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Efficacy of Different Endodontic Irrigant Activation Systems on Smear Layer Removal and Canal Cleanliness: Comparative Scanning Electron Microscopic Study

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Abstract

AIM: This study assessed the effectiveness of 5 different irrigant activation systems on canal cleanliness and removal of smear layer from root canals.

METHODS: A total of 110 mandibular premolars with straight root canal were assigned to five groups (n = 20): conventional needle irrigation, passive ultrasonic activation, sonic activation with EndoActivator, negative apical pressure EndoVac (EV), or EDDY system, besides a control group (n = 10). All teeth were prepared to size 40, and irrigated with NaOCl (5.25%) according to the respective technique. Roots were split longitudinally and subjected to scanning electron microscopic analysis. The presence of smear layer and debris was evaluated using 5-grade scoring systems with ×1000 and ×400 magnification, respectively. Data were analyzed at 5%.

RESULTS: Regarding the smear layer, activation with EV and ED was significantly more effective than other activation groups ($p < 0.05$). Activation of the irrigant significantly improved removal of debris ($p < 0.05$).

CONCLUSION: No activation technique was able to eliminate smear layer and debris completely from root canals, nevertheless, EDDY is significantly better in removing debris and smear layer from the apical third of the canal.

Introduction

The goal of root canal treatment is the eradication of intraradicular infection [1], [2]. Irrigation plays an essential role in cleaning and disinfecting the main root canal as well as isthmuses that are frequently inaccessible to endodontic instruments [3].

Sodium hypochlorite (NaOCl) has been considered the most widely used endodontic irrigating solution. it has tissue dissolving activity and acts as a bactericidal agent. However, its effectiveness is limited in the removal of the endodontic smear layer. Chelating irrigants, such as ethylenediaminetetraacetic acid (EDTA), have shown their effectiveness in removal of smear layer and root canal system disinfection [4], [5]. During root canal treatment, the accumulation of hard tissue debris which produced during the shaping procedures poses a greater problem as it facilitates the formation of a bacterial biofilm [4]. Bacterial biofilm interferes with root canal disinfection and sealing ability [5], [6].

An effective irrigation delivery system is required for the irrigants to reach the working length (WL). Such a delivery system should have adequate flow and deliver sufficient volume of irrigant all the way to WL to be effective in debriding the complete canal system [7]. It has been reported that manual irrigation was ineffective for the removal of smear layer and debris from anatomical complexities of the root canal system [8], [9].

Tronstad was the first to report the use of sonic instruments for endodontic purposes in 1985 [10]. Sonic irrigation is different from ultra-sonic irrigation in that it operates at a lower frequency (1–6 kHz) and produces smaller shear stresses. The sonic energy also generates significantly higher amplitude or greater back-and-forth tip movement [10].

The EndoActivator (EA) (Dentsply, Maillefer, Ballaigues, Switzerland) can allow the penetration of the irrigant agent within the dentinal tubules of the root canal system by means of continuous sonic movement [11].

EndoVac (EV) (Discus Dental, Culver City, CA, USA) represents a novel approach to irrigation, instead of delivering the irrigant through the needle, as it's based on a negative-pressure approach whereby the irrigant placed in the pulp chamber is sucked down the root canal and back up again through a thin needle with a special design [12].

Innovative sonic-powered irrigation (EDDY) uses flexible polyamide tips to prevent cutting dentin and changing root canal morphology during sonic activation at high frequency, which is useful in removing debris and organic tissues from root canal [13], [14].

To the best of our knowledge, there are very limited data in the literature comparing EDDY system with other systems for smear layer removal. Hence, the aim of this study is to evaluate and compare five different endodontic irrigation systems including conventional needle irrigation (CNI), passive ultrasonic, EA, EV, and EDDY irrigation in the efficacy of canal cleanliness and smear layer elimination using scanning electron microscope (SEM).

Materials and Methods

Specimen selection

Based on the data of a previous study [15], a total of 110 permanent mandibular first premolar teeth that were extracted from 15- to 25-year-old patients during orthodontic treatment were used in this study. Radiographs of the teeth were taken in both the mesiodistal and buccolingual aspects to confirm a single root canal and no previous root canal treatment. Teeth with root lengths shorter than 13 mm, restoration, caries, cracks, fractures, or immature apexes were excluded from the study.

