ORIGINAL RESEARCH

The Effectiveness of Different Irrigation Techniques on Debris and Smear Layer Removal in Primary Mandibular Second Molars: An *In Vitro* Study

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Abstract

Aims: The aim of the present *in vitro* study was to compare the effectiveness of passive ultrasonic irrigation (PUI), sonic irrigation, and mechanic dynamic activation on the removal of debris and smear layer from primary mandibular second molars during pulpectomy.

Materials and methods: Mesial roots of 48 primary mandibular second molars were prepared with an R-motion 21 mm file (30/0.04) (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland), irrigated with 1% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA), and divided into four groups ($n = 24$ canals) according to the final irrigation activation technique: control group without activation, PUI with Ultra-X (Eighteeth, Changzhou, China), mechanical activation with XP-endo Finisher (FKG), and sonic irrigation with EQ-S (Meta Biomed, Chungcheongbuk-do, Korea). The roots were split longitudinally and analyzed using scanning electron microscopy (SEM). The presence of debris and smear layer was assessed using a 5-grade scoring scale with 200× and 1000× magnification, respectively. The Kruskal–Wallis and Friedman tests were used for data analysis.

Results: The activation of the irrigant significantly improved debris and smear layer removal ($p < 0.001$). There was no significant difference between Ultra-X, XP-endo Finisher, and EQ-S ($p > 0.05$). No activation technique was able to completely eliminate debris and smear layer from the root canals of primary mandibular second molars.

Conclusions: During pediatric pulpectomy, the irrigation protocol must include activation of the irrigation solutions using either ultrasonic, sonic, or mechanical activation techniques to enhance the removal of debris and smear layer for a better prognosis.

Clinical significance: During root canal treatment on primary teeth, the clinician must incorporate an activation technique in the irrigation protocol to enhance the removal of debris and smear layer and increase the success of the treatment.

Keywords: Endodontic irrigation, Passive ultrasonic irrigation, Primary teeth pulpectomy, Smear layer, Sonic irrigation.

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Introduction

Thorough disinfection is crucial in the prognosis of root canal treatment of primary teeth.[1] The complex anatomy of the primary roots comprising isthmuses and lateral canals harboring dental germs, coupled with physiologic resorption, which begins soon after the completion of the formation of a primary tooth, leads to alteration of the dimension, position, and shape of the apical foramen, and renders the cleaning and shaping process with even the most sophisticated instrumentation less predictable and likely insufficient.[2,3]

The persistence of debris and smear layer, generated by root canal instrumentations on root canal walls, prevents the penetration of irrigation solutions, medications, and sealers into the dentinal tubules.[4] The removal of the smear layer is particularly important in primary teeth with initial signs of pulpal necrosis and peri-radicular lesions, and it has been demonstrated that the long-term outcome of primary teeth pulpectomy was improved after elimination of the smear layer.[5] Studies have shown that a combination of sodium hypochlorite (NaOCl), a deproteinizing agent, and ethylenediaminetetraacetic acid (EDTA), a chelating agent, was found to be highly effective in removing the smear layer.[6,7]

Moreover, the delivery and activation of irrigation solutions have been suggested to enhance the flow and distribution of solutions within the root canal system. In the primary dentition, the EndoVac (Discus Dental, Culver City, CA, USA) apical negative

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pressure system was found to be more efficient in the removal of the smear layer in the apical region when compared to the conventional needle;[8] while in another study, double side-vented needle caused less postoperative pain after pulpectomy than a conventional open-ended needle in a randomized clinical study.[9] Laser and photodynamic therapies have also been proposed to enhance the disinfection of primary teeth.[10]

Among different activation methods, sonic and ultrasonic activation was extensively studied. Passive ultrasonically activated irrigation generates microstreaming around the file and secondary acoustic streaming.[11] Mechanical activation with files induces mechanical agitation along the curved part of the files,[12] whereas sonic activation produces mechanical agitation primarily on the tip of the files.[13] These techniques have been well investigated in the last few decades regarding the removal of debris and smear layer on permanent teeth; whereas, in primary dentition, very few studies explored the most efficient activated irrigation technique during pulpectomy.[14,15]

The objective of this *in vitro* study was to compare the efficiency of EQ-S sonic activation, Ultra-X PUI, and XP-endo Finisher file as a supplementary irrigation approach in the removal of debris and smear layer from primary mandibular molars using SEM.

