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ORIGINAL RESEARCH

The efficacy of laser, ultrasound and self-adjustable file in removing smear layer debris from oval root canals following retreatment: A scanning electron microscopy study

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Abstract

This study aims to compare the efficacy of different irrigation activation methods to remove smear layer and debris from oval-shaped root canals following retreatment. Ninety mandibular canines with oval-shaped root canals were selected. Retreatment was performed with R-Endo retreatment files. The samples were randomly divided into six groups ($n = 15$). Groups were assigned according to agitation technique: R-Endo with classic irrigation, with self-adjustable file, with passive ultrasonic irrigation, R-Endo + Er:YAG, R-Endo + PIPS and R-Endo + Nd:YAG. Compared with the classic irrigation (R-Endo + CI) group, all other groups were more successful in reducing smear layer and debris ($P < 0.05$). The least amount of residual smear layer and debris was detected in the Er:YAG laser group ($P < 0.05$). Additional use of different agitation methods contributes to removal of debris and smear layer following root canal filling removal with rotary instruments; however, none of the techniques tested render root canal walls completely free of smear layer or debris.

Introduction

The primary goals of retreatment are to completely remove the previous root canal filling material and to provide a biomechanical preparation and disinfection of the entire root canal system (1,2). Smear layer, debris and residues of root canal filling materials on root canal walls are detected following root canal filling removal procedures (3). Treatment success depends on the removal of smear layer and debris from root canal walls (4,5).

Passive ultrasonic irrigation (PUI) (5), self-adjustable file (SAF) (6) and laser-activated irrigation (LAI) (7) techniques have been used to improve the chemical and mechanical effects of irrigation solutions, and they are found to be successful in removing smear and debris. PUI transfers acoustic energy into the irrigation solution through a passive device, allows irrigant activation by creating acoustic flow and cavitation and, thereby, removes dentin debris from root canal (5). The SAF system has been reported to adapt to root canal section and thus effectively remove smear layer and debris by circumferentially shaping and cleaning root canals (8). LAI removes smear and debris from the complex root canal system by producing an explosive vapour bubble in the solution as a secondary cavitation effect upon transference of the laser pulse energy (9,10).

A new LAI system, photon-initiated photoacoustic streaming (PIPS), has been introduced. The PIPS tip is inserted just into the coronal access opening of the pulp chamber and kept stationary without advancing into the orifice of canal. PIPS was developed to reduce the risk of thermal damage to the dentin wall using minimally ablative energy levels while increasing the cleaning and disinfection activity of the solution inside the root canal system (11).

Recently, the additional methods for the removal of filling remnants from root canals have been investigated with successful results (12–15). The SAF system, meanwhile, has been found to be successful in removing residual filling material, but it is inadequate in terms of removing the smear layer and debris (3). The aim of this study was to utilize scanning electron microscopy (SEM) to evaluate the efficacy of these methods to remove smear layer and remnant from oval root canals following root canal filling removal with R-Endo retreatment files.

Materials and methods

Sample selection

The study protocol was approved by the University Ethical Committee (protocol 2014/109). One hundred forty straight and single-rooted mandibular canines extracted for periodontal reasons were collected. Teeth with open apex, previous root canal treatment, calcification and resorption were excluded. X-ray radiographs (Belmont Phot-X II Takara Belmont Corp., Osaka, Japan) were performed both buccolingually and mesiodistally (60 kVp, 4 mA) in order to measure canal shape using image J (1.44p, National Institutes of Health, Bethesda, MD, USA). Then, 90 teeth with a buccolingual canal diameter of 2:1 and mesiodistal canal diameter of 3:1 were selected. Each tooth was assigned randomly to one of six experimental groups ($n = 15$), disinfected in 0.1% thymol solution and stored in 4° C distilled water until use. After checking the normality assumption (Shapiro–Wilk test), the degree of homogeneity of the six groups was confirmed with respect to the morphologic parameters of the root canals by one-way analysis of variance test ($P > 0.05$).

