Smear Layer Removal and Canal Cleanliness Using Different Irrigation Systems (EndoActivator, EndoVac, and Passive Ultrasonic Irrigation): Field Emission Scanning Electron Microscopic Evaluation in an *In Vitro* Study

Manuele Mancini, DDS, Loredana Cerroni, DDS,† Lorenzo Iorio, DDS,* Emiliano Armellin, DDS,† Gabriele Conte, DDS,* and Luigi Cianconi, MD, DDS**

Abstract

Introduction: The purpose of this study was to evaluate the effectiveness of different irrigating methods in removing the smear layer at 1, 3, 5, and 8 mm from the apex of endodontic canals. **Methods:** Sixty-five extracted single-rooted human mandibular premolars were decoronated to a standardized length of 16 mm. Specimens were shaped to ProTaper F4 (Dentsply Maillefer, Ballaigues, Switzerland) and irrigated with 5.25% NaOCl at 37°C. Teeth were divided into 5 groups (2 control groups [n = 10] and 3 test groups [n = 15]) according to the final irrigant activation/delivering technique (ie, sonic irrigation, passive ultrasonic irrigation [PUI], or apical negative pressure). Root canals were then split longitudinally and observed by field emission scanning electron microscopy. The presence of debris and a smear layer at 1, 3, 5, and 8 mm from the apex was evaluated. Scores were analyzed by Kruskal-Wallis and Mann-Whitney U tests. **Results:** The EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) was significantly more efficient than PUI and the control groups in removing the smear layer at 3, 5, and 8 mm from the apex. The EndoVac System (Discus Dental, Culver City, CA) removed statistically significantly more smear layer than all groups at 1, 3, 5, and 8 mm from the apex. At 5 and 8 mm from the apex, PUI and the EndoVac did not differ statistically significantly, but both performed statistically better than the control groups. **Conclusions:** In our study, none of the activation/delivery systems completely removed the smear layer from the endodontic dentine walls; nevertheless, the EndoActivator and EndoVac showed the best results at 3, 5, and 8 mm (EndoActivator) and 1, 3, 5, and 8 mm (EndoVac) from the apex. *(J Endod 2013;39:1456–1460)*

Key Words

EndoActivator System, EndoVac System, field emission scanning electron microscopy, irrigant activation, passive ultrasonic irrigation, smear layer

Debridement of the root canal system is essential to endodontic success (1, 2). Shaping of root canals creates a smear layer that consists of organic and inorganic substances, including fragments of odontoblastic processes, microorganisms, and necrotic materials (3, 4). The smear layer has been shown to prevent the penetration of intracanal disinfectants (5) and sealers (6) into the dentinal tubules, which may result in compromising the seal of the root filling (7, 8). Many irrigating solutions have been used to reduce residual debris, necrotic tissue, and bacteria as well as the smear layer formed by the mechanical instrumentation of the root canal system (5, 9). Sodium hypochlorite (NaOCl) has become the most widely used irrigating solution in endodontics (10). The alternate use of NaOCl, a deproteinizing agent, and EDTA, a calcium-chelating agent, has been recommended for the efficient removal of the smear layer (4, 11). To improve cleanliness, irrigants should be in contact with root canals (9). The traditional needle irrigation technique delivers solutions no more than 0–1.1 mm beyond the needle tip (12). This is insufficient for complete cleaning of the complex anatomy of the root canal system (lateral canals, isthmuses, fins, and accessory canals) (13). A vapor lock that results in trapped air in the apical third of root canals has also been considered because it might hinder the exchange of irrigants and affect their debridement efficacy (14). Different devices for irrigation delivery have been proposed to increase the flow and distribution of irrigating solutions within the root canal system (15), especially at the apical third level. The EndoActivator System (EA) (Dentsply Tulsa Dental Specialties, Tulsa, OK) is a sonically driven irrigant activation system designed to produce vigorous intracanal fluid agitation that has been shown to increase the efficacy of irrigation better than traditional needle irrigation (16). It comprises a portable handpiece and 3 types of disposable flexible polymer tips of different sizes that do not cut root dentin. Passive ultrasonic irrigation (PUI), first described by Weller et al (17), uses a stainless steel file to activate the irrigant in the canal (18). PUI is able to disrupt the endodontic biofilm, facilitating better penetration of irrigants throughout the endodontic dentinal walls (15, 18). The EndoVac System (EV) (Discus Dental, Culver City, CA) is an apical negative pressure irrigation device that is designed to drain irrigating solution at the apical third level of the canal system and to remove debris via a negative pressure mechanism (19).

