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ORIGINAL RESEARCH

Effects of different irrigation activation methods on root canal treatment of primary teeth

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Abstract

There is currently a lack of research on the application of newly developed irrigation techniques in root canal treatment of primary teeth. This study aimed to evaluate the effects of various irrigation activation techniques on two key parameters: apical debris extrusion (ADE) and dentinal tubule penetration depth (DTPD) of the root canal filling material. A total of 96 primary mandibular second molars were randomly divided into 4 groups: Group 1—Conventional Needle Irrigation (CNI), Group 2—XP-Endo Finisher (XPF), Group 3—EndoActivator (EA), and Group 4—Passive Ultrasonic Irrigation (PUI). In all groups, the One Reci single-file system was used for root canal preparation. For ADE measurement, each group was rinsed with distilled water. For DTPD assessment, sodium hypochlorite (NaOCl) was applied. ADE quantification was performed by collecting debris in pre-weighed Eppendorf tubes. A combination of fluorescent dye and root canal filling material (DiaPex Plus) was used for root canal filling. In order to examine DTPD, horizontal cross-sections of the coronal and apical regions of the teeth were taken with a thickness of 1 mm. The maximum and mean DTPD was examined by confocal laser scanning microscopy. Data were analyzed using the Kruskal-Wallis, One-way ANOVA, and Mann-Whitney U tests (p = 0.05). As a result, PUI had the highest mean ADE and CNI had the lowest mean ADE, while CNI had the highest mean DTPD in both the coronal and apical regions, whereas PUI had the lowest mean DTPD in the coronal region, and EA had the lowest mean DTPD in the apical region. There were no statistically significant differences in DTPD and ADE among the four groups. Comparing intragroup maximum DTPD across all groups, it was significantly higher in the coronal region than in the apical region ($p < 0.05$). ADE and DTPD of root canal filling materials in primary teeth did not differ significantly among CNI, XPF, EA and PUI irrigation activation techniques.

Keywords

Root canal treatment; Irrigation; Activation; Primary tooth

1. Introduction

In pediatric dentistry, the function of primary teeth is prioritized until the age of natural exfoliation. Root canal treatment preserves primary teeth in the oral cavity until natural shedding [1].

Root canal treatment includes adequate chemomechanical preparation, disinfection and precise filling of the root canal system [2]. It is, however, difficult to achieve complete chemomechanical preparation due to the complex anatomy of root canals and the limited ability of irrigation solutions to reach the entire root canal system, as well as the physical constraints of root canal shaping systems, preventing effective elimination of microorganisms and thorough debridement [3].

Irrigation solutions are delivered passively to the root canal using needles or cannulas with various tip designs [4]. For irrigants to be effective, they must contact the root canal wall directly. Traditionally, conventional needle irrigation (CNI) introduced these solutions through simple insertion or up-and-down movements [5]. Solutions could not be delivered beyond the irrigation needle tip. It has been established that CNI fails to eliminate debris effectively, facilitate dentinal tubule penetration by solutions, and disinfect root canals completely [6]. Consequently, several irrigation activation techniques have been developed to enhance root canal irrigation efficiency to penetrate all canal spaces, eliminate bacterial remnants, debris and the smear layer, and facilitate effective root canal filling with canal filling material [7]. By transferring energy to the irrigation solution, these activation techniques result in increased flow rates and better solution distribution within the intricate root canal system [8]. Studies have shown that irrigation activation techniques are more effective at removing smear layer from permanent teeth and enhancing the dentinal tubule penetration depth (DTPD) of root canal filling materials [9, 10]. Three-dimensional activation, however, must prevent periapical extrusion while ensuring irrigation solutions penetrate mechanically untouched areas [4]. Hizarci *et al.* [11] discovered that the activated groups exhibited a greater extent of apical debris extrusion (ADE) than the non-activated groups.

Achieving adequate mechanical preparation and irrigation of primary teeth is challenging due to their intricate canal morphology, anastomoses and lateral and accessory canals [12, 13]. Moreover, resorbable pastes are used in root canal fillings of primary teeth instead of gutta-percha [12]. For effective filling, irrigation is necessary to remove the smear layer and penetrate the canal filling material into the dentinal tubules. As a result, various irrigation techniques have emerged as a promising means to improve root canal treatment efficacy in primary teeth [2]. Conversely, to prevent damage from apically extruded material, it is crucial to consider factors such as the physiological resorption of primary teeth, which differs from that of permanent teeth, and the presence of underlying permanent teeth, necessitating a comprehensive assessment of both their advantages and disadvantages [1].