Root canal preparation

The teeth were not decoronated in order to ensure a sufficient reservoir for laser activation of the irrigants. Straight endodontic access cavities were prepared with high-speed diamond burs (SybronEndo, Orange, CA, USA) under cooling with water spray. Working lengths (WL) were determined by subtracting 1 mm from the length at which the #10 K-file (Dentsply, Maillefer, Ballaigues, Switzerland) first appeared at apical foramen.

Root canals were prepared by a single, experienced operator with Revo-S NiTi rotary instruments (Micro-Mega, Besançon, France) driven by a torque-controlled motor using in-and-out movement set at 300 rpm in the crown-down technique. Following SC1 and SC2 files, apical enlargement was achieved by apical preparation files (AS 30, 35 and 40) and manual size 45 K-files (Mani Co., Tokyo, Japan). Each instrument was discarded after being used for five times. Irrigation was performed between each preparation step using a total of 20 mL of 5% NaOCl per canal along with disposable syringes with 30 G Navi-type needle (Ultradent, South Jordan, UT, USA) placed in the canal 1 mm shorter than the WL. After irrigation was performed with 5 mL of 17% EDTA (pH = 7.7) at 1 mL min^{-1} rate for 5 min, the canals were rinsed with 5 mL of bidistilled water for 5 min. Then, the canals were dried with paper cones (Dentsply).

Root canal filling

The canals were obturated using a warm vertical compaction technique (BeeFill 2in1, VDW, Munich, Germany). The root canal walls were coated with a thin layer of sealer (AH Plus, Dentsply Detrey GmbH, Konstanz, Germany), and a size 45 0.02 taper gutta-percha master cone (Aceone-Endo, Aceonedent Co., Gyeonggi-do, Korea) was inserted into the root canal with a tug back to the WL. The sequential removal of thermoplasticized gutta-percha and vertical condensation of the remaining gutta-percha were completed when an ISO size 60 hot plugger (BeeFill Downpack, VDW) was 3–4 mm from the WL. The middle and coronal thirds of the root canal were obturated using BeeFill Backfill unit. Radiographs were taken in both buccolingual and mesiodistal directions to verify that there was sufficient canal filling. Then, the roots were stored for 1 week (under 37° C, 100% relative humidity) to allow the complete setting of the sealer.

Root canal retreatment

Retreatment procedures were performed with R-Endo NiTi rotary instruments (Micro-Mega) driven by a torque-controlled motor (W&H) at 340 rpm with circumferential filing motion. Re rotary files (15 mm, size 25, open 12:12) were used in the 3 mm cervical portion of the canal; NiTi rotary files of R1 (15 mm, dimension 25, angle 0.08) were used at the beginning of the middle third of the canal, of R2 (19 mm, dimension 25, angle 0.06) in the middle third and of R3 (23 mm, dimension 25, angle 0.04) to the WL. Finally, size 45 K-files were used manually at the WL. After filing, the root canals were irrigated with 2.5 mL of 5% NaOCl. The instruments were discarded after being used for four times.

Root filling removal was accepted as completed when the file reached to the WL, no filling material was detected between the flutes of files and debris-free irrigation solution was visible after the final rinse. The tooth apices were coated with wax in order to prevent the overflow of irrigation solution and to obtain a closed-end root canal system creating a vapour lock effect. The processes described up to this step were performed identically for all groups, after which different procedures were employed for the six groups, as described next.

R-Endo + CI group

The teeth were irrigated with a conventional syringe needle, 5 mL of 5% NaOCl for 1 min and 5 mL of 17% EDTA for 1 min during retreatment procedure. Then, the root canals were flushed with final rinse of 15 mL of distilled water and dried with paper points.

R-Endo + SAF group

SAF files measuring 2.0 mm in diameter were used at the WL for 2 min working with 0.4 mm amplitude and RDT3-NX (redent-Nova) tip allowing the vibrational motion. A special irrigation device (VATEA, Redent-Nova, Ra'anana, Israel) was used for 2 min in total, along with 5 mL of 17% of EDTA for 1 min and 5 mL of 5% of NaOCl for 1 min using a 5 mL min^{-1} flow rate. The canals were then flushed with a final rinse and dried, as Group 1.

