

Debris and Smear Layer Removal from Oval Root Canals Comparing XP-Endo Finisher, EndoActivator, and Manual Irrigation: A SEM Evaluation

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Abstract

Objective This study aimed to assess and compare XP-Endo Finisher (XP) cleaning efficiency with respect to the amount of remaining debris and smear layer versus Max-I-Probe needle (CI), EndoActivator device (EA), and combination of XP-Endo Finisher file with EndoActivator device (XP+EA) in oval root canals.

Materials and Methods This *in vitro* study was performed on 36 extracted single root/canal mandibular premolars. Radiographic images were taken in buccolingual and mesiodistal projections to evaluate the shape of the root canal and determine whether it met exclusion criteria. All teeth were decoronated and prepared using Reciproc (R40). The samples were divided randomly into four groups: CI, EA, XP, and XP + EA. The root canals were irrigated with 5 mL of 17% EDTA and 2.5% NaOCl, respectively. Apart from the CI group, both solutions were activated by using the tested techniques for 1 minute. The teeth were split longitudinally, and the best visible identified sections of the roots were used as the representing samples for scanning electron microscope (SEM) evaluation. Each half was divided into the following three parts: 1 mm from the anatomic apex and a standardized photomicrograph with 500x and 1500x magnifications for debris and smear layer were obtained. A five-grade scoring system was utilized to quantify the results at the coronal, middle, and apical regions. Statistical analysis was performed by using the Kruskal–Wallis and Mann–Whitney U tests.

Results Group differences in debris and smear layer scores were found statistically significant for all locations as well as for overall assessment, except for the coronal third. Intragroup comparison of debris and smear layer in CI, EA, and XP had the minimum score at the middle third, with no significant difference compared with the coronal and apical thirds. XP + EA had less debris and smear layer score at the coronal third, significantly different from apical third.

CI and EA had less debris and smear layer compared with XP and XP + EA at all locations with a significant difference at the middle and apical third ($p < 0.05$).

Conclusion EA and CI showed less debris and smear layer than XP and XP + EA in the middle and apical third. The use of the XP in conjunction with the present irrigation protocol failed to have debris-free dentin surface in the apical portion of most of the root canals.

Keywords

- smear layer
- irrigation protocol
- Scanning Electrical Microscope
- EndoActivator
- XP-Endo Finisher

Introduction

Endodontic management of preparing an oval root canal is considered one of the most significant clinical challenges.¹ The NiTi rotary instruments form a round bulge preparation and leave intact lingual and buccal extensions filled with debris and smear layer,² performing comparably poor in long oval canals. A study by Metzger et al found that rotary instruments were unable to prepare nearly 35% or more of the canal surface.³ Besides harboring bacterial biofilms and pulp remnants, these recesses could be filled with dentin chips. The dentin chips will be produced and compacted during canal shaping,⁴ which can interfere with the quality of obturation.⁵ Wu et al claimed that canal anatomical complexity is one of the main challenges in managing infections during canal instrumentation.¹

Jou et al defined the long oval canal as having a maximum diameter of two to four times the minimum diameter and a maximum diameter of two times the minimum diameter of an oval canal.⁶ In the apical third of the human teeth, the incidence of long oval root canals is approximately 25% in mandibular incisors, greater than 50% in maxillary second premolars, and 25 to 30% in distal roots of mandibular molars.¹

Different irrigation techniques and devices are currently being used to enhance root canal system disinfection. The manual or conventional needle irrigation system is one of the most commonly used methods of irrigation, with reasonable control over the penetration of the needle and the amount of the provided irrigant.⁷ As a sonic system, it has been proved that EndoActivator System (Advanced Endodontics; Santa Barbara, CA) eliminates the smear layer and dislodges artificial biofilm lumps inside curved canals when used with other demineralizing agents like EDTA.⁸

The difficulty of smear layer removal in the apical region could be caused by the inability to deliver agents such as NaOCl and EDTA, due to the smaller dimensions of the apical canal, which obstructs irrigation delivery.⁹ In addition, the presence of smear film can block or prevent direct contact of antibacterial medicaments with the microorganism which could infect the dentinal tubules. The assessment of debris and the existence of the smear surface requires higher magnification (200x–2000x), which can only be accomplished by using scanning electron microscope (SEM).¹⁰