Irrigation activation techniques such as XP-Endo Finisher (XPF), EndoActivator (EA), and Passive Ultrasonic Irrigation (PUI) are newly developed [9, 14–16]. XPF (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is a nickel-titanium alloy file system (MaxWire; FKG Dentaire) designed to enhance the cleaning and disinfection of the root canal following canal instrumentation in the final phase of treatment [15, 16]. EA (Dentsply-Sirona, Ballaigues, Switzerland) is a sonic activation technique with various polymer tip sizes. It addresses the challenge of apical file transportation, offering effective cutting efficiency without compromising its cutting efficiency [9, 14]. By contrast, PUI generates ultrasonic energy along the ultrasonic file, producing horizontal vibrations. Compared to the sonic system, this technique operates at a higher frequency (25–30 kHz) and lower amplitude [14].

There are a wide range of results in studies examining how these techniques impact DTPD in permanent teeth [10, 15, 17–19]. However, these techniques are generally considered more effective than CNI [10]. Studies have shown similar efficacy between EA and XPF, while others suggest that XPF may be more effective [17, 20]. In permanent teeth studies, PUI is equally or more effective than XPF [5, 17, 21]. Primary teeth, however, have not been studied specifically. Furthermore, studies involving permanent teeth have reported different results when evaluating the impact of activation techniques on ADE [22, 23]. Moreover, although only two studies have addressed this topic in the context of primary teeth, none compared CNI with EA, XPF or PUI. One study [24] found no significant difference between CNI and laser activation, whereas another [7] found that CNI resulted in more debris than the EndoVac and Self-Adjusting File (SAF).

The rationale for this study was based on the argument that although several studies have compared the effect of CNI and newly developed irrigation techniques on ADE and DTPD in permanent teeth [4, 6, 15, 22]. Primary teeth differ anatomically, histologically, and physiologically from permanent teeth, so endodontic treatment for primary teeth differs from adult therapy [12]. Thus, clinical results obtained in permanent teeth cannot be applied to primary teeth.

Studies on new irrigation techniques for primary teeth are limited [7, 24]. In this study, we examine the impact of various irrigation activation techniques, including CNI, XPF, EA and PUI, on two critical parameters: ADE and DTPD of root canal filling materials, using confocal laser scanning microscopy (CLSM) in primary teeth.

2. Materials and methods

According to a previous study [24], a minimum of 24 teeth per group was computed using G*Power software (Ver. 3.1.9.2, University of Dusseldorf, Dusseldorf, NRW, Germany). The type I error (alpha) and power (1 − beta) were 0.05 and 0.97, respectively. The effect size was 0.45. A total of 96 primary teeth were examined. In this study, primary mandibular second molars recently extracted were collected from patients for orthodontic reasons and stored in physiological serum at 4 °C before use. This study had no relation to the reasons for extraction (retained primary teeth, ankylosis, *etc.*). A visual evaluation of buccal and mesiodistal preoperative radiographs of the teeth was performed before the study was conducted.

The inclusion criteria were as follows:

• Teeth with root curvatures between 10° and 20° according to the Schneider classification [25],

• Teeth with root lengths based on the data created by Kramer and Ireland [26] for standard root lengths before resorption in primary teeth (mesial root length is 11.37 mm, and distal root length is 10.55 mm),

• The independent presence of two separate canals in the mesial root and a single, noncomplicated buccal canal in the mesial root,

• Teeth with root canals without obliteration, calcification, resorption or previous root canal treatment.

Teeth with caries extending below the cementoenamel junction (CEJ) or a fracture, crack or resorption of the roots were excluded from the study. The mesiodistal and buccolingual diameters of the teeth were measured at CEJ using a digital caliper. Roots with a difference of 20% from the mean were discarded [25]. Also, the distance between the CEJ and the apical foramen was recorded. To standardize the root length, only teeth with a mesiobuccal root length of 11.3 mm were used on the study.

Distal roots of the teeth were removed from the CEJ using a high-speed fissure bur under water cooling. The mesiobuccal canal orifices of each tooth were exposed, creating an access cavity under continuous water cooling. The working length (WL) of the mesiobuccal canal was determined to be 1 mm short of the length of a size 10 K-file visible at the apical foramen. Based on the chosen irrigation activation techniques, the teeth were randomly divided into 4 groups of 24 each. The study consisted of two stages: evaluating ADE and assessing DTPD.