R-Endo + PUI group

Residues found in root canals were removed using a piezoelectric unit (mini Master, EMS, Nyon, Switzerland). An ultrasonic non-cutting tip (EMS) was placed in the canal to 1 mm shorter than the WL. The ultrasonic tip and irrigation were simultaneously initiated, vibrating at the endomod setting and with the flow towards the apex with the parameters at approximately 30 kHz, according to the manufacturer's instructions. The irrigation was ultrasonically applied to the root canals for 2 min in total, along with a continuous flow of 5 mL of 17% EDTA and 5 mL of 5% NaOCl for 1 min. Finally, the canals were rinsed and dried, as Group 1.

R-Endo + Er:YAG group

A 2940 nm, flat-tipped Er:YAG laser (Fidelis AT, Fotona, Ljubljana, Slovenia) was irradiated at 1 W, 20 Hz and 50 mJ per pulse with a pulse duration of 50 µs. The air and water on the laser system were switched off during operation. A 14 mm long and 300 µm in diameter plain optical fibre tip (Preciso 300/14 Photon A) was placed 3 mm short of the WL; the laser device was activated and gently pulled from apical to coronal region with helical motion and then reintroduced towards the apex.

R-Endo + PIPS group

A 300 µm in diameter and 14 mm long conical PIPS fibre tip (Fidelis; Fotona) was irradiated at 20 Hz with 45 mJ with a pulse duration of 50 µs. A total of 0.9 W of power was released. The tip was placed at the access opening of pulp chamber and was not inserted to apical third of root canal during laser activation.

R-Endo + Nd:YAG group

A 1064 nm Nd:YAG laser (Fidelis AT; Fotona) was irradiated at 1 W, 20 Hz and 50 mJ with a pulse duration of 50 µs. The air and water on the laser system were switched off during operation. A 320 µm thin fibre end was placed into the root canal 3 mm short of WL, and then the laser was activated and the fibre tip moved as above.

For three laser groups (Groups 4, 5 and 6), the laser unit was set to use both air and water spray features. The root canals were passively filled with 5% NaOCl. Ten second intervals of LAI were followed by 10 s of no activation ('resting') in between. These intervals were repeated for six times (for a total of 60 s) using a volume of 5 mL of 5% NaOCl. Then, the same irrigation protocol and laser irradiation were performed using 17% EDTA as irrigant solution. After the laser treatment, a final rinse was performed with 15 mL of distilled water, and the root canals were dried with paper points. Following completion of additional procedures, the teeth were decoronated at the cementoenamel junction.

SEM preparation and evaluation methods

Diamond discs were used to form grooves in the buccal and lingual surfaces of the teeth to a depth that did not reach to the root canal. The roots were longitudinally split into two following the grooves using a separating disc. The two root halves were considered as separate samples. SEM (LEO EVO 40, Cambridge) images were used to evaluate smear and debris. To evaluate smear, 2000× magnified SEM images were taken from seven different test points: coronal buccal (CB), coronal medial (CM), coronal lingual (CL) (Fig. 1a), middle buccal (MB), middle medial (MM), middle lingual (ML) (Fig. 1b) and apical medial (AM) (Fig. 1c). The numbers of open dentinal tubules were counted using Adobe Photoshop software (Adobe Systems Inc, San Jose, CA, USA). For debris evaluation, 100× magnified SEM images were taken from the coronal, middle and apical thirds (Fig. 1d).

Statistical analysis

In order to evaluate the findings obtained in this study, IBM SPSS Statistics 22 software (PASW Statistics 20; SPSS Inc., Chicago, IL, USA) was used. Non-parametric tests were used as the variables were discrete data and results were not in compliance with a normal distribution as shown by a Kolmogorov–Smirnov test. A Kruskal–Wallis test was used to compare variables between groups, and a Bonferroni-corrected Mann–Whitney *U*-test was used to detect the group causing differences, and significance was