After extraction, teeth were stored in 2% thymol solution at room temperature. Inclusion and exclusion criteria were verified under ×20 magnification microscope. After the access cavity created under endodontic microscope, a size 10 K-file (Dentsply, Maillefer, Ballaigues, Switzerland) was inserted into the canal until the instrument tip were barely visible at the apical foramen.

The root lengths were standardized 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 melted wax to obtain closed canal system according to Tay *et al*. [16], to prevent the wax from entering the canal, a size 10 K-file were inserted before the apex sealing. Specimens were randomly divided into five experimental groups (n = 20) and control group (n = 10).

This study was performed at the Department of Endodontics of the Mansoura University (Mansoura, Egypt), between April and September 2021. This study was approved by the Mansoura University Ethical Committee (process no. A09021121).

All the patients were informed and consented to transfer their teeth for the study.

Root canal preparation

A glide path was established in all groups with a size 15 reamer (VDW, Munich, Germany) up to WL. Root canals were instrumented using ProTaper Ni-Ti rotary instruments (Dentsply, Maillefer, Ballaigues, Switzerland) according to the manufacturer's instructions until the ProTaper F4 file reached the WL by using an electric motor (VDW Silver, VDW) in a rotation motion. According to the manufacturers' instructions, the instrument was used with a gentle in-and-out pecking motion of about 3 mm in amplitude. After 3 pecking motions (one cycle), the ProTaper instrument was withdrawn from the canal and cleaned. Each time the instrument was removed, 5 mL 5.25% NaOCl was applied using a 30-gauge open-end tip needle (Endo-EZE, Ultradent, South Jordan, UT, USA) adapted to a disposable plastic syringe and inserted as deep as possible without binding, respecting the maximum distance of 2 mm from the WL. Root canal preparation was completed after 4 cycles of three pecking motions. Instruments were discarded after four uses or if an unwinding occurred. After completion of preparation, a final rinse with 5 mL 5.25% NaOCl was performed.

Final irrigation protocols

Specimens were randomly divided into five experimental groups (n = 20) and control group (n = 10).

Group 1 (irrigation with conventional needle irrigation): Final irrigation was done with 5 mL 5.25% NaOCl, followed by 5 mL of 17% EDTA, followed by 5 mL 5.25% NaOCl. Irrigation was done using a 30-gauge needle (NaviTip, Ultradent, South Jordan, UT, USA), no activation was applied in this group [17].

Group 2 (Passive Ultrasonic Irrigation [PUI]): Final irrigation was conducted with passive ultrasonic activation of the irrigants, using a noncutting size 25 IRRI S ultrasonic tip (VDW) driven with an ultrasonic device, with the power setting at 30% (VDW Ultra, VDW). The ultrasonic file was placed into the canal 2 mm short of the WL without touching the walls and was activated at power setting of 4. The final irrigation consisted of 5 mL of 5.25 % NaOCl with 1 min of activation. This was followed by 5 mL 17%EDTA, with 1 min activation and then by 5 mL of 5.25% NaOCl which was also activated for 1 min [18].

Group 3 (Sonic activation with EA): The final irrigation performed with size 15.,02 taper EA tip at 2 mm from WL with the highest frequency (166 Hz) and consisted of 5 mL of 5.25% NaOCl with 1 min of sonic activation. This was followed by 5 mL 17% EDTA, with 1 min activation and then by 5 mL of 5.25% NaOCl which was also activated for 1 min [19].

Group 4 (EV activation with apical negative pressure): Final irrigation was conducted with the EV (Discus Dental, Culver City, CA, USA) which was used according to manufacturer's instructions. The procedure consisted of 4 cycles of irrigation, each beginning with 30 s of vacuum assisted irrigation followed by 30 s of "soaking" (leaving the solution in the canal with no action). The first cycle was done using the macrocannula which was inserted to 1 mm from WL while the three following cycles were performed with the microcannula which was inserted to 9 mm from WL. In the first and second cycles 5.25% NaOCl was used. In the third cycle 17% EDTA was used which was followed by the forth cycle in which 5.25% NaOCl was used again [20].