From the Departments of *Restorative Dentistry and Endodontics and †Dental Materials, University of Rome "Tor Vergata," Rome, Italy.
Address requests for reprints to Dr Manuele Mancini, Via Tuscolana 58/64, 00182 Rome, Italy. E-mail address: manuele.mancini@tiscali.it
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TABLE 1. Experimental Groups and Protocols

Group name	*n*	Shaping	Activation	Protocol
Negative control	10	No	No	—
Positive control	10	Yes	No	—
PUI	15	Yes	Yes: PUI	Final rinse with 5 mL 5.25% NaOCl 37°C activated with PUI; a #.15 K-file (Dentsply Maillefer) was used driven by an ultrasonic device (MiniEndo II; SybronEndo, West Collins, Orange, CA) with power set at 5 for 1 minute at 1 mm from the WL
EA	15	Yes	Yes: EA	Final rinse with 5 mL 5.25% NaOCl 37°C activated for 1 minute with the EA system with a 15/.02 point at 2 mm from the WL
EV	15	Yes	Yes: EV	Final rinse with 5 mL 5.25% NaOCl 37°C activated according to manufacturer's protocol for the EV; to standardize the draining procedure, a rubber stop was placed 9 mm from the tip of the macrocannula, used 30 seconds with 5.25% NaOCl 37°C, plus 30 seconds of soaking in NaOCl, plus 3 cycles of irrigation using microcannula: (1) 30 seconds with 5.25% NaOCl 37°C + 30 seconds soak NaOCl in the channel, (2) 1 min 17% EDTA + 1 min by soaking, and (3) 1 min with 5.25% NaOCl 37°C + 1 min of soaking in 5.25% NaOCl 37°C

EA, EndoActivator System; EV, EndoVac System; PUI, passive ultrasonic irrigation.

The EV has been shown to introduce a higher flow of irrigant and produce better debridement compared with that achieved by needle irrigation (20). Additionally, the EV has been shown to extrude less irrigant in the periapical tissues, thus reducing accidental extrusion of NaOCl (21). There is a scarcity of data evaluating debris removal with similar experimental protocols; therefore, the aim of this study was to evaluate smear layer removal and endodontic wall cleanliness after different irrigant activation regimens.

Materials and Methods

Root Canal Preparation

Sixty-five single-rooted mandibular premolars extracted for orthodontic therapeutic indications were randomly selected from the same age group (15- to 25-year-old patients) with the approval of the Ethics in Research Committee of the Centre of Health Sciences of the University of Rome "Tor Vergata," Rome, Italy. Teeth were devoid of caries, cracks, endodontic treatments, and restorations. Only teeth with intact and mature root apices and roots longer than 14 mm were selected. Teeth were then x-rayed buccolingually and mesiodistally. Teeth with root canal curvatures greater than 20° or calcified root canals were excluded. After extraction, teeth were stored in 2% thymol solution at room temperature and used within 1 week. Inclusion and exclusion criteria were verified under a 20× magnification laboratory microscope (Stemi DV4 Spot; Carl Zeiss, Oberkochen, Germany). After the access cavity was created, a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the canal until the instrument tip was barely visible at the apical foramen. The root lengths were standardized to 16 mm by decoronation of the tooth perpendicular to the long axis by means of a high-speed, water-cooled diamond disc. To simulate clinical conditions, apices were sealed with hot glue, and to prevent the glue from entering the canal, a #10 K-file was inserted before the apex was sealed. The Pro-Train (Simit Dental, Mantova, Italy) was used during the experimental protocol to standardize the procedures for tooth preparation. Specimens were randomly divided into 2 control groups (n = 10) and 3 experimental groups (n = 15). Except for the negative control group, groups were shaped by means of ProTaper Ni-Ti rotary instruments (Dentsply Maillefer) according to the manufacturer's instructions until the ProTaper F4 file reached the working length (WL). Each instrument was used to shape only 4 specimens. After each instrumentation and before the next, canals were rinsed with 3 mL 5.25% NaOCl at 37°C (Chematek SpA, Rome, Italy). The apical patency was checked after each instrument with a #10 K-file. Each group was then irrigated with 17% EDTA (Chematek SpA) and left in the canal for 1 minute before being rinsed with 3 mL 5.25% NaOCl at 37°C. Finally, 5.25% NaOCl at 37°C was activated/delivered with different methods (Table 1). Irrigating solutions were delivered by means of a 30-G syringe needle (NaviTip; Ultradent, South Jordan, UT) inserted deeply at 1 mm from the WL. All specimens were then irrigated with 5 mL distilled water and dried with sterile paper points.