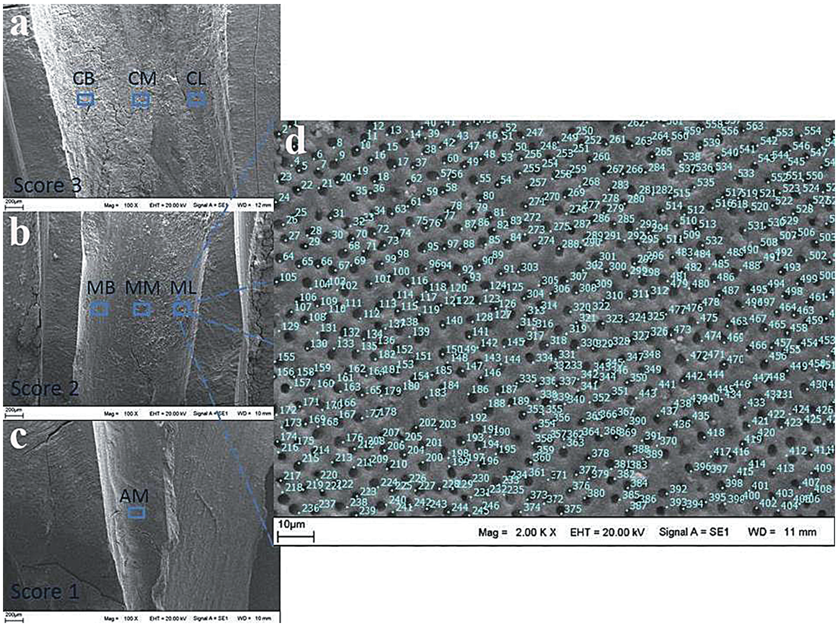

Figure 1 (a) Coronal third test points: coronal buccal (CB), coronal medial (CM) and coronal lingual (CL); (b) middle third test points: middle buccal (MB), middle medial (MM) and middle lingual (ML); (c) apical medial test point (AM); (d) determination of open dentinal tubules.

evaluated at $P < 0.003$ level. A Friedman test was used for comparison of variables within groups, and a Bonferroni-corrected Wilcoxon signed-rank test was used for paired comparisons of variables and significance was evaluated at $P < 0.017$ level. A Wilcoxon signed-rank test was used for two-point comparisons within the groups. General significance was evaluated at $P < 0.05$ level.

Results

Analysis of debris

Mean standard deviations of groups and statistical differences for debris scores in the coronal, middle and apical thirds are shown in Table 1. There was a statistically significant difference among groups in all (coronal, middle and apical) thirds ($P = 0.001$, $P = 0.001$ and $P = 0.048$, respectively).

In comparison within groups, the R-Endo + PIPS method was found to remove more debris in the middle third of root canals than in the apical third ($P < 0.05$). The other groups exhibited a similar amount of debris removed in each third.

Smear layer analysis

The mean standard deviations of groups and statistical differences among them for the number of open dentinal tubules at test points are presented in Table 2. Statistically significant differences among groups were found at all points. Samples of R-Endo + CI group had less open dentinal tubules at the three points in the coronal third than did other groups ($P = 0.001$). Samples in the R-Endo + Er:YAG laser and R-Endo + PIPS groups were found to have the least smear at these three points ($P = 0.001$). There was no statistically significant difference between the R-Endo + SAF and R-Endo + PIPS groups at the CB and CL points ($P > 0.05$).

Comparison within groups for the CB, CM and CL points generally revealed statistically significant differences, although there was no statistically significant difference between these points in the R-Endo + SAF group ($P > 0.05$), while the greatest smear layer in the R-Endo + CI group was found at the CL point ($P < 0.05$). The highest open dentinal tubule number in other groups was found at the CB point, but at the CM and CL points there was no significant difference.

The R-Endo + CI group samples had less open dentinal tubules at the middle third (MB, MM and ML) points than other groups ($P = 0.001$). It was also found that R-Endo + Er:YAG laser and R-Endo + PIPS removed more smear layer from each of these three points ($P = 0.001$). There was no significant difference between the R-Endo + SAF and R-Endo + PIPS groups at the MB and MM points ($P > 0.05$).