Group 5 (Sonic activation with EDDY [ED]): The procedure was similar to that used in the EA group, but the activation was performed at 2 mm from WL with the EDDY tip (VDW), coupled to an air scaler (SonicFlex, intensity mode III; KaVo, Biberach, Germany) with a frequency of 6000 Hz.

Group 6 (Control group): not irrigated.

After these procedures, each sample was immediately irrigated with 10 mL distilled water and dried with # 40 ProTaper paper points.

Examination of specimens with SEM

After the coronal portion of the root canals was covered with a cotton piece, longitudinal sulcus was generated along buccal and lingual surfaces of all specimens by using a diamond disc without water cooling or perforating the inner surface of the root canal system. Specimens were sectioned longitudinally using chisel. One half of the root canal was selected randomly and each specimen was dehydrated in 50%, 70%, 80%, and 100% series of ethanol solutions.

To ensure standardization of the area examined for each sample, the central beam of the SEM was directed to the center of each third of the canal space being analyzed. This distance was 9 mm (location C), 6 mm (location M), and 3 mm (location A) from the apex. The SEM operator did this under ×50 magnification. Magnification was then increased to ×1000 magnification for the smear layer and ×400 for debris. The cleanliness of the canals was evaluated visually using the 5-step scale method by Rodig *et al*. [21]. The photomicrographs were analyzed by two examiners who were specialists in endodontics and were blind to group status. The presence of a smear layer was evaluated from images at ×1000 magnification (Figure 1) using a scale of 5 scores as follows:

1. No smear layer and dentinal tubules open
2. Small amounts of scattered smear layers and dentinal tubules open
3. Thin smear layer and dentinal tubules partially open (characteristic image of crescent)
4. Partial covering with a thick smear layer
5. Total covering with a thick smear layer The specimens were gold-sputtered and examined under SEM (JSM–5600LV, JEOL, Tokyo, Japan) at 20 kV.

The presence of debris was evaluated from images at ×400 magnification (Figure 2) using a scale of 5 scores as follows:

1. Clean root canal wall and only few small debris particles
2. Few small agglomerations of debris
3. Many agglomerations of debris covering <50% of the root canal wall
4. More than 50% of the root canal wall covered by debris
5. Complete or nearly complete root canal wall covered by debris.

Statistical analysis

Two observers evaluated the SEM images three times independently with 1-week interval without knowledge of the previous results. To validate the subjective findings, weighted coefficient kappa (Kw) was used to measure interobserver and intraobserver reproducibility in separate time periods and for each observer. The differences between irrigation techniques were compared statistically by using the Kruskal–Wallis nonparametric analysis of variance. Mann–Whitney U-test was used for post hoc comparisons. Additionally, scores were counted and analyzed using the monte carlo test. The significance level for all statistical analyses was set at $p < 0.05$. Statistical analysis was performed with SPSS for Windows-16.0 software package (SPSS Inc, Chicago, IL).

Results

Results of the SEM analysis regarding remaining debris and smear layer were summarized in Tables 1 and 2. None of the irrigation techniques completely removed debris and smear layer.

Debris

There was a significant difference between the (control) group and the remaining groups in coronal, middle and apical thirds, also a statistically significant difference between the four activation groups ($p < 0.05$) and (CNI) group was recorded ($p < 0.05$) in coronal, middle and apical thirds. No statistically significant difference was reported among the four activation groups ($p > 0.05$) in coronal, middle, and apical thirds, except for (EDDY) which showed a significant difference in apical third compared to the other activation groups. No significant differences between coronal, middle, and apical levels within the same group ($p < 0.05$).