Recently, XP-Endo Finisher has been developed as a highly flexible universal NiTi made instrument measured 0.25 mm at the tip and zero taper (25/.00) that can expand itself up to 3 mm or hundredfold of corresponding sized file.¹¹ It is developed using NiTi MaxWire alloy (Martensite-Austenite Electropolish Flex), which is capable of working in mixed phases of Martensite and Austenite. This material reacts at different temperature levels with high flexibility that shows unparalleled resistance to cyclic fatigue developed and can be used after any ISO 25 or more root canal preparation. The result enables mechanical cleaning of the canal in regions that could not be touched. According to the manufacturer's argument, the adjustment of the file to root canal cross-section is likely expected to restrict the potential accumulation

of debris in unprepared sections in an oval canal with the preservation of dentin.

The purpose of this study was to evaluate XP-Endo Finisher's effectiveness on debris and smear layer removal in oval canal cross-sections compared with Max-I-Probe needle, EndoActivator device, and combination of XP-Endo Finisher file and EndoActivator device.

Material and Methods

Teeth Selection and Preparation

Upon approval by the Ethics and Research Committee (RD-2016/2017-02), teeth were collected and then soaked in 2.5% NaOCl for 48 hours to eliminate organic debris. Afterward, the external root surfaces were scaled using ultrasonic instruments, washed with distilled water, and stored in saline until they were used.

The inclusion criteria was oval canal with a straight root canal or curvature of less than 20°, in concordance with Schneider.¹² Each tooth was radiographed in mesiodistal and buccolingual directions to determine the shape of the root canal and find out whether there are any criteria for exclusion. The oval canal of the root canal was determined by measuring maximum diameter of up to two times greater than the minimum diameter at 5 mm.¹ The exclusion criteria were teeth with variant root canal anatomy, previous root canal treatment, open apices, internal or external root resorption, caries, calcification, visible cracks, fracture, and apical diameters larger than size #30.

Freshly extracted 36 single canal lower premolars were included in the study.

At the cemento-enamel junction (CEJ), the teeth were sectioned using diamond disk. Patency of root canal was established by inserting #10 hand K-file through the apical foramen before canal preparation. Two mm of root apices were sealed with melted beading wax (Associated Dental Products Ltd; Wiltshire, UK) and polyvinyl siloxane PVS (Zhermack SpA, Badia Polesine, Italy) to simulate the vapor lock effect.

Each canal was checked with #20 hand K-file. If it reached the working length, no further preparation was required. If the canal was narrower, then it was prepared until #20 K-file could freely reach the working length to provide a glide path along with 1 mL saline irrigation. Reciproc NiTi instrument (VDW; Munich, Germany) size 40 with taper 0.06 was used to prepare all root canals in crown down direction. The R40 instrument was operated in reciprocal movement using 6:1 contra-angle handpiece, driven using an electric motor (VDW Silver; VDW GmbH, Munich, Germany). Working in-and-out pecking motion of approximately 3 mm and between every pecking motion, the canal was irrigated by 2 mL 2.5% NaOCl and recapitulated using #20 K-file. After that, the canals were dried with absorbent paper points, and cotton pellet placed to protect the canal orifices.

Final Irrigation Procedures

After the root canals had been biomechanically prepared, two buccolingual longitudinal grooves were cut along the

length of the root. Colored gutta-percha cone was fitted inside the canal to be an indicator for measuring the longitudinal groove depth without perforating the canal. This step was taken to avoid any intrusion of the cutting disc into canals that would contaminate the specimens by splattering the cutting debris into the canal.⁸

The samples were randomly coded with a random 4-digit alphanumeric code as a way of controlling operator bias.

Based on the final irrigation protocol, the teeth were randomly assigned into four groups:

CI Group ($n = 9$): Max-I-Probe; 5 mL 17 % EDTA left *in situ* for 1 minute, then 5 mL 2.5% NaOCL irrigation using Max-I-Probe 30-G needle for 1 min and no further irrigant agitation was undertaken.