To measure ADE, we followed Myers and Montgomery's experimental setup [27]. First, the stoppers of the Eppendorf tubes were removed, and the tubes were weighed 3 times using an analytical balance (Laboratory Balance, Denver Instrument GmbH, Göttingen, Germany) with an accuracy of 10^{-4} g. The mean value from these measurements was recorded as the initial weight of the tubes. A hole was then created in each Eppendorf tube stopper. Each tooth was inserted into the tube up to the CEJ. A 27-G needle (Berika Technology Co., LTD., Konya, Turkey) was placed alongside the stopper to equalize the internal and external air pressure, subsequently placed inside the Eppendorf tube, and the tube was secured in a vial to hold the device during the instrumentation process. During both preparation and irrigation procedures, the vial surface was consistently covered to maintain study blindness.

In all groups, a single operator conducted root canal preparation using the Ai-Motor (Guilin Woodpecker Medical Instrument Co., LTD., Guilin, Guangxi, China) endodontic motor, set to reciprocate at 170° counterclockwise and 60° clockwise rotations per minute, as instructed by the manufactures. Root canal preparation was performed using the 25/06 One Reci single-file system (Micro-Mega SA, Besançon, France). A distilled water irrigation solution of 6 mL was used for each tooth during preparation procedure. Following, the preparation procedures, each group received 3 mL of distilled water for irrigation activation. The specific irrigation procedures for each group are detailed below (Fig. 1).

Group 1 (CNI): A 30-G side-vented needle tip (KerrHawe SA, Bioggio, Switzerland) was positioned in the canal, 1 mm short of the WL. Back-and-forth movements were used to activate the needle, and 3 mL of distilled water was irrigated for 1 min.

Group 2 (XPF): An XPF file (FKG Dentaire, La Chaux-de-Fonds, Switzerland) was used with 3 mL of distilled water. Placed 1 mm short of the WL, the file was activated for 1 min at 800 rpm and 1 Ncm torque.

Group 3 (EA): A polymer tip (25/04) designed for the EA technique (Dentsply-Sirona, Ballaigues, Switzerland) was inserted into the canal 1 mm short of the WL. EA was activated using 3 mL distilled water with 2–3 mm vertical strokes at a frequency of 0.166 kHz.

Group 4 (PUI): A non-cut stainless steel passive ultrasonic tip (200 μm) (Guilin Woodpecker Medical Instrument Co., LTD., Guilin, Guangxi, China) was affixed to the DTE D600 ultrasonic system (Guilin Woodpecker Medical Instrument Co., LTD., Guilin, Guangxi, China). The tip was inserted into the canal, placed 1 mm short of the WL. It was activated with 2–3 mm back-and-forth movements for 1 min using 3 mL of distilled water.

Upon removing the Eppendorf tubes from the vials following root canal irrigation, debris adhering to the root surface was rinsed and collected with 1 mL of distilled water inside each tube. Tubes were incubated at 37 °C for 15 days to allow the irrigation solution to completely evaporate [23]. 3 times were weighed using the same analytical balance following incubation, and mean values were calculated. Each tube's ADE amount was calculated by subtracting the mean initial weight from the mean final weight.

In the second phase of this study, teeth were carefully removed from the Eppendorf tube stoppers. A final irrigation activation procedure using 3 mL of 1.25% sodium hypochlorite (NaOCl) was performed for 1 min for each group following the above procedure. 1 mL of distilled water was then irrigated into each root canal and dried with paper points. Using CLSM, the root canal filling material (DiaPex Plus, DiaDent Group International Inc., Burnaby, Canada) was mixed with 0.1% rhodamine B fluorescent dye (Sisco Research Lab., Maharashtra, India) [4, 15]. Following root canal fillings with the lentulo spiral technique [28], the access cavities were temporarily sealed with Cavit temporary filling material (3M ESPE, St. Paul, MN, USA) (Fig. 2). 2 weeks of incubation at 37 °C with 100% humidity was necessary to effectively set the filling material.