Intra-group comparisons performed on the middle third points revealed statistically significant differences ($P < 0.05$). There was no significant difference between the MB and MM points of the R-Endo + PIPS and

Table 1 Evaluation of debris score in intra-group and inter-groups

	Debris			
	Coronal Median (%25–75 P)	Middle Median (%25–75 P)	Apical Median (%25–75 P)	*P*
R-Endo + Er:YAG	^{a}2 (1.75–2)^{AB}	^{a}1.5 (1–2)^{B}	^{a}2 (1.75–3)^{A}	**NS**
R-Endo + PIPS	^{ab}2 (2–2)^{AB}	^{b}2 (1–2)^{B}	^{ab}2 (2–3)^{A}	**0.037**
R-Endo + SAF	^{ab}2 (2–2)^{A}	^{bc}2 (2–3)^{A}	^{ab}2 (2–3)^{A}	**NS**
R-Endo + PUI	^{bc}2.5 (2–3)^{A}	^{b} 2 (2–3)^{A}	^{ab}2 (2–3)^{A}	**NS**
R-Endo + Nd:YAG	^{c}3 (2–3)^{A}	^{c}2.5 (2–3)^{A}	^{ab}3 (2–3)^{A}	**NS**
R-Endo + CI	^{c}3 (2–3)^{A}	^{c}3 (2–3)^{A}	^{b}3 (2–3)^{A}	**NS**
P	**0.001**	**0.001**	**0.048**	

Different superscript lowercase letters in the same column mean statistically significant difference within group ($P < 0.05$; Friedman's test). Analysis of columns was performed with Kruskal–Wallis test at 0.05 levels of significance. Bonferroni-corrected Mann–Whitney *U*-test was performed for post hoc analysis and level of significance was established as 0.003. Analysis of rows was performed with Friedman test at 0.05 level of significance. Bonferroni-corrected Wilcoxon signed-rank test was used for post hoc evaluation and level of significance was established as 0.017. Different superscript capital letters in the same line mean statistically significant difference within group ($P < 0.05$; Kruskal–Wallis test). P values and groups are written in bold. CI, classic irrigation; Er:YAG; Nd:YAG; NS, non-significant; P, percentile; PIPS, photon-initiated photoacoustic streaming; PUI, passive ultrasonic irrigation; SAF, self-adjustable file.

R-Endo + SAF groups for the number of open dentinal tubules ($P > 0.05$); larger numbers of open dentinal tubules were found on the MB than ML points ($P < 0.01$) in all the other groups.

The highest numbers of open dentinal tubules at the AM point were obtained from the R-Endo + Er:YAG laser, R-Endo + PIPS and R-Endo + SAF groups ($P = 0.001$). There was no significant difference between the R-Endo + CI and R-Endo + PUI groups ($P > 0.05$). In all groups, no significant difference between the CB and MB points was found ($P > 0.05$).

Statistical analyses revealed intra-group differences in relation to the MB and ML points. There was no significant difference between the MB and ML points for the R-Endo + CI, R-Endo + PIPS and R-Endo + SAF groups ($P < 0.05$); however, the R-Endo + Er:YAG laser, R-Endo + Nd:YAG laser and R-Endo + PUI groups removed more smear layer from the MB than ML points ($P = 0.031$, $P = 0.004$ and $P = 0.007$, respectively).

Discussion

After preparation of oval-shaped root canals with circular cross-sectional files, smear layer and debris have been reported to remain on the buccal and lingual surfaces of root dentin (16–21). An effective irrigation can help to overcome the morphological difficulties in oval-shaped root canals (22). Therefore, we aimed to enhance cleaning efficacy in oval-shaped root canals using different agitation techniques.

Small apical size of root canal can limit the penetration of irrigation solution (23). In this study, the size of the final preparation was standardized as ISO #45 to allow the irrigation solution to be activated with a laser fibre optic tip (300 μm) and the SAF file and passive ultrasonic tip to more effectively reach the apical region.

Flow models for activated irrigation solutions in root canals show variation. The emerging energy during LAI with fibre is carried forward in the irrigation solution both laterally and vertically. This process causes an expansion of energy vapour bubbles, and also cavitation with increased pressure within the limits of the root canal (24). Ultrasonic activation, on the other hand, creates an acoustic flow by producing a rapid circular-like motion and swirling in the irrigation solution (5). Micro-currents around vibrating files can produce gas bubbles, which can develop a cavitation effect around the file, but cavitation-produced ultrasonics do not play an effective role in root canal debridement (25,26). The irrigation solution has been shown ineffective through the entire WL (26) as a result of files vibrating only with a transverse oscillatory motion and not in the direction of the apical along the root canal (27,28).