The first null hypothesis is that activating the irrigant does not improve the removal of the smear layer and debris from mandibular primary molars. The second null hypothesis is that there is no significant difference between EQ-S sonic irrigation, Ultra-X PUI, and the XP-endo Finisher file for irrigant activation on primary molars.

Materials and Methods

Sample Selection

Cone-beam computed tomography (CBCT) (Newtom VGI, Verona, Italy) was performed on 100 freshly extracted primary mandibular molars between March 2019 and March 2022. The teeth were extracted for reasons unrelated to this study, as part of treatment plans at the University of X's Department of Pediatric Dentistry. There were 48 primary mandibular second molars with two separate mesial canals (Vertucci type IV[16]) and only one-third of the root resorbed were included. The sample size was calculated using the IBM SPSS statistics software (version 27.0). Four groups of 24 canals each were finally formed to ensure more than 80% power, and an alpha error probability of 0.05.

This study was conducted in accordance with the Declaration of Helsinki and the ethics committee of the university of X approved its protocol (X-2019-237).

The teeth were cleaned using an ultrasonic tip and kept in distilled water until the start of the study. Exclusion criteria were teeth with previous pulpotomy or pulpectomy, internal resorption, and advanced root resorption. Following access cavity preparation, patency was verified with a size 10 K-file (Dentsply Sirona, Ballaigues, Switzerland). The crowns of the teeth were sectioned with a diamond disc (Kerr Dental, Bioggio, Switzerland) to standardize the root length at 12 mm and the working length (WL) was determined, 1 mm short of the apical foramen, with a size 15 K-file (Dentsply Sirona, Ballaigues, Switzerland).

Root Canal Shaping and Irrigation

A single experienced pediatric dentist performed all the root canal shaping procedures. To simulate the clinical situation, the apex was sealed with sticky wax before root canal preparation to achieve a closed system.[17] To create a smooth path from the orifice to the apical part, the R-motion Glider® (15/0.03) (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) was used until the WL, operated on a rooter X3000 endo motor with R-motion preset mode (FKG Dentaire SA, Switzerland). The file was then retrieved and irrigation with 3 mL of 1% NaOCl using a 30G side-vented needle (NaviTip, Ultradent) was carried out.

For each root, the mesial canals were prepared with an R-motion® 21 mm file (30/0.04) (FKG Dentaire SA) which was advanced in the apical direction by applying a slow in and out motion of approximately 3 mm in amplitude with light apical pressure in a reciprocating motion until reaching the WL. The file was removed from the canal and cleaned after three pecking motions and 3 mL of 1% NaOCl was flushed inside the canal. Each instrument was used to prepare two root canals and then discarded. The WL was attained in the third wave of instrumentation for all canals. A total of 9 mL of NaOCl was used with the R-motion, and overall 12 mL of NaOCl was needed for the shaping phase. The groups were divided as follows ($n = 24$):

- Group I: control group, no activation.
- Group II: passive ultrasonic activation with Ultra-X (25/0.02) (Eighteeth, Changzhou, China) cordless device operating at a high frequency of 45 kHz.[18]
- Group III: mechanical activation with XP-endo Finisher (FKG) operated at 1000 rpm, as suggested by the manufacturer.[19]
- Group IV: sonic activation with EQ-S (25/0.02) (Meta Biomed, Chungcheongbuk-do, Korea) cordless device with two speeds, a multidirectional movement, generating a 133/217 Hz frequency.[20]

For all activation devices, as well as the irrigation needle, the tips were placed 2 mm short of the WL without binding, and activation was carried out for 30 seconds. All the canals were dried with paper points and 1 mL of 17% EDTA was injected and left for 1 minute inside the canals. Activation of EDTA was executed in all four groups, following the same protocol. For the final irrigation, 3 mL of saline was used. Canals were dried with paper points, and the access cavity was sealed with Teflon tape and reinforced zinc oxide eugenol (Intermediate Restorative Material, IRM; Dentsply, Sirona, USA).