Table 1: Median scores for evaluation of smear layer and residual debris

	Coronal	Middle	Apical	Total
Smear Layer	Median (1^{st}–3^{rd} Q)	Median (1^{st}–3^{rd} Q)	Median (1^{st}–3^{rd} Q)	Median (1^{st}–3^{rd} Q)
Control	5 (4–5)^{Aa}	5 (5–5)^{Aa}	5 (4–5)^{Aa}	5 (4–5)
CNI	3 (2–5)^{Ab}	4 (3–4)^{Ab}	4 (3–5)^{Bb}	4 (3–4)
PUI	3 (2–4)^{Ac}	3 (2–4)^{Ac}	3 (3–4)^{Ac}	3 (2–4)
EA	3 (2–4)^{Ad}	2 (2–4)^{Ad}	3 (3–4)^{Bc}	3 (2–4)
EV	2 (2–3)^{Ad}	2 (2–4)^{Ad}	3 (2–4)^{Bd}	2 (2–4)
EDDY	2 (1–3)^{Ad}	3 (2–3)^{Ad}	3 (2–4)^{Bd}	3 (2–3)
Kruskal Wallis test	KW = 18.41 p = 0.001*	KW = 23.13 p < 0.001*	KW = 23.51 p ≤ 0.001*	
Debris				
Control	5 (4–5)^{Aa}	5 (4–5)^{Aa}	5 (5–5)^{Aa}	5 (4–5)
CNI	3 (2–4)^{Ab}	3 (3–4)^{Ab}	3 (3–4)^{Ab}	3 (3–4)
PUI	2 (1–3)^{Ac}	2 (1–3)^{Ac}	2 (2–3)^{Ac}	2 (1–3)
EA	2 (1–2)^{Ac}	2 (1–2)^{Ac}	2 (1–3)^{Ac}	2 (1–2)
EV	2 (2–3)^{Ac}	2 (2–3))^{Ac}	2 (1–3)^{Ac}	2 (2–3)
EDDY	2 (1–3)^{Ac}	2 (2–3)^{Ac}	2 (1–2)^{Bd}	2 (1–3)
Kruskal Wallis test	KW = 27.45 p < 0.001*	KW = 36.11 p < 0.001*	KW = 37.73 p < 0.001*	KW = 98.64 p < 0.001*

Similar superscripted Small letters in same column denote non sign difference between groups. Similar superscripted Capital letters in same row denote non sign difference between thirds.

Smear layer

A statistically significant difference was recorded between coronal, middle, and apical levels within the same group ($p < 0.05$). There was a significant difference between the(control) group and the remaining groups in coronal, middle and apical thirds, also a statistically significant difference between four activation groups ($P < 0.05$) and (CNI) group was recorded ($p < 0.05$) in coronal, middle and apical thirds. (PUI) and (EA) showed significant difference in coronal and middle thirds ($p < 0.05$) with no significant difference in apical third ($p > 0.05$), there was no significant difference between (EDDY) and (EV) groups in all thirds ($p > 0.05$), while there was a significant difference in apical third of (EDDY) and (EV) groups compared to the other activation groups ($p < 0.05$).

Table 2: Scores for evaluation of smear layer and residual debris (monte carlo)

Smear Layer	Coronal n (%)	Middle n (%)	Apical n (%)	MC p =
Control				
3–5	10 (100)	10 (100)	10 (100)	....
CNI				
1–2	7 (35.0)	7 (35.0)	6 (30.0)	0.99
3–5	13 (65.0)	13 (65.0)	14 (70.0)	
PUI				
1–2	12 (60.0)	12 (60.0)	9 (45.0)	0.545
3–5	8 (40.0)	8 (40.0)	11 (55.0)	
EA				
1–2	14 (70.0)	15 (75.0)	11 (55.0)	0.553
3–5	6 (30.0)	5 (25.0)	9 (45.0)	
EV				
1–2	13 (65.0)	12 (60.0)	18 (90.0)	0.07
3–5	7 (35.0)	8 (40.0)	2 (10.0)	
EDDY				
1–2	13 (65.0)	14 (70.0)	19 (95.0)	0.05
3–5	7 (35.0)	6 (30.0)	1 (5.0)	
MC p =	0.001*	0.002*	0.003*	
Debris				
Control				
3–5	10 (100)	10 (100)	10 (100)	.
CNI				
1–2	8 (40.0)	6 (30.0)	7 (35.0)	0.07
3–5	12 (60.0)	14 (70.0)	13 (65.0)	
PUI				
1–2	12 (60.0)	13 (65.0)	13 (65.0)	0.931
3–5	8 (40.0)	7 (35.0)	7 (35.0)	
EA				
1–2	14 (70.0)	15 (75.0)	14 (70.0)	0.503
3–5	6 (30.0)	5 (25.0)	6 (30.0)	
EV				
1–2	13 (65.0)	14 (70.0)	13 (65.0)	0.754
3–5	7 (35.0)	6 (30.0)	7 (35.0)	
EDDY				
1–2	13 (65.0)	12 (60.0)	19 (95.0)	0.003*
3–5	7 (35.0)	8 (40.0)	1 (5.0)	
MC p =	<0.001*	<0.001*	<0.001*	