EA Group ($n = 9$): EndoActivator (Dentsply Tulsa); 5 mL of 17% EDTA left *in situ* for 1 minute, then 2.5 mL 2.5% NaOCL was agitated using EndoActivator blue tip (35/0.04) at 10,000 cycles/min for 1 minute and finally 2.5 mL 2.5% NaOCL flushing using Max-I-Probe 30-G needle.

XP Group ($n = 9$): XP-Endo Finisher file; 5 mL of 17% EDTA left *in situ* for 1 minute, then 2.5 mL 2.5% NaOCL was agitated using XP-Endo Finisher file rotating at 800 rpm and reaching the working length. Slow and gentle 7 to 8 mm lengthwise movements of XP-Endo Finisher file was made for 1 minute and finally 2.5 mL 2.5% NaOCL flushing using Max-I-Probe 30-G needle.

XP + EA Group ($n = 9$): 5 mL of 17% EDTA left *in situ* for 1 minute, then 2.5 mL 2.5% agitated with the blue tip of the EndoActivator (35/0.04) for 1 minute at 10,000 cycles/min, and finally 2.5 mL 2.5% NaOCL was agitated using XP-Endo Finisher file.

After final rinse in all groups, activity of the NaOCL was stopped by saline and kept at 4°C until sectioning protocol was initiated.⁸

Scanning Electron Microscopy (SEM) Analysis

Each sample was vertically split by applying slight pressure and using mallet into the longitudinal groove. The half encountering the most detectable part of the apex was selected, coded, and examined under the stereomicroscope under 25x magnification (Tessovar; Leitz, Oberkochen, Germany).

Then all the sections were prepared for SEM analysis (SEM 5600; JEOL Ltd, Tokyo, Japan). The sections were dehydrated using 50 percent, 70 percent, 90 percent and 100 percent ethyl alcohol for 8 hours,¹³ then permitted for air-drying for 72 hours in a desiccator, sputter coated with a gold-palladium layer of 20 nm, fixed on aluminum stubs, and evaluated using SEM.

Serial SEM digital photomicrographs were acquired at different magnifications using a Genesis 5.21 software (EDAX Laboratories, Prairie View, IL). The images were arranged, so that a horizontal panoramic view was created at low magnification (18x) and high magnifications (500x, 1500x) at the apical (1–2), middle (5–6), and coronal (10–12) levels from the working length.

Image acquisition in the most visible areas of the specimen was performed with a magnification of (500x) for debris

and (1500x) for smear layer analysis. Images were projected onto a large screen in a darkened classroom for evaluation. The evaluators were advised to strictly apply the Hülsmann criterion,¹⁰ and each evaluator gave an individual score independently in a blinded manner.

The absence and presence of the debris was assessed using the following scores: score 1 = clean canal wall, few debris particles; score 2 = few small agglomerations; score 3 = many agglomerations, less than 50% of the canal wall covered; score 4 = more than 50% of the canal wall covered with debris; and score 5 = complete coverage of the canal wall by debris.

The absence and appearance of the smear surface was assessed using the following scores: score 1 = no smear layer, orifices of the dentinal tubules patent; score 2 = small amount of smear layer, some open dentinal tubules; score 3 = homogeneous smear layer along almost the entire canal wall, with only very few open dentinal tubules; score 4 = the entire root canal wall covered with a homogeneous smear layer, with no open dentinal tubules; and score 5 = a thick homogeneous smear layer covering the entire canal wall.¹⁰

Statistical Analysis

The Cohen kappa coefficient checked interexaminer agreement for the SEM assessment. If the two examiners disagreed, they achieved an “acceptable decision” after reviewing the photograph.

Based on the Kruskal–Wallis nonparametric variance and Mann–Whitney U analyses, comparisons between groups are evaluated statistically. The level of statistical significance was set at $p < 0.05$.

Results

The analysis of the interexaminer convention showed good agreement (weighted kappa = 0.66) between both examiners. This meant that the examiners were accurate. ►Table 1 and ►Table 2 show the mean SEM experimental results of canal walls with respect to the scores of the debris and the smear layer, respectively. ►Table 3 demonstrates the summary of the score result of debris and smear layer, while ►Figs. 1 and 2 show represented specimens of SEM micrographs of different groups of root canal dentine surfaces.