Root Sectioning and SEM Examination

After biomechanical preparation, the canals were divided into two halves with a fine diamond disc, with the guidance of superficial grooves mesiodistally along their long axis in their outer walls. A chisel and mallet were used to split each sample. The specimens were dehydrated in a graded series of ethanol solutions (50, 70, 90, and 100%, 3 minutes each) and mounted on metallic stubs using conductive double-coated carbon tape, and were then sputter coated with a 20 nm thick layer platinum using Quorum 150 V Plus (Quorum Technologies Ltd, Kent, UK) and visualized with SEM 10 k voltage (MIRA 3 TESCAN, Kohoutovice, Czech Republic).

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For the evaluation of residual debris and smear layer, the better half of the canal was chosen, and one photomicrograph was taken for each third (coronal, middle, and apical), thus three images per sample.[21] After inspection of the entire sample, always the area displaying the greatest amount of debris and smear layer was selected.

The absence and presence of the debris at 200× magnification were assessed using the following scores:[22,23] 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; score 5 = complete coverage of the canal wall by debris.

The absence and appearance of the smear slayer at 1000× magnification were 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; score 5 = a thick homogeneous smear layer covering the entire canal wall.

The calibrated observer could not identify the irrigation technique used in each group and had been trained in the scoring procedure, resulting in sufficient intraobserver reproducibility.[22]

Statistical Analyses

The statistical analyses were carried out using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). The level of significance was set at $p \leq 0.05$. The study's outcome variables were debris and smear layer scores. The Kolmogorov–Smirnov tests were used to assess the normality distribution of scores. Since variables were not normally distributed, non-parametric tests were used. Kruskal–Wallis and Friedman tests followed by multiple comparisons tests with Bonferroni adjustments were used to compare debris scores and smear layer scores among the four groups in the apical, middle, and coronal levels.

Results

Debris Evaluation

A higher score of debris was statistically detected for the control group compared to Ultra-X, XP-endo Finisher, and EQ-S for the coronal, middle, and apical thirds ($p < 0.05$). Among the three-thirds, there was no statistically significant difference between Ultra-X, XP-endo Finisher, and EQ-S ($p > 0.05$) (Table 1).

Concerning the control group, a higher score of debris was detected at the apical third compared to the coronal and middle thirds ($p < 0.05$), while no significant difference was found between the coronal and the middle third ($p > 0.05$).

Concerning the XP-endo Finisher group, a higher debris score was identified at the apical third (2.33 ± 0.91) compared to the middle (3.00 ± 0.72) and coronal thirds (3.33 ± 0.96) ($p < 0.05$), as well as lower debris score was detected in the coronal third compared to the middle third ($p < 0.05$). Ultra-X and EQ-S groups demonstrated no statistically significant differences between their thirds ($p > 0.05$) (Fig. 1).

Smear Layer Evaluation

Higher smear layer scores were statistically detected for the control group compared to Ultra-X, XP-endo Finisher, and EQ-S for the coronal, middle, and apical thirds ($p < 0.05$). No statistically significant difference was found between Ultra-X, XP-endo Finisher, and EQ-S among the three-thirds ($p > 0.05$) (Table 2). Concerning the control group, a lower smear layer score was spotted at the coronal third (2.79 ± 0.83) compared to the apical and middle thirds ($p < 0.05$), while no significant difference was found between the apical (3.46 ± 0.97) and the middle third (3.17 ± 0.76) ($p > 0.05$).