As part of the CLSM analysis, roots were sectioned perpendicularly to their long axis at 2 and 9 mm from their apex to obtain two 1-mm-thick horizontal sections from both the apical and coronal regions of the root, using a low-speed microcut machine (Metkon Micracut 151, Metkon Instruments Inc., Bursa, Turkey) with a 0.3-mm- thick diamond disk (Metkon Instruments Inc., Bursa, Turkey) under water cooling. Silicon carbide abrasive paper was then used to polish the slices and mount them on glass slides. With a diode-pumped solid-state laser at a wavelength of 561 nm, these sections were examined by a ZEISS LSM 710 CLSM (Carl Zeiss CMP GmbH, Göttingen, Germany). The images were created by merging 9 squares, each with a resolution of 1024 × 1024, at a magnification of 10, and then processed with the ZEN 3.2 (Blue Edition) program (Carl Zeiss CMP GmbH, Göttingen, Germany) for further analysis (Fig. 3). DTPD was calculated by measuring the distance between the canal wall and the furthest point of the canal filling penetration [4]. The mean DTPD was calculated by choosing 4 fixed points around the canal and measuring the distance from canal wall to the point where the canal filling penetration ended. Averaging these four measurements yielded the mean DTPD [4] (Fig. 4).

The statistical analysis was conducted using IBM SPSS software (version 20.0; IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to assess data normality. ADE measurements were analyzed using the Kruskal-Wallis test. DTPD maximum and mean variables were analyzed statistically using the One-Way ANOVA test. Comparing coronal and apical DTPD intragroup was performed using the Mann-Whitney U test. All statistical analyses were performed at a 95% confidence level ($p < 0.05$).