Generally, the statistical significance of debris score for the experimental groups at the different locations were identical

Table 1 Mean score of the debris for the coronal, middle, and apical third of the canals of the different experimental groups

Group	Coronal	Middle	Apical
Group CI	1.67 ^a	1.56 ^{aA}	1.89 ^{aA}
Group EA	1.44 ^{aA}	1.44 ^{aA}	1.56 ^{aA}
Group XP	2.44 ^{aA}	2.22 ^{aB}	2.44 ^{aA,B}
Group XP + EA	1.78 ^{aA}	2.22 ^{a,B}	3.00 ^{bB}

Note: Values with the same letters were not statistically different at ($p > 0.05$). Lowercase letters indicate the intragroup comparison, while superscript letters indicate intergroup comparison for the different experimental groups. Group CI (Max-I-Probe), group EA (EndoActivator), group XP (XP-Endo Finisher), and group XP + EA (EndoActivator & XP-Endo Finisher).

to the score for smear layer removal. The Kruskal–Wallis analysis revealed the presence of a significant difference between the different groups ($p < 0.05$), with the exception of the coronal region.

Intragroup comparison of debris and smear layer:

When comparing the amount of smear layer and debris removal at each location of all groups, the middle third was the cleanest area in all groups, except XP + EV that has lower score of smear layer and debris with significant difference detected in coronal third compared with apical third.

Intergroup comparison of debris and smear layer:

Group EA showed less debris at all locations compared with group CI, whereas group CI showed less smear layer than group EA in middle and apical third with no significant difference.

Comparison of group CI with group XP revealed less debris with a significant difference at middle third ($p < 0.043$). In addition, it has less smear layer with a significant difference compared with apical third ($p < 0.004$).

Group EA revealed less debris at all locations with a significant difference at middle third ($p < 0.03$) and apical third

($p < 0.019$) when compared with group XP, whereas group EA had less smear layer when compared with group XP at all locations with significant difference at apical third ($p < 0.013$).

Group CI and EA had higher clean root surface with a significant difference ($p < 0.05$) at all locations except coronal third when compared with group EA + XP.

Discussion

In daily clinical practice, the anatomical variation such as long oval canal has been considered as one of the most difficult challenges for proper cleaning and disinfection. Therefore, freshly extracted lower premolar teeth that have high-incidence for long oval canals were collected for orthodontic reasons from a young patient with vital pulp tissue.¹ Some studies highlighted the importance of standardizing variable factors such as the age of biofilm and the existence of sclerotic dentin.^{14,15}

The root canal was standardized to be straight or with curvature, less than 20° , and 30 G needle was used for irrigation.¹² This will increase the needle depth compared to severely curved roots,¹⁶ and improve the efficacy of irrigation solutions.^{17,18} The application of an irrigation protocol with total irrigation time and volume were standardized, with the alternating administration of 1 minute of 5 mL 17% EDTA and 1 minute of 5 mL 2.5% sodium hypochlorite.⁸ This made the dentin surface of the root canal free of the smear layer³ and increased the frequency of negative bacterial cultures.¹⁹

Although SEM is destructive way of evaluation, it was used as numerical evaluation of the smear layer and debris in the coronal, middle and apical third of the canal, and to study the effectiveness of various irrigation systems in the cleaning of oval root canals which are consistent with other researchers' methodology.^{8,10}

The sampling location was predetermined as apical, middle, or coronal third at low magnification (18x) by measuring the length from apex to 1–2 mm for apical third, 5 to 6 mm

Table 2 Mean score of the smear layer for the coronal, middle, and apical third of the canals of the different experimental groups

Group	Coronal	Middle	Apical
Group CI	1.67 ^{a,A}	1.56 ^{a,A}	1.56 ^{a,A}
Group EA	1.44 ^{a,A}	1.67 ^{a,A}	1.67 ^{a,A}
Group XP	2.33 ^{a,A}	2.33 ^{a,A,B}	2.78 ^{a,B}
Group XP + EA	1.56 ^{a,A}	2.44 ^{b,B}	3.11 ^{c,B}

Note: Values with the same letters were not statistically different at ($p > 0.05$). Lowercase letters indicate the intragroup comparison, while superscript letters indicate the intergroup comparison for the different experimental groups. Group CI (Max-I-Probe), group EA (EndoActivator), group XP (XP-Endo Finisher), and group EA + XP (EndoActivator & XP-Endo Finisher).