Specimen Preparation

Field emission scanning electron microscopy was used to evaluate endodontic smear layer removal from the instrumented root canals. To facilitate fracture into halves, all roots were grooved longitudinally on the external surface with a diamond disc without penetration into the root canals. The roots were then split into halves with a chisel with a ProTaper F4 gutta-percha cone in the root canal to limit tooth fragments covering endodontic canal walls. For each root, the half containing the most visible part of the endodontic wall was conserved and coded. The coded specimens were secured on metal stubs, desiccated, and viewed with field emission scanning electron microscopy (SUPRA 35; Carl Zeiss SMT, Oberkochen, Germany). The main operating parameters of the instrument were 5 KeV as gun voltage and a working distance of about 11 μm; both parameters were chosen to avoid an excessive charging of the specimens. The detector used was the "second electron detector" (SE2) because the interest was focused mainly on the topography of the canal structure. Five micrographs for each tooth were taken in the same positions inside the canal (tip of the tooth, 1 mm, 3 mm, 5 mm, and 8 mm from the apex) at 3 different magnifications (300×, 1,000×, and 3,000×).

Field Emission Scanning Electron Microscopic Evaluation

Cleanliness was evaluated by micrographs taken at 1, 3, 5, and 8 mm from the apex at a 1,000× magnification (Fig. 1). Two observers performed blind evaluation independently after examining 20 specimens for calibration purposes. Intra- and interexaminer reliability for field emission scanning electron microscopic assessment was verified by the kappa test. Cleanliness was evaluated according to a 5-score index system codified by Hulsmann et al (22), which measured the presence, quantity, and distribution of the smear layer as follows: score 1 = no smear layer (dentinal tubules open), score 2 = small amount of smear layer (some dentinal tubules open), score 3 = homogenous smear layer covering the root canal wall (only a few dentinal tubules open), score 4 = complete root canal wall covered by a homogenous smear layer (no open dentinal tubules), and score 5 = heavy nonhomogenous smear layer covering the complete root canal wall. Data were analyzed using Kruskal-Wallis and Mann-Whitney U tests.