Discussion

Removal of the smear layer with different irrigation protocols is an essential procedure for successful treatment outcomes [22], [23]. The reason behind is that the smear layer can form a barrier and promote the invasion of bacteria in the dentinal tubules. Therefore, its removal will promote greater penetration of irrigating substances to reach underlying accessory canals and dentinal tubules, allow greater penetration of intracanal medications and also promote a better seal between dentin and filling material [13], [24].

The purpose of this study was to assess the effectiveness of different irrigant activation systems in removing smear layer and dentin debris at coronal, middle, and apical thirds of root canals of mandibular first premolar teeth.

An *in vitro* closed-end canal model was used in this study because it more accurately simulates clinical conditions such as gas entrapment in the root canal and periodontal ligament [17], Boutsioukis *et al*. [25] reported that an increase in root canal taper and apical preparation size enhances the irrigant replacement. Therefore, the root canals were enlarged to an apical size of # 40 to improve the performance of irrigation.

The irrigating solution used during the cleaning procedures of the root canals was NaOCl because of its antimicrobial and tissue dissolving ability [26]. Also, EDTA solution was used during the cleaning procedures because of its ability to remove the inorganic part of smear layer [27], [28].

For debris removal, all the studied groups were found to be superior with significant difference to control group, with no significant difference among each other or in the same group (coronal, middle, and apical), except for EDDY system, which showed the lowest debris score at the apical third compared to other systems.

The superior efficacy of debris removal by EDDY system at the apical third can be explained as the manufacture claimed that EDDY is made from a safe and flexible polymer material, unlike the stiff metal of irrigation needles and ultrasonic tips. Thus, it can easily go around curves – maintaining the integrity of the root canal anatomy with reliable removal of residual tissue and dentine chips.

Overall, in this study the average amount of smear layer removal of the studied groups was reduced from the coronal to the apical root thirds, this may be