Table 3 Summary score of SEM evaluation of remaining debris and smear layer

Score Debris	Group CI			Group EA			Group XP			Group XP + EA		
	C	M	A	C	M	A	C	M	A	C	M	A
Score 1	5	6	3	6	6	5	2	1	0	4	0	0
Score 2	3	2	4	2	2	3	3	5	6	3	7	1
Score 3	0	0	2	1	1	1	3	3	2	2	2	7
Score 4	1	1	0	0	0	0	0	0	1	0	0	1
Score 5	0	0	0	0	0	0	1	0	0	0	0	0
Smear Layer												
Score 1	6	6	4	6	6	4	3	1	0	5	0	0
Score 2	1	1	5	2	2	4	3	5	4	3	6	2
Score 3	1	2	0	1	1	1	1	2	4	1	2	4
Score 4	1	1	0	0	1	0	1	1	0	0	1	3
Score 5	0	0	0	0	0	0	1	0	1	0	0	0

Abbreviation: SEM, scanning electron microscope.

Note: Group CI (Max-I-Probe), group EA (EndoActivator), group XP (XP-Endo Finisher), and group XP + EA (EndoActivator & XP-Endo Finisher) at the coronal (C), middle (M) and apical (A) thirds.

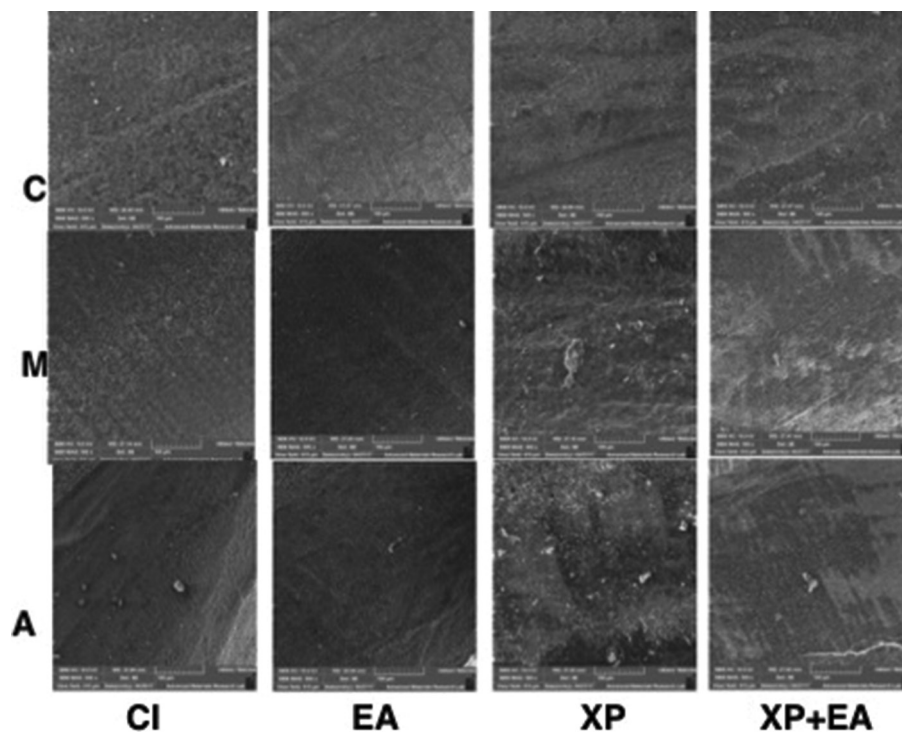


Fig. 1 Representative SEM photomicrographs (500x) of debris of different experimental groups at the coronal (C), middle (M), and apical (A) thirds. Group CI (Max-I-Probe), group EA (EndoActivator), group XP (XP-Endo Finisher), and group XP + EA (EndoActivator & XP-Endo Finisher). SEM, scanning electron microscope.