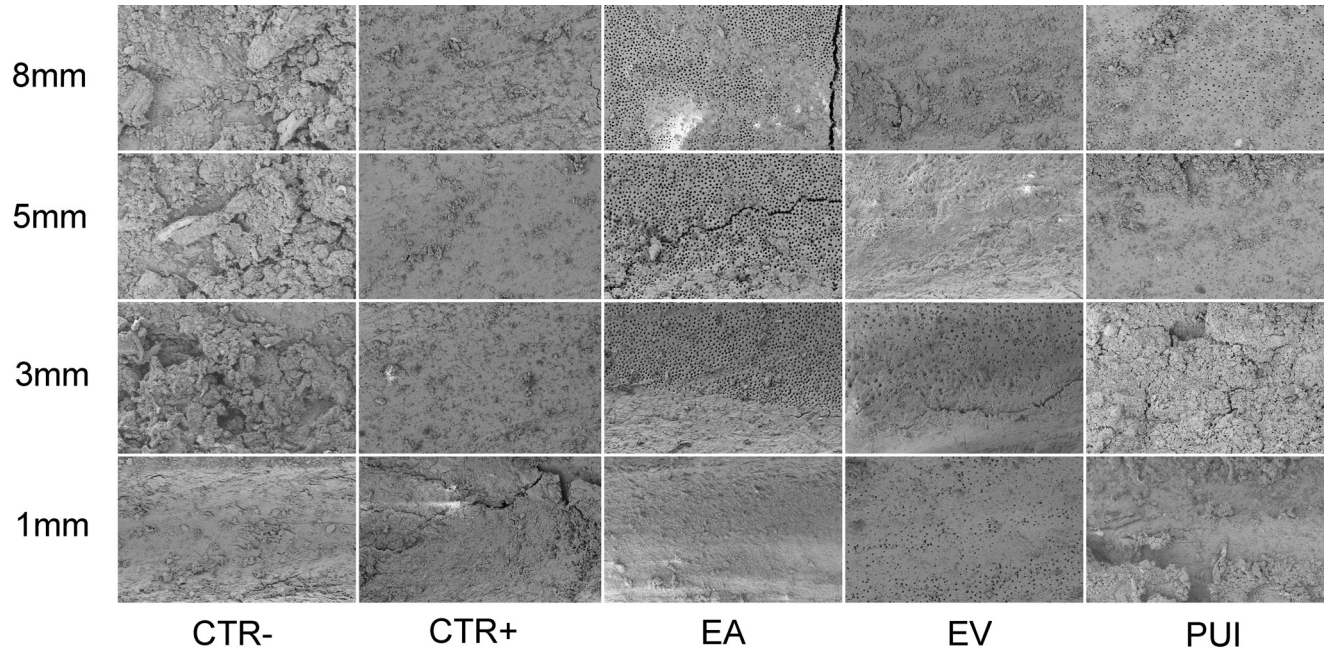

Figure 1. Field emission scanning electron microscopic images at 1, 3, 5, and 8 mm from the apex (1,000×).

Bonferroni, Scheffé, and Sidak multiple comparison tests were used; *P* values were computed and compared with statistical significance at the $P = .05$ level. The data were analyzed with the statistical software STATA (STATA Statistical Software Release 12.1; Stata Corp, College Station, TX).

Results

Kappa test results, with a significance set at 0.5, showed good intra- and interexaminer agreement, with values ranging from 0.90 and above for the different groups. On analysis of the field emission scanning electron microscopic photomicrographs, cleanliness was evaluated, and the results for the various groups are reported in Table 2 as the mean score and standard deviation. At 1 mm from the apex, the dentin surface was covered by heavy coherent deposits of smear layer and debris with irregular shapes and sizes, and the dentinal tubules were not visible in all groups, with the exception of tooth irrigated with 5.25% NaOCl at 37°C delivered with the EV system. The EV group was the only group that at 1 mm showed the root canal to be cleaner than in the other groups; the mean score was significantly reduced (20%, $P < .05$) when compared with that of the negative control group. At 3 mm from the apex, the EA and EV showed statistically significant differences when compared with the negative control group (34% and 24%, respectively). The EA also showed statistically significant differences compared with PUI and the positive control group. When the samples were exposed to NaOCl with sonically driven activation, the effect of NaOCl on the dentinal surface was enhanced, and some of the dentinal tubules were partially opened, with some removal of the smear layer. As the 3 corrections showed, the differences between the negative control (CTR−) and EA (1.5566), CTR− and EV (1.1154), the positive control (CTR+) and EA (1.1912), and EA and PUI (−1.0523) were statistically significant, at least at the 0.05 level, whereas the other differences were not significant. At 5 mm from the apex, the EV, EA, and PUI showed statistically significant reductions of debris when compared with the negative control group (40%, 40%, and 28%, respectively). EV and EA showed statistically significant differences with the positive control group, and the 2 irrigating systems enhanced smear layer removal by 30%. The 3 corrections showed a difference between CTR− and EA (1.8688), CTR− and EV (1.9145), CTR− and PUI (1.3034), and CTR+ and EV (1.2222), all of which are statistically significant, at least at the 0.05 level. Finally, at 8 mm from the apex, it was shown that all the techniques were efficient in improving root canal cleanliness. Moreover, all groups showed increased smear layer removal, moving apically to coronally (Table 2). There was agreement in the differences between the means of CTR− and CTR+ (1.3365), CTR− and EA (2.0498), CTR− and EV (1.8504), and CTR− and PUI (1.5727); the other differences were minor and not statistically significant.