Rotary instruments employed during the preparation of oval-shaped canals have been reported to head towards the buccal side and centre of the root canal, due to the anatomical structure of the tooth (29,30). The results of this study are consistent with these reported results. A higher level of debris accumulation in the coronal and middle thirds of the R-Endo + CI group was determined on the lingual side of the root canal. After the R-Endo retreatment file use, higher numbers of open dentinal tubules were obtained at each test point with the additional irrigation techniques implemented. With PIPS and SAF, similar open dentinal tubules were obtained at the buccal (MB) and lingual (ML) points of the middle third. Also with the additional SAF application, similar numbers of open dentinal tubules were obtained at the

Table 2 Number of open dentinal tubules with smear layer in intra-group and inter-groups with all tested points

	Coronal third			
	CB Median (%25–75 P)	CM Median (%25–75 P)	CL Median (%25–75 P)	*P*
R-Endo + Er:YAG	^{a}452 (336.8–523.3)^{A}	^{a}354.5 (235.8–476.3)^{B}	^{a}332 (225–496)^{B}	**0.001**
R-Endo + PIPS	^{b}345.5 (255.3–473)^{A}	^{a}347 (252–427.5)^{A}	^{a}321 (238.8–374)^{B}	**0.045**
R-Endo + SAF	^{b}320.5 (240.8–414)^{A}	^{ab}287.5 (197.8–375.3)^{A}	^{ab}249 (160–426.8)^{A}	**NS**
R-Endo + PUI	^{c}205.5 (162.8–334)^{A}	^{bc}191 (139–281)^{AB}	^{bc}213 (117.8–267)^{B}	**0.003**
R-Endo + Nd:YAG	^{c}214 (131–296.5)^{A}	^{c}187.5 (123.8–230.3)^{A}	^{c}133 (111.5–222.3)^{C}	**0.001**
R-Endo + CI	^{d}64 (34.5–87)^{A}	^{d}67.5 (28.8–87)^{A}	^{d}53 (28.5–63.8)^{B}	**0.011**
P	**0.001**	**0.001**	**0.001**	
	Middle third			
	MB Median (%25–75 P)	MM Median (%25–75 P)	ML Median (%25–75 P)	*P*
R-Endo + Er:YAG	^{a}412.5 (295.5–583.8)^{A}	^{a}316.5 (216–410.5)^{B}	^{a}242.5 (195–490.5)^{B}	**0.002**
R-Endo + PIPS	^{a}304.5 (220–468)^{A}	^{ab}263.5 (209–309.3)^{B}	^{a}316 (229.5–383.3)^{AB}	**0.016**
R-Endo + SAF	^{ab}269.5 (210.3–345.3)^{A}	^{bc}225.5 (162.5–268)^{B}	^{a}209 (164.8–259.5)^{AB}	**0.020**
R-Endo + PUI	^{bc}179 (94.8–279.3)^{A}	^{cd}134 (89.3–258.8)^{B}	^{b}125.5 (76–170.3)^{B}	**0.001**
R-Endo + Nd:YAG	^{c}194 (139.5–233.5)^{A}	^{d}127.5 (104.5–187.8)^{B}	^{b}120 (86.5–153.3)^{C}	**0.001**
R-Endo + CI	^{d}62.5 (26.3–79.3)^{A}	^{e}4 46 (22.8–71)^{AB}	^{c}4 41.5 (20.5–72.5)^{B}	**0.008**
P	**0.001**	**0.001**	**0.001**	
		Apical third AM Median (%25–75 P)		
R-Endo + Er:YAG		^{a}164 (142–203.25)		
R-Endo + PIPS		^{a}149.5 (123.75–186.75)		
R-Endo + SAF		^{a}162 (129–200.5)		
R-Endo + PUI		^{bc}49 (42.5–94.25)		
R-Endo + Nd:YAG		^{c}70.5 (48–124.25)		
R-Endo + CI		^{b}49 (25.75–68.5)		
P		**0.001**		