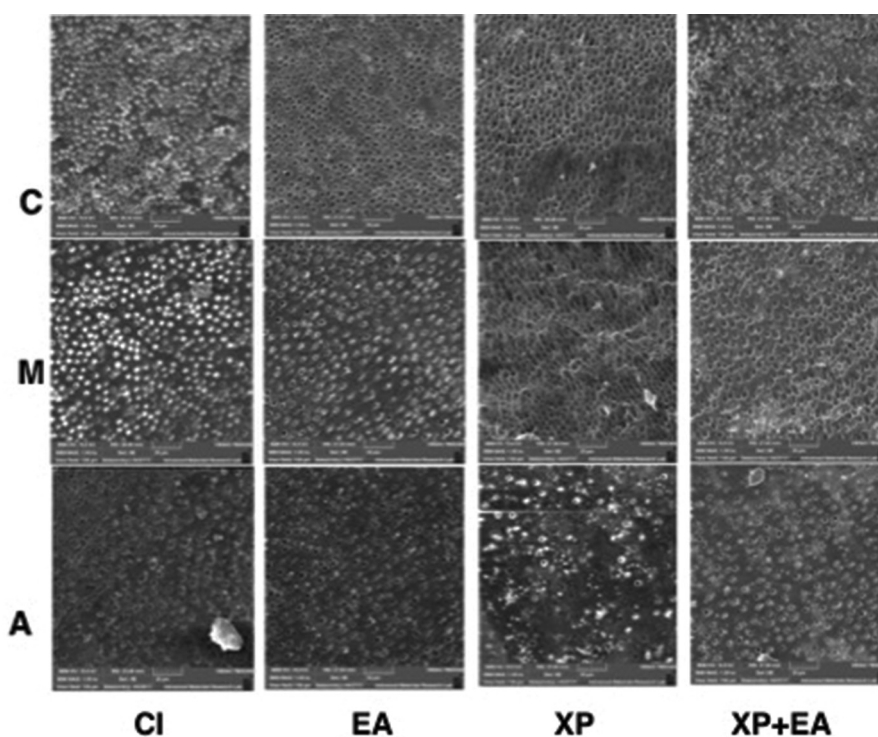


Fig. 2 Representative SEM photomicrographs (1500x) of smear layer of different experimental groups at the coronal (C), middle (M), and apical (A) thirds. Group CI (Max-I-Probe), group EA (EndoActivator), group XP (XP-Endo Finisher), and group XP + EA (EndoActivator & XP-Endo Finisher). SEM, scanning electron microscope.

for middle third and 10 to 12 mm for coronal third, zoomed into a higher magnification (500x) to obtain three sample areas for debris, and zoomed again into the three sample

areas for smear layer at (1500x). The power magnification was limited to (1500x) only, as higher magnification will decrease the evaluated area size.

A simple and logical scoring system was used by two well-trained calibrated examiners, as described by Hülsmann.¹⁰ The examiners evaluated the projected images that have randomized 4–9 digit alphanumeric codes onto a large screen in a darkened class room with concordance between them (kappa test 66%), providing good agreement, as well as the acceptable number of observations (36 sample), which may clearly increase the reliability of the results and reduce the human bias.

Generally, in our study, the finding of debris score for the experimental groups at the different locations were matching the score for smear layer removal, and it showed that the different methods used could not eliminate the debris and smear layer totally along the dentinal walls.

When comparing different experimental groups, the results for the intragroup comparison showed there was no significant influence of the scanned site and position of the debris and smear layer removal, except for combined XP-Endo Finisher with EndoActivator device group.

The middle third was the cleanest third, and the apical were vice versa. This finding is consistent with Heard and Walton SEM analysis when they compared four techniques for root canal preparation using conventional irrigation.²⁰ Mancini and his colleagues found that EndoActivator device showed the best result at the middle third,²¹ and Zivkovic et al showed that coronal and middle thirds were cleaner than apical third.²²

Several studies showed that apical area had higher scores of debris and smear layers relative to coronal areas, but no significant difference was found.^{17,23–25}

For the combined EndoActivator device with XP-Endo Finisher group, the coronal third was cleaner than the middle third, significantly different from the apical third, due to the inability of the old irrigant that has the detached biofilm and loosened debris to be replenished by the new irrigant. Due to the standardized protocol, there was no chance in using the conventional needle to replenish the irrigant.