Discussion

The aim of this study was to evaluate the effectiveness of different irrigating systems in removing the smear layer from endodontic walls from the apex to the coronal third. An *in vitro* closed-end canal model was used because it more accurately simulates *in vivo* conditions such as gas entrapment in the root canal and periodontal ligament (14). The removal of the smear layer is usually accomplished by irrigants capable of dissolving both organic and inorganic components (17, 23). The recommended combination is a final rinse of 15% or 17% EDTA solution followed by 1%–6% of NaOCl (4, 11). However, there is no consensus on volume (18, 24), time of application (15, 25), or activation method (26, 27) of irrigating solutions. Recently, different irrigation delivery and activation systems have been proposed to increase both flow and distribution within the root canal system (16). In our study, to increase volume exchange of irrigants at the WL, groups were shaped to a ProTaper F4 (apical size .40, taper 6%) (28). For improved irrigant delivery at the apical third level, apical patency was confirmed (29) after each instrumentation. Analyses of the 4 distances from the apex showed that the EA performed significantly better than the control groups at 5 and 8 mm from the apex and a significant increase of smear layer removal when compared with control groups and PUI at 3 mm from the apex. Similar results were described by Rodig et al (30), who showed significantly greater smear layer removal when the EA was used rather than ultrasonic agitation and

TABLE 2. Cleanliness of Root Canals Treated with Different Methods Expressed as the Mean Score

	CTR−		CTR+		EA		EV		PUI	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1 mm	4.92[a]	0.28	4.50	0.76	4.41	0.87	3.94[a]	0.99	4.56	0.70
3 mm	4.62[bc]	0.77	4.25[d]	0.71	3.06[bde]	0.83	3.5[c]	1.04	4.11[e]	0.96
5 mm	4.69[fgh]	0.75	4.00[il]	0.76	2.82[fi]	0.73	2.78[gl]	0.55	3.39[h]	0.98
8 mm	4.46[mnop]	1.05	3.13[m]	0.64	2.41[n]	0.51	2.61[o]	0.50	2.89[p]	0.76

SD, standard deviation.

Different superscript letters indicate different groups ($P < .005$).

a canal brush. Conversely, these results are in contrast to those from a recent study reporting no significant improvement of smear layer removal with the EA (31). These findings might be attributed to the lower volume of irrigant used (ie, 1 mL 17% EDTA and 3 mL 4% NaOCl) compared with the present study in which 17% EDTA and 5.25% NaOCl were used for longer times and at higher volumes. Ultrasonics showed poor results in the apical third (1 and 3 mm from the apex), which is in agreement with previous authors (15), possibly because of the reduced time of activation (1 minute) and the contact between the ultrasonic file and the canal walls (32). Conversely, other studies (33, 34) have shown that the activation of different concentrations (3% and 5%) of NaOCl with PUI for a period of time from 3 to 5 minutes is sufficient to completely remove the smear layer in instrumented root canals. Some authors showed that files and ultrasonic activation are not efficient in removing the smear layer in straight root canals when using a final flush of 17% EDTA (27). In our research protocol, PUI showed a reduced ability to remove the smear layer along endodontic walls from apex to crown. These findings are confirmed by a recent study reporting better results with the EV and manual activation than with PUI and passive irrigation (35). In our study, the difference of smear layer removal at 5 and 8 mm from the apex between PUI and EV was not statistically significant, but both devices performed significantly better than the control groups. The EV system was introduced in endodontics to solve the air entrapment and irrigant flushing drawbacks at the root end (19). In our study, which is in agreement with the study of Schoeffel (19), the EV system showed the highest degree of cleanliness at 1 mm from the apex. Nevertheless, the EA system showed similar results, if compared with the EV system, regarding the degree of cleanliness at 3, 5, and 8 mm from the apex. This may be explained by the fact that the EA tip activated NaOCl only and it was positioned at 2 mm from the apex, whereas the microcannula of the EV reached the WL, ensuring the irrigating solutions (both NaOCl and EDTA) were refreshed and eliminating the vapor lock at the apex as confirmed by other studies (20, 21).

Conclusion

Based on the results of this study, the activation/delivering of 5.25% NaOCl at 37°C with different irrigating systems is not a currently viable technique for the consistent removal of the smear layer from endodontic walls. Nevertheless, the EV and EA showed statistically significant results at 1, 3, 5, and 8 mm and 3, 5, and 8 mm from the apex, respectively, thus showing how combinations of activation/delivery systems may help in straightforward clinical protocols. Further methodologically sound *in vivo* investigations of irrigating solutions and activation/delivery systems are needed for an appropriate evaluation of the cleanliness of endodontic canals.

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The authors deny any conflicts of interest related to this study.

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