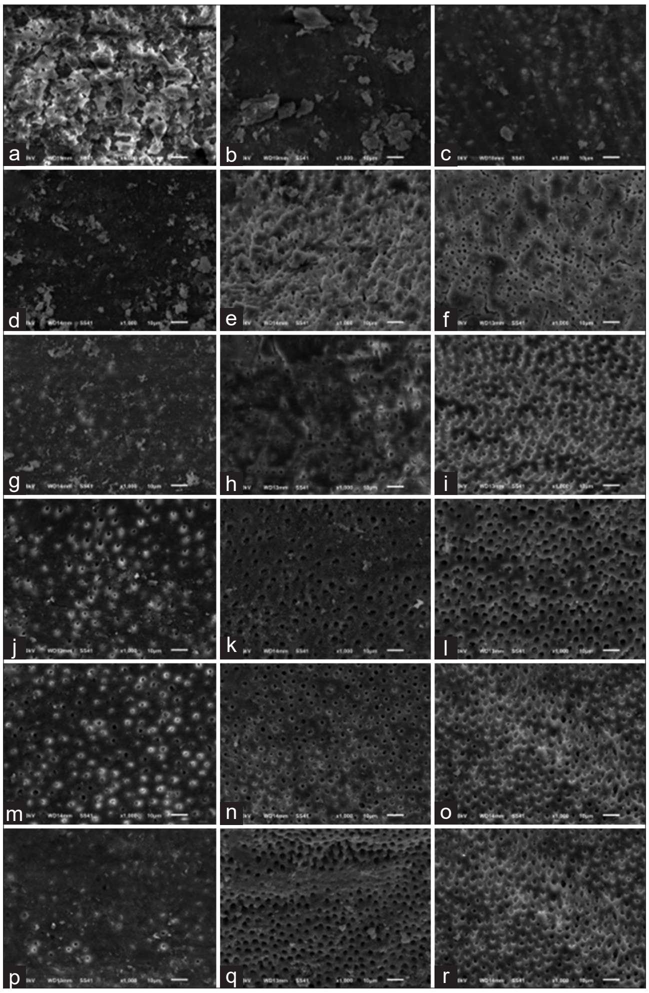

*Figure 1: Typical SEM micrographs showing the coronal, middle, and apical segments of root canals in control group, ([a], apical third; [b], middle third; [c], coronal third), CNI ([d], apical third; [e], middle third; [f], coronal third); PUI ([g], apical third; [h], middle third; [i], coronal third), Endoactivator ([j], apical third; [k], middle third; [l], coronal third), Endovac ([m], apical third; [n], middle third; [o], coronal third) and EDDY ([p], apical third; [q], middle third; [r], coronal third) at *1000 magnification*

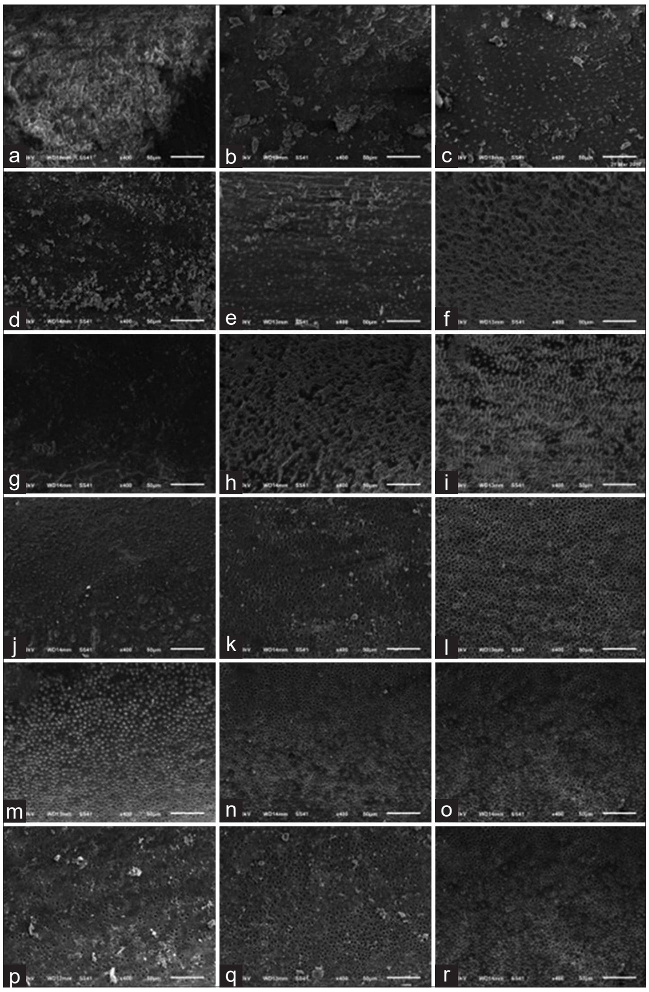

*Figure 2: Typical SEM micrographs showing the coronal, middle, and apical segments of root canals in control group, ([a], apical third; [b], middle third; [c], coronal third), cni ([d], apical third; [e], middle third; [f], coronal third); PUI ([g], apical third; [h], middle third; [i], coronal third), Endoactivator ([j], apical third; [k], middle third; [l], coronal third), Endovac ([m], apical third; [n], middle third; [o], coronal third) and EDDY ([P], apical third; [q], middle third; [r], coronal third) at *400 magnification*

because the dentinal tubules number and diameter were reduced toward the apical root third [29] and due to the sclerotic dentin present at the apical root third, which shows a higher resistance of irrigant solutions to remove the smear layer and also to endodontic sealer penetration [30]. The results of this study were in agreement with previous studies, which indicated that irrigating solutions were less effective in the apical root third [31]. Although the activation with different irrigation systems showed an obvious decrease in the debris and smear layer amount of the root canal system compared to the control group ($p < 0.05$), none of them were able to remove completely the smear layer present in the root canal system. These findings were consistent with previous studies [32], [33], [34].