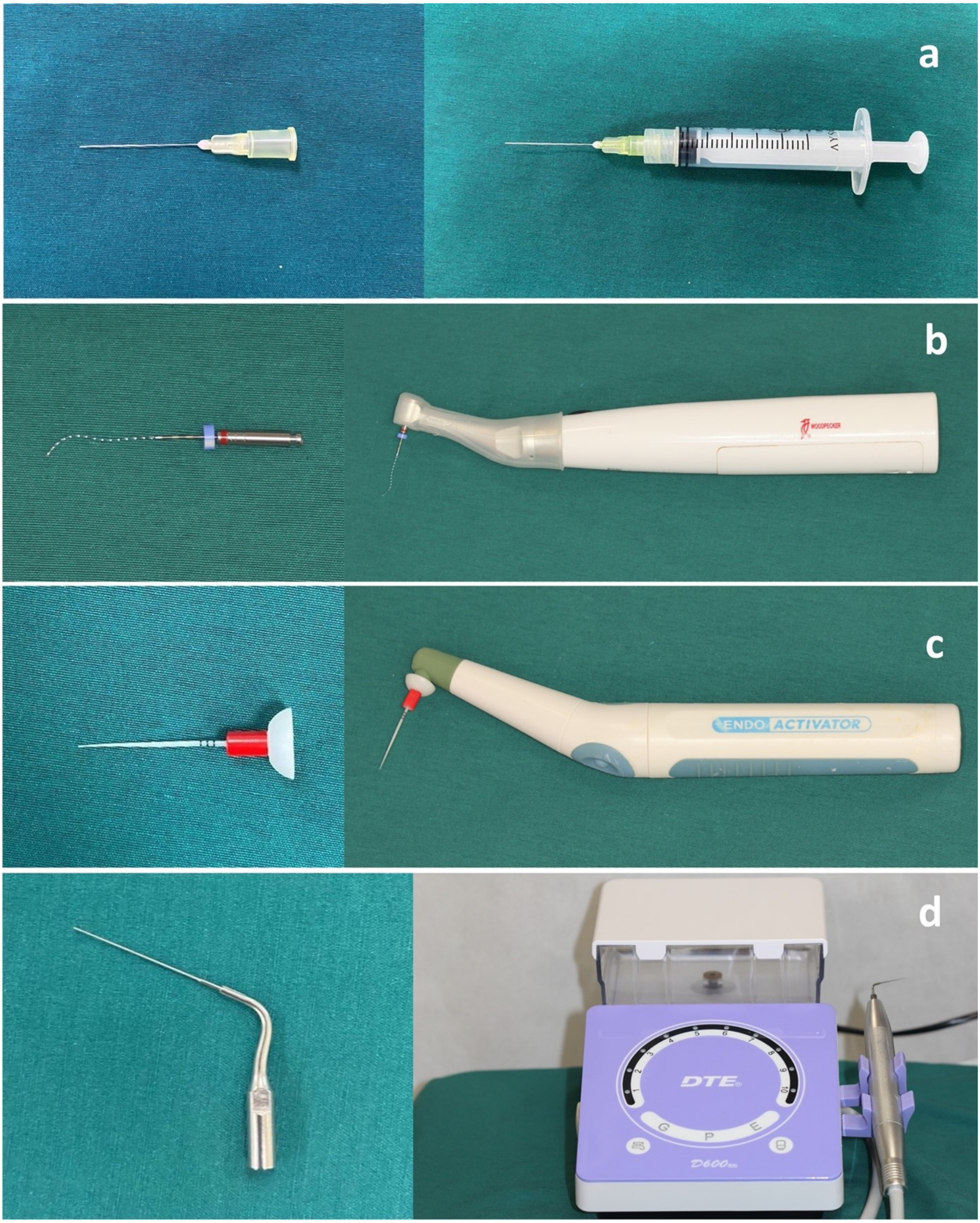
3. Results

The study examined 96 primary teeth, with 24 teeth each allocated to the 4 groups.

Table 1 summarizes the ADE data for each group. PUI showed the highest mean ADE, while CNI group showed the lowest. In spite of this, statistical analysis revealed that there were no significant differences between the groups in terms of ADE ($p = 0.196$).

Data on maximum and mean DTPD are presented in Table 2 for coronal and apical regions. Both coronal and apical regions showed the highest maximum DTPD for the CNI group and the lowest maximum DTPD for the PUI group. The 4 groups did not differ statistically ($p > 0.05$). In intragroup comparisons, all groups had significantly higher maximum DTPD in the coronal region than in the apical region ($p < 0.05$) (Table 2).

The CNI group exhibited the highest mean DTPD, while the PUI group displayed the lowest. The CNI group had the highest values in the coronal region, and the EA group had



F I G U R E 1. Irrigation activation techniques used in research. (a) Conventional Needle Irrigation (CNI). (b) EndoActivator (EA). (c) The XP-Endo Finisher (XPF). (d) Passive Ultrasonic Irrigation (PUI).

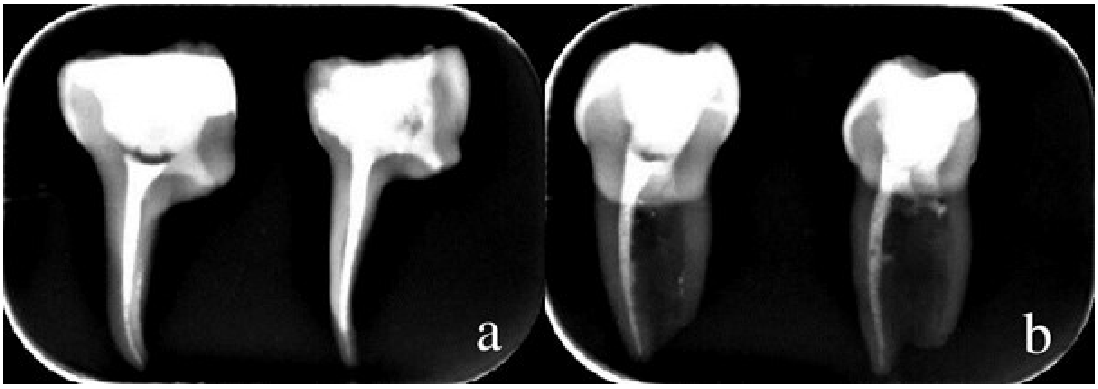


FIGURE 2. Periapical radiography of root canal fillings. (a) Buccolingual periapical radiography. (b) Mesiodistal periapical radiography.