Analysis of columns was performed with Kruskal–Wallis test at 0.05 levels of significance. Bonferroni-corrected Mann–Whitney *U*-test was performed for post hoc analysis and level of significance was established as 0.003. Analysis of rows was performed with Friedman test at 0.05 level of significance. Bonferroni-corrected Wilcoxon signed-rank test was used for post hoc evaluation and level of significance was established as 0.017. P values and groups are written in bold. CB, coronal buccal; CI, classic irrigation; CL, coronal lingual; CM, coronal medial; Er:YAG; MB, middle buccal; ML, middle lingual; MM, middle medial; NS, non-significant; P, percentile; PIPS, photon-initiated photoacoustic streaming; PUI, passive ultrasonic irrigation; SAF, self-adjustable file.

CB and CL points of the coronal third. In addition, rotary systems might contribute to the movement and activities of middle and coronal regions of the laser fibre ends, SAF and ultrasonic tips.

The activation of irrigation solution during PUI has been claimed to eliminate acoustic currents and cavitation effects when the irrigant comes in contact with the gas bubbles in the apical region (31). Ultrasonically activated irrigation solution is associated with apical penetration (28). Insufficient activity, especially in the apical region, can be explained by the use of devices at low-power density and lack of cavitation effects produced; Jiang *et al.* (28) also reported that ultrasonic activation increases the cleanliness relative to the level of energy. In this study, even though ultrasonic irrigation with low energy was partly sufficient for cleaning the coronal and central regions, it was found insufficient in apical regions.

Gas bubbles might occur in the apical region during the irrigation with a syringe. When an Er:YAG laser is used, surface tension is disrupted with the blow-back of steam bubbles from the apical region, allowing the irrigation solution to move towards the apical third (24,32), which might explain the superior cleanliness activity of LAI at the apical third.

The reason that PIPS is less effective in removing the smear layer compared with the Er:YAG laser is related to the reduction of thermal effects of low-energy laser (7,33). Producing flow three times faster than PUI, the LAI technique is thought to more effectively remove the smear layer and debris owing to the formation of a deeper photoacoustic and photomechanical effect (9) and to enhance the solution reaction rate by increasing the production of NaOCl chlorine and oxygen ions due to the heating effect (34).

An Nd:YAG laser with low wavelength and less absorption by dental hard tissue has also been used to remove the smear layer (35,36). The most important limitation of the Nd:YAG laser is that the tip of the laser proceeds evenly in the root canal, and lateral irradiation is impossible. The Nd:YAG laser technique is known to remove smear layer at the points where the laser is in contact with the dentine surface (37). In the Nd:YAG laser group, the coronal and middle regions had greater numbers of open dentinal tubules than did the apical region; we think that this resulted from the contact of fibre ends used in a circular motion with the canal wall at a nearly perpendicular angle when drawn from the apical to the coronal region. In the apical region, where the fibre end is moved parallel to the canal wall, smear layer and debris were observed not to be removed. Therefore, the movement and activity of the Nd:YAG laser end in the root canal is limited.

In this study, temperature increase during the laser operation could not be monitored. However, when compared with the previous literature, the parameters and time used were found to be within safe limits (37). In addition to this, the morphological changes resulting from thermal side effects, such as carbonization and ebullition formation in dentin, were not encountered in the SEM images obtained, which indicate a minimum occurrence of thermal-related reduction.

No method has been able to fully remove the smear layer from the root canal walls in the apical region. Due both to the lower number and more irregular structure of the dentine tubules in apical region than in the middle and coronal third regions (38), as well as their smaller size and mostly sclerotic structure, the effectiveness of smear layer removal in this area may be reduced (38). However, root canal dentin hardness is observed to increase from coronal to the apical region (39). Therefore, the reduced effectiveness of root canal dentine in the apical region might also result from structural differences between regions.

Conclusions

The additional use of different agitation methods contributed to the removal of smear layer and debris after retreatment operation with rotary tools. However, none of the techniques employed completely removed the smear layer and debris.

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