In the present study, comparing CNI and four activation systems, it was found that irrigation activation/delivering techniques are more effective in removing the smear layer than the CNI technique. This can be illustrated by the flushing action of syringe irrigation which is relatively weak and is dependent not only on the anatomy of the root canal but also on the depth of placement and the diameter of the needle. It has been shown that irrigants can only progress 1 mm beyond the tip of the needle [35]. A plausible description for obtaining clean canals due to irrigant activation is that increased frequency of EA and EDDY systems and acoustic streaming and cavitation generated by PUI system led to an increase in flow velocity which aids in efficient debris dislodgement [31], [36]. Also, irrigant activation by EV system increases the dentinal debris removal from the apical third of the root canal due to the negative pressure created, the irrigant gets pulled down the walls of the canal up to the apex, thus forming a quick turbulent force of current toward the microcannula's terminus may help in necrotic tissue debridement [30].

As regards to the smear layer removal at the apical third, the results of this study revealed that EDDY and EV systems had the lowest smear layer scores among the studied groups. This can be explained to that EDDY works with 6000 Hz that creates a three-dimensional movement. The polymer material of EDDY causes a highly effective oscillation in the irrigant that triggers two cleaning effects cavitation and acoustic streaming. However, further research is warranted to provide a more detailed understanding of the oscillation pattern of the EDDY tips. Moving to EV system, due to the negative apical pressure created, the irrigant gets pulled down the walls of the canal up to the apex, thus forming a quick turbulent force of current toward the microcannula's terminus. The microcannula's orifices clear the debris from the closed apical end of the root canals. This mechanism allows for an effective irrigation by helping it to overcome the vapor lock [37]. The EV result of this study is in accordance with the results obtained by Ribeiro *et al*. [38] who demonstrated a significant superiority of the EV system in the removal of debris from the apical portion of the root canal. Yet another study by Siu and Baumgartner [39] demonstrated that EV irrigation system to be significant in having less debris at 1 mm from the WL in comparison with the CNI.

Next to the EDDY and EV systems, the EA system demonstrated a better efficacy in removing the smear layer in the cervical and middle thirds of the instrumented root canals compared to the PUI and CNI. These results were consistent with the findings of the study by Schiavotelo *et al*. [40], who compared non-activated irrigation, PUI and EA to remove the smear layer and found that the EA was more effective. The superior performance of EA in removal of the smear layer from the cervical and middle thirds can be explained to the basis that activation by EA causes vigorous fluid agitation in the pulp chamber. Vibrating the tip in combination with moving the tip up and down in short vertical strokes, synergistically produced a hydrodynamic phenomenon [1]. However, there was no statistically significant difference in the removal of the smear layer between EA system and PUI at the apical region. These findings are in agreement with the study of Urban *et al*. who found that the EA system did not enhance the removal of smear layer as compared with PUI [13].

It was also observed that, at the coronal and middle thirds, there were no notable difference between the EA system and the EV system. However, at the apical third, the EA group demonstrated inferior smear layer removal than the EV group. The inferior performance of the EA system in the removal of the smear layer at the apical third could be partially explained by the findings of Jiang *et al*. [41] who found a lot of contact of the EA tip with the dentinal walls, thereby inhibiting the free oscillation of the tip required to generate efficient irrigant streaming and cavitations' effect.

This study concluded that the use of irrigant activation systems (PUI, EA, EV and EDDY) remove smear layer and debris better than CNI (non-activated irrigation). EDDY and EV system were more efficient in "smear layer removal" than other systems at apical third.

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