Concerning the XP-endo Finisher group, a higher smear layer amount was detected at the apical third (2.38 ± 0.77) compared to the coronal (1.63 ± 0.64) and middle thirds (1.96 ± 0.62) ($p < 0.05$); a lower debris amount was detected in the coronal third compared to the middle third ($p < 0.05$). Ultra-X and EQ-S groups demonstrated no statistically significant differences between their thirds ($p > 0.05$) (Fig. 2).

In all groups, the debris and smear layer scores increased from the apical to the coronal thirds. In all thirds, the control group exhibited the highest remaining score for debris and smear layer. The activation of the irrigation solution increases the removal of debris and smear layer in all canal thirds.

Discussion

Implying the gold standards used on permanent teeth for the root canal treatment of primary teeth aims to render pulpectomy easier, reproducible, and predictably successful. Acquiring new data on the root canal anatomy of primary teeth,[3] introducing new rotary instrumentation adapted for such anatomy,[24] and exploring different obturating materials aim to fulfill such goals.[25] However, there is still a lack of studies addressing the irrigation solutions and their activation relevance to integrate this simple act into the standard treatment protocol. This is the first study to investigate the use of PUI with Ultra-X, sonic activation with EQ-S, and mechanical dynamic activation with XP-endo Finisher as supplementary approaches for irrigation activation on primary teeth.

Until recently, the main focus in pediatric pulpectomy was to find the safest root canal irrigant, in an attempt to replace NaOCl, due to its caustic and allergic potential.[26] Substances such as allium sativum extract, extract of propolis, aqueous ozone, green tea, oils, and normal saline were proposed.[27,28] Nevertheless, most of them proved to be ineffective in removing the smear layer.[29] In a systematic review and meta-analysis, the authors concluded that the ideal irrigant during pulpectomies in primary teeth remains an issue and there is a need for more evidence-based randomized clinical trials to endorse the shift for any particular intracanal irrigant.[30] In the current study, NaOCl was used since it remains the irrigant of choice due to its tissue dissolution properties and highest antibacterial effect but with a low concentration of 1%, as recommended for primary teeth pulpectomy.[31]

Moreover, 17% EDTA was also included in the irrigation protocol, since it is an essential step to dissolve the inorganic component of the smear layer. The smear layer was described as an organic matter trapped within translocated inorganic dentin. It is constituted of a superficial layer of 1 – 2 µm and a second layer where the material is packed into the dentinal tubule up to 40 µm, blocking the optimum penetration of disinfecting agents.[32] The removal of the smear layer may facilitate the penetration of NaOCl into the dentinal tubule and enhance the elimination of bacteria embedded deep within tubules.

Therefore, for this current study, the focus was rather to investigate whether activating the most common endodontic irrigants will bring them in contact with dentin debris and necrotic pulp-tissue remnants inside the dentin tubules, canal ramifications, and resorption indentations of deciduous teeth.

Table 1: Mean and SD of scores for debris evaluations

Debris scores (means ± SD)	*Control*	*XP-endo Finisher*	*Ultra-X*	*EQ-S*	*Statistical analysis ($p < 0.05$)*
Coronal	$2.83 \pm 0.86^{a,B}$	$1.79 \pm 0.77^{b,C}$	2.17 ± 1.09^{b}	1.96 ± 0.69^{b}	a–b
Middle	$3.00 \pm 0.72^{a,B}$	$2.04 \pm 0.75^{b,B}$	2.08 ± 0.83^{b}	2.21 ± 0.72^{b}	a–b
Apical	3.33 ± 0.96^{A}	2.33 ± 0.91^{A}	2.25 ± 0.67	2.21 ± 0.83	a–b
Statistical analysis ($p < 0.05$)	A–B	A–B–C	No	No	

Lowercase superscript letters indicate the presence of significant differences between the groups (a,b) and uppercase superscript letters indicate the presence of significant differences between the thirds (A,B,C)