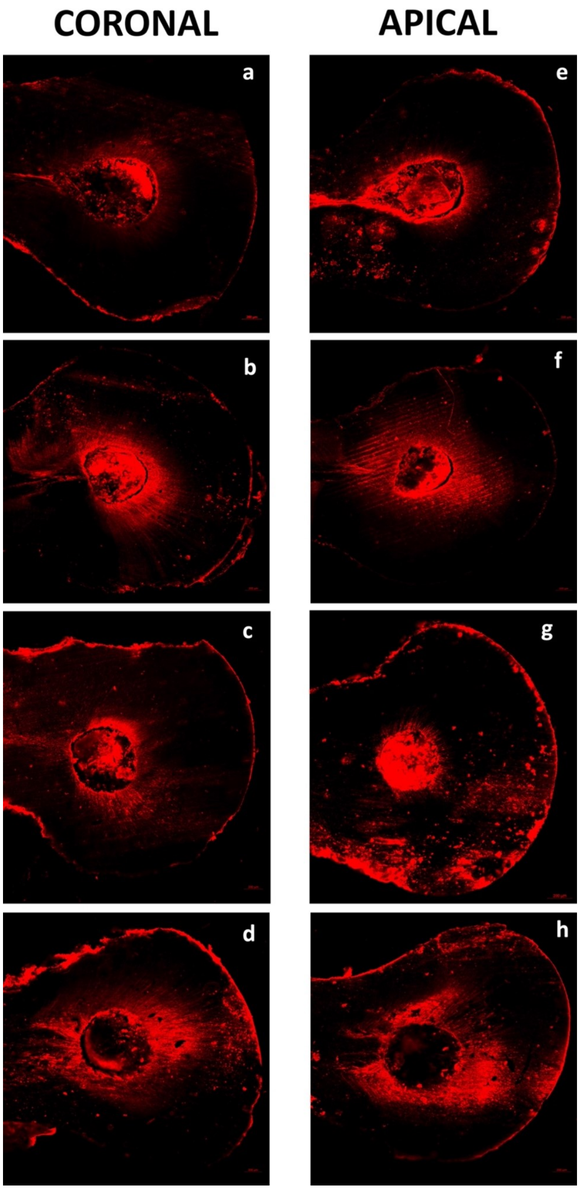


FIGURE 3. Confocal laser scanning microscopy images. (a) The coronal region for the CNI group. (b) The coronal region for XPF group 2. (c) The coronal region for the EA group. (d) The coronal region for the PUI group. (e) The apical region for the CNI group. (f) The apical region for XPF group. (g) The apical region for EA group. (h) The apical region for PUI group. CNI: Conventional Needle Irrigation, XPF: The XP-Endo Finisher, EA: EndoActivator, PUI: Passive Ultrasonic Irrigation.

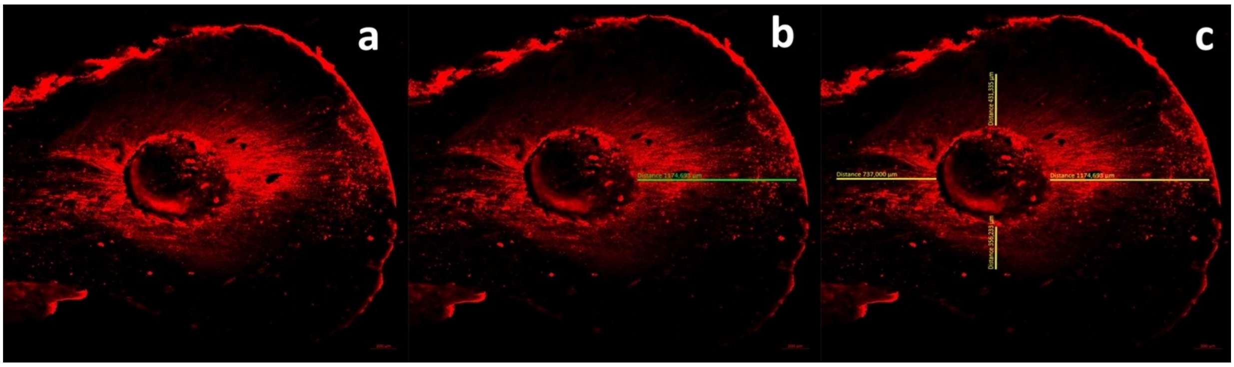


FIGURE 4. Confocal laser scanning microscopy images of the sample. (a) The sample image without measurement. (b) Measuring the maximum dentin tubule penetration depth. (c) Measuring the mean dentin tubule penetration depth.

the lowest values in the apical region. Nevertheless, the four groups did not differ significantly in the coronal and apical regions ($p > 0.05$). In intragroup comparisons, there were no statistically significant differences between the coronal and apical regions ($p > 0.05$) (Table 2).

TABLE 1. Findings of apical debris extrusion.