EndoActivator device and Max-I-Probe had less middle and apical debris and smear layer with a significant difference when compared with XP-Endo Finisher alone or when it was combined with the EndoActivator device.

The EndoActivator device group showed less debris score at all locations compared to Max-I-Probe needle with no significant difference. EndoActivator has polymer-based tips that do not affect the canal wall,²⁶ and their activation method may have made it free of ultramicroscopic debris that seems to collect during the instrumentation of the root canal, especially in the apical part of the root canal.²⁷

Max-I-Probe needle showed less smear layer than EndoActivator group at middle and apical thirds. It may be related to preparation size 40,²⁸ which allowed the irrigation 1–2mm 1mm shorter shorter than the working length and permitted efficient use of gauge #30 irrigation needle tips.²⁹ This improved the irrigation needle's penetration length, which had a good impact on hydrodynamic activation³⁰ and irrigation mechanical effectiveness.³¹ Uroz-Torres et al revealed that there is no considerable difference between

the EndoActivator system and Max-I-Probe needle.³² Some other studies are in contrast with our result and showed that EndoActivator is superior to conventional irrigation.^{33,34}

Our study contradicted with Leoni et al results in which XP-Endo Finisher group has a higher average percentage of cumulative hard-tissue debris reduction (89.7%) than conventional irrigation (45.7%) with no significant difference. It may be related to the different evaluation method since micro CT was used in their study.^{35,36} Also, these findings contradict the result of Elnaghy et al who reached the conclusion that there was no significant difference between XP-Endo Finisher and EndoActivator device at all locations.²³ This may be due to differences between the studies protocol, such as the number of samples, canal shape, canal curvature, and method of assessment.

The XP-Endo Finisher group scores were higher than other groups. It is unexpected, because according to the manufacturer, XP-Endo Finisher is very flexible and can expand its range to 6 mm in diameter or 100-fold larger than an equivalent file, thus enabling mechanical cleaning of the canal in previously inaccessible areas.¹¹ XP-Endo Finisher's company claimed that the apical preparation and vibration of this highly flexible, delicate file within the continuously replaced fluid had a synergistic effect on debridement. However, the results of this study revealed that the XP-Endo Finisher file failed to optimize the removal efficacy of NaOCl to debris and smear layer *in vitro*, which could be related to the fact that it is made of metal, producing more debris and smear layer.³⁷

The combined XP-Endo Finisher with EndoActivator device had more debris and smear layer compared to the other systems. Adding EndoActivator device did not improve the result of XP-Endo Finisher, but may have increased the debris and smear layer in some samples. The explanation for it that the irrigation solution may contain debris and biofilm materials that may have been loosened by XP-Endo Finisher, and in our protocol, adding EndoActivator device to activate irrigant, without using the conventional needle to replace old irrigant, made the dissolved and detached biofilm stay in the canal, especially the apical third.

Therefore, a couple of cycles of new fresh irrigant using conventional needle will have the ability to improve cleaning, dissolving, and detaching the biofilm by replacing the old irrigant.³⁸

Null hypotheses were rejected since additional uses of XP-Endo Finisher file did not differ in the amount of cleanliness with other available techniques.

Study Limitation

A potential limitation of this study, as in many SEM studies, is the relatively small sample size of 36 canals in total, and standardization of the oval shape canal width may affect results. The wider the canal, the harder to touch the walls in it.

In SEM, potential bias in selecting the field for high-power magnification may affect the result, and it is not very easy to check all the parts of root canal walls for cleanliness, so more than shot was taken for some samples to check if the

all the canal walls were clean, but mostly all shots show near scores.

Conclusion

Within the limits of this study, it can be concluded that none of the irrigation methods used were able to have canal walls free of surface debris and smear layer. EndoActivator and Max-I-Probe needle were better than XP-Endo Finisher and XP-Endo Finisher combined with EndoActivator in debris and smear layer removal. XP-Endo Finisher used in combination with the experimented irrigation protocol failed to have free debris on the dentin surface in the apical area of root canals.

Conflict of Interest

None declared.

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