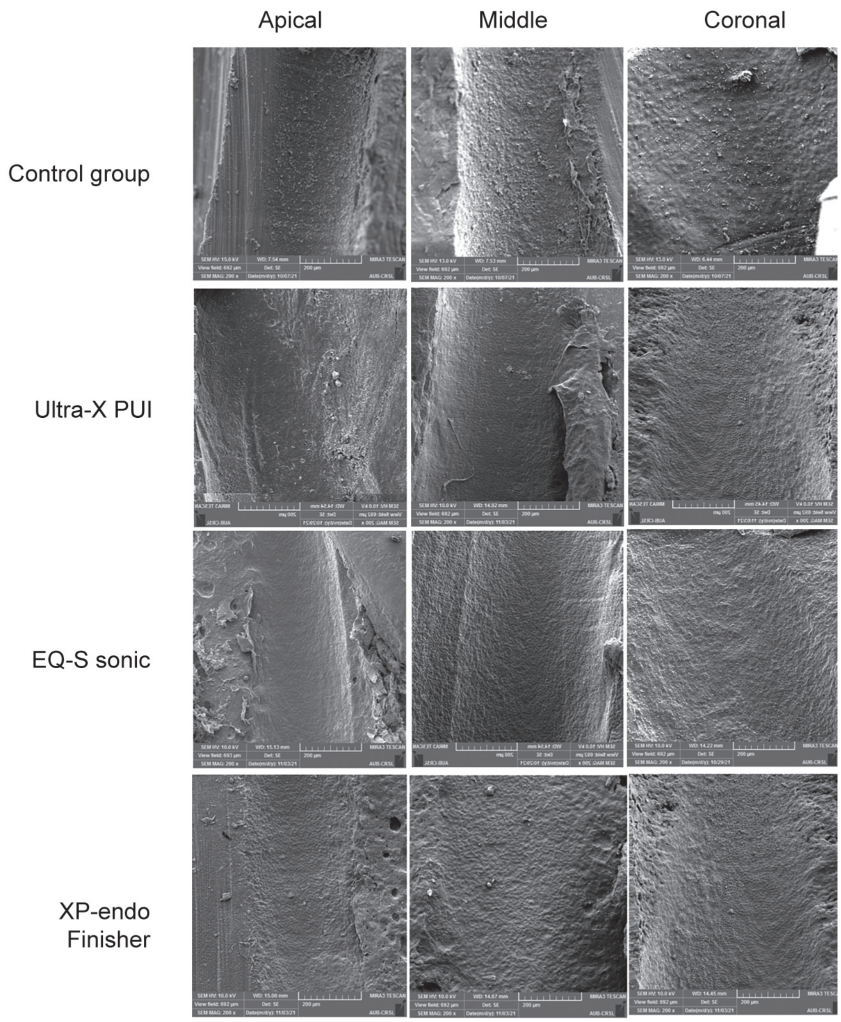

Fig. 1: Representative images of debris in the apical, middle, and coronal thirds in the control group, PUI, sonic irrigation, and XP-endo Finisher groups

Table 2: Mean and SD of scores for smear layer evaluations

Smear layer scores (means ± SD)	*Control*	*XP-endo Finisher*	*Ultra-X*	*EQ-S*	*Statistical analysis ($p < 0.05$)*
Coronal	$2.79 \pm 0.83^{a,A}$	$1.63 \pm 0.64^{b,C}$	1.83 ± 0.86^{b}	1.83 ± 0.86^{b}	a–b
Middle	$3.17 \pm 0.761^{a,B}$	$1.96 \pm 0.62^{b,B}$	1.88 ± 0.68^{b}	2.21 ± 0.65^{b}	a–b
Apical	$3.46 \pm 0.97^{a,B}$	$2.38 \pm 0.77^{b,A}$	2.08 ± 0.58^{b}	2.46 ± 0.72^{b}	a–b
Statistical analysis ($p < 0.05$)	A–B	A–B–C	No	No	

Lowercase superscript letters indicate the presence of significant differences between the groups (a,b) and uppercase superscript letters indicate the presence of significant differences between the thirds (A,B,C)

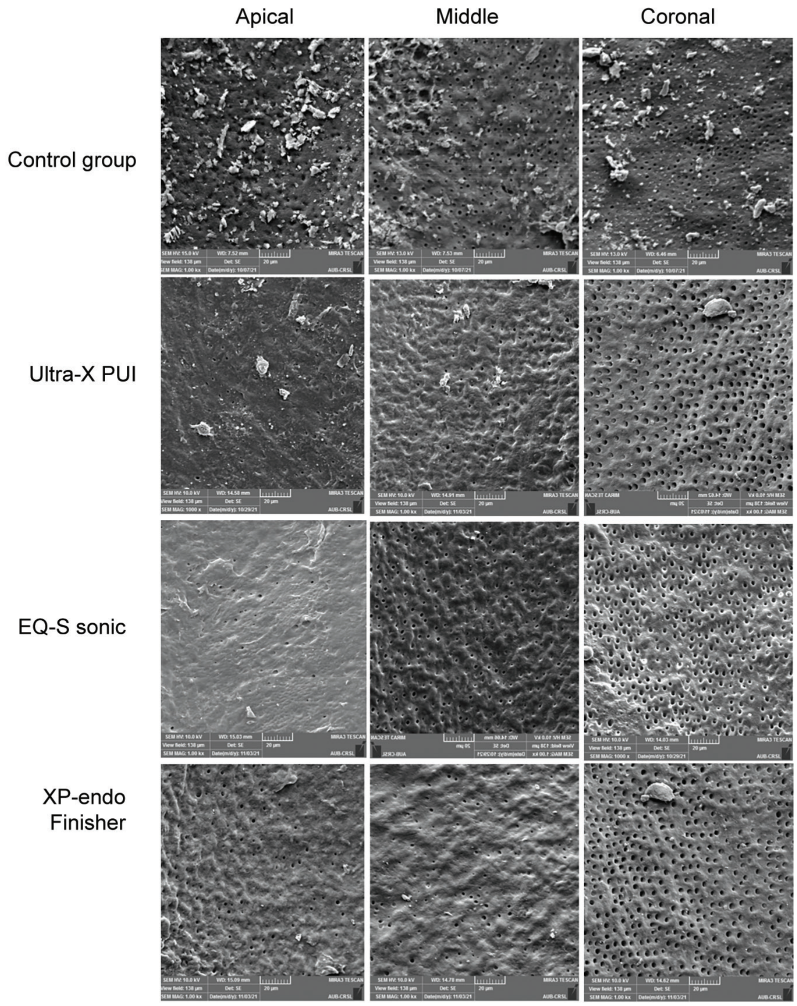

Fig. 2: Representative images of smear layer in the apical, middle, and coronal thirds in the control group, PUI, sonic irrigation, and XP-endo Finisher groups

Regarding the activation process, there is no consensus about the best way to activate the irrigant. Therefore, the most commonly used activation techniques were selected in this study: the ultrasonic (Ultra-X), the sonic (EQ-S), and the mechanical (XP-endo Finisher) to explore any potential advantage of one technique over the other.

The enlargement of the apical preparation has been advocated to improve the cleaning of the apical third, through better mechanical debridement and penetration of root canal irrigants. It was reported that a basic preparation to a tip size 25, 0.06 taper produced significantly less clean root canal walls than a preparation size 40, 0.04 taper.[33] Nonetheless, the preparation size of primary teeth must be carefully chosen. The obturation technique does not require a tapered preparation, since it is based only on filling the canal using a lentulo spiral or injection pressure technique, and due to anatomical restrictions such as the reduced dentine thickness on the furcation side;[3] consequently, the teeth were prepared to a size 30/0.04, based on an unpublished pilot study.

