PUI	66.0	0.025*
	LAI vs CI	1.5	<0.001*
	PUI vs CI	8.5	<0.001*

* statistically significant values; LAI – laser-activated irrigation;

PUI – passive ultrasound irrigation; CI – conventional irrigation.

Table 3. Results of the Mann-Whitney U test comparing the debris scores between the apical and coronal grooves within each group. A p-value ≤ 0.05 was considered statistically significant

Comparison	Irrigation technique	Mann-Whitney U test	p-value
Apical vs coronal	LAI	111.0	0.929
	PUI	108.0	0.836
	CI	75.5	0.098

LAI – laser-activated irrigation; PUI – passive ultrasound irrigation; CI – conventional irrigation.

between groups. In the apical groove, LAI removed significantly more dentine debris than PUI ($p = 0.038$) and CI ($p < 0.001$). Passive ultrasonic irrigation removed significantly more dentine debris than CI ($p = 0.001$). In the coronal groove, LAI was significantly better than PUI ($p = 0.025$) and CI ($p < 0.001$) in removing dentine debris. Passive ultrasonic irrigation was more efficient than CI ($p < 0.001$) in removing dentine debris. The Mann-Whitney U test revealed that there was no significant difference on the debris removal score according to the location of the grooves within the same experimental irrigation group ($p > 0.05$) (Table 3).

Discussion

This study showed that CI was significantly less effective in dentine debris removal when compared to the LAI and PUI techniques, which is in accordance with previous studies.²³ Conventional irrigation exhibited a limited distribution and a weak stream action and therefore, its flushing action was not sufficient to remove organic and inorganic debris.^{3,4} The findings of this study indicate that LAI was significantly more efficient in dentine debris removal in comparison to PUI, in agreement with the findings of the previous studies which used a plain fiber tip within the root canal.^{12–14} In this study, however, a conical fiber tip was used in the pulp chamber without inserting it in the canal. This may be explained by the fact that the conical tip was able to transfer the laser energy along the root canal walls.²⁷

The statistical analysis shows that LAI was significantly better than PUI at removing dentine debris from both apical and coronal grooves, which is compatible with the findings of a previous study that used a modified conical fiber tip – photon-initiated photoacoustic streaming (PIPS) tip – in the pulp chamber without inserting it within the root canal to remove dentine debris and antibiotic paste.^{28,29} The stronger mechanical effect and better fluid movement of LAI resulting from the bubbles' impulsive nature induced by laser energy improve the dentine debris removal.^{13,20,30} The term PIPS describes the interaction of laser energy with irrigant solutions when using a special laser fiber (the conical end and distal 3-mm without coating), which differs from the fiber used in the present study, a conical fiber tip (Xpulse; Fotona, Ljubljana, Slove-

nia). The use of this fiber design with a minimal ablative energy of 40 mJ permitted efficient dentine debris removal with consideration of the safety of the procedure.²⁵

The findings concerning the efficacy of LAI in dentine debris removal according to the root canal thirds are compatible with a previous study evaluating the efficacy of LAI in removing antibiotic paste from artificial coronal and apical grooves.²⁹ However, Meire et al. claimed that the removal of the dentine debris was promoted when the fiber tip was held next to the apical groove rather than placed in the canal entrance or the pulp chamber.²⁵ In the present study, NaOCl was used as an irrigant solution, which may enhance the amount of secondary activation bubbles, improving the cleaning of the apical part, whilst Meire et al. used water as an irrigant solution.²⁵ In addition, the activation time was longer in this study (60 s), which may correlate with better dentine debris removal.

The root canal-groove model used in the present study ensures the standardization of the location and size of the grooves, making possible consistent evaluation with high reproducibility for the remaining debris.^{4,23} However, this standardized groove method does not perfectly simulate an in vivo irregularity and the complex anatomy of the natural RCS, exhibiting a limitation of this study. Therefore, further studies are still required to evaluate the cleaning efficiency of LAI in vivo.

Conclusion

Laser-activated irrigation was significantly more efficient in dentine debris removal when compared to CI and PUI. Therefore, the 1st null hypothesis was rejected. The 2nd null hypothesis was accepted, as the efficacy of LAI in removing dentine debris was not affected by the root canal thirds. Thus, Er:YAG LAI enhances dentine debris removal from artificial irregularities in the root canal walls.

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