GROUPS	N	Mean ± SD (g)	*p* value
Group 1 (CNI)	24	0.0000833 ± 0.00006446	
Group 2 (XPF)	24	0.0000986 ± 0.00008310	0.196*
Group 3 (EA)	24	0.0000944 ± 0.00015717	
Group 4 (PUI)	24	0.0001306 ± 0.00012035	

**The Kruskal-Wallis test ($p > 0.05$, no significant difference). SD: Standard Deviation, CNI: Conventional Needle Irrigation, XPF: XP-Endo Finisher, EA: EndoActivator, PUI: Passive Ultrasonic Irrigation.*

4. Discussion

The present study evaluated the impact of various irrigation techniques on the ADE and DTPD of root canal filling material during primary tooth root canal treatment. A comparison of the new irrigation techniques with CNI in primary teeth revealed no significant differences in ADE and DTPD. Due to the lack of similar studies in the existing literature, interpreting our findings poses a challenge.

Irrigation activation techniques have been experimentally and clinically proven to increase irrigation solutions' effectiveness [14, 15, 17, 19]. With PUI, pulp and dentin debris are removed more effectively, bacteria are removed more efficiently than CNI, and arcuate canals and isthmuses are effectively cleaned [14, 15]. PUI also has the advantage of being more affordable than laser activation techniques [15]. EA, sonic activation of irrigation, which consist of shaking the irrigation solution placed in the canal, increases the canal disinfection effectiveness and is widely used in clinical practice today [9, 14]. There are advantages to it, such as removing debris. PUI, however, has been reported to be more potent than EA in some studies [14]. Endodontic motor drives XPF. Comparative to EA and PUI, it does not require an additional device. Furthermore, XPF's phase change capability is reported to be beneficial in eliminating bacteria and debris from the root canal system and cleaning its irregular structure [18]. A very limited number of studies have been conducted in primary dentition to determine which active irrigation technique is the most effective for root canal treatment [2, 3]. Gümüş *et al.* [2] recommended applying EA as a sonic activation technique during final irrigation of primary molars with irreversible pulpitis. Hachem *et al.* [3] concluded that using ultrasonic, sonic or mechanical activation techniques increases the removal of residue and smear layer in primary molars. It is unclear how to appropriately irrigate primary and permanent teeth, despite manufacturers offering advantages associated with activating both [18]. CNI has also been found to be the most frequently used root canal method in many studies of primary teeth [4]. PUI, XPF, EA and CNI, the most commonly applied activation techniques in permanent teeth, were chosen to investigate the potential advantages of each in primary teeth.

During the chemomechanical preparation process for root canal treatment, necrotic debris, pulp remnants, microorganisms, dentin shavings and irrigation solutions can inadvertently extrude through the apical foramen [6, 29]. It is possible for ADE to cause complications such as postoperative pain, periapical inflammation, and impairment of periapical healing [29]. Irrigation needle design and root canal irrigation activation techniques influence the extent of ADE [6]. ADE is particularly problematic in deciduous dentition compared with permanent dentition since it can harm apical cells and develop permanent tooth germs [30]. Thus, we studied primary molar teeth to assess irrigation techniques' effect on ADE. The most common method, described by Myers and Montgomery [27], was used.

Only Gungor *et al.* [7] and Buldur *et al.* [24], have evaluated irrigation activation techniques' impact on ADE in primary teeth. Both studies, however, did not compare CNI with the new techniques.

Previous research on permanent teeth has consistently shown that PUI results in less ADE than CNI [6, 22]. In a study by Ada *et al.* [22], they compared the effects of CNI, manual dynamic activation, PUI and EA on ADE in mandibular premolars. PUI led to the least ADE, whereas

TABLE 2. Findings of dentinal tubule penetration depth.

GROUP		N	Mean ± SD (μm)	*p* value	*p* value (coronal)	*p* value (apical)
Maximum DTPD						
Group 1 (CNI)	Coronal	24	992.16867 ± 237.907081	0.004*	0.469**	0.188**
	Apical	24	857.99592 ± 207.061671			
Group 2 (XPF)	Coronal	24	982.74271 ± 219.377214	<0.001*		
	Apical	24	755.99017 ± 219.441922			
Group 3 (EA)	Coronal	24	974.15054 ± 219.821040	0.002*		
	Apical	24	749.09821 ± 233.714190			
Group 4 (PUI)	Coronal	24	890.57754 ± 305.897415	0.023*		
	Apical	24	730.91558 ± 218.787733			
Mean DTPD						
Group 1 (CNI)	Coronal	24	