The results of this study demonstrated that the irrigation solution, composed of NaOCl with EDTA, must be activated inside the root canal, as the control group showed the highest scores for debris and smear layer in all canal thirds ($p < 0.001$), corroborating the results of Urban et al., and Susila and Minu.[21,34] The first null hypothesis was therefore rejected.

Moreover, there was no significant difference between PUI, XP-endo Finisher, and EQ-S groups for both debris and smear layer removal in all canal thirds ($p > 0.05$). The second null hypothesis was accepted. All activation systems proved to be efficient since a high percentage of scores 1, 2, and 3 were observed, referring to clean dentinal tubules in all canal thirds. The mechanism of ultrasonic and sonic activation has already been extensively detailed in many publications on permanent teeth.[33] Ultra-X activates the irrigant via acoustic streaming and cavitation, whereas EQ-S sonic activation produces a hydrodynamic phenomenon through the oscillation of the polymer. The XP-endo Finisher is a power-driven irrigant activating instrument that has been recently launched. The file has a 0 taper and 0.25 mm tip. The particularity of this file relies on the MaxWire alloy (Martensite-Austenite Electropolish-FleX), which engages in a form modification when exposed to body temperature increasing the capacity of the irrigant to steer the complexities of the root canal system.[35]

Furthermore, according to the results of this study, canal cleanliness increased significantly from the apical to the coronal third of the root canal ($p < 0.001$) for the control group and the

XP-endo Finisher group. This was also observed in the studies of Johnson et al. and Urban et al., and could be explained by a reduced apical diameter, affecting the volume and exchange of irrigant in that portion of the root canal.[13,21] This could also be attributed to the fact that a conventional needle cannot reach properly WL and hence allow adequate irrigant replacement. XP-endo Finisher showed controversial results in other studies on permanent teeth. In a meta-analysis, it was found to be less effective than PUI,[36] while in another study, it was more effective than PUI in the removal of debris from the apical part.[37] Passive ultrasonic irrigation and sonic activation performed equally in all canal thirds, supporting the results of Urban et al. and Martins et al. on permanent teeth.[21,38] Their efficiency in the removal of debris and smear layer from the entire root canal could be due to rapid fluid movement around the ultrasonic file, or the creation of multiple bubbles known as the cavitation effect, associated with sonic activation.

In the present study, debris and smear layer were evaluated using SEM based on a numerical evaluation scheme at coronal middle and apical levels. The conventional SEM methods consisting of mounting, sectioning, and gold sputtering teeth could potentially affect the remaining debris or smear layer on canal walls. The evaluation is therefore limited to certain areas of the canal. In an attempt to overcome such limitation, the canal walls were screened and only the areas with the greatest amount of residual debris and smear layer were evaluated. Some authors opted for a micro-CT assessment of the remaining debris after the final irrigation regimen[7] and it would be interesting to conduct further studies on primary teeth using the micro-CT to determine the effectiveness of different irrigation techniques in the isthmus and lateral canals.

Activation of the irrigant has not yet been incorporated in the pediatric pulpectomy literature; thus, the novelty and clinical significance of this study in introducing the concept of activation of irrigation in the root canal treatment of primary teeth.

The limitations of this study are its *in vitro* design and the destructive methodology that combines sectioning and SEM. Further studies should be conducted to validate the effectiveness of irrigation activation during root canal treatment of primary teeth, and a standard protocol should be elaborated to increase the prognosis of pulpectomy.

Conclusions

According to this study, irrigation activation during primary teeth pulpectomy is mandatory and deserves to be better explored. Furthermore, there was no significant difference between mechanical activation, sonic, or ultrasonic activation for the removal of debris and smear layer from primary second mandibular molars. The irrigation protocol should contain an activation technique to be used as a supplementary approach to increase the effectiveness of irrigation during pediatric endodontics.

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Ethics and Consent to Participate

This *in vitro* study was approved by the institutional ethics committee of Saint Joseph University of Beirut, Lebanon (X-2019-237). Moreover, all patients at X sign a written consent allowing the faculty to use their extracted teeth if they wish to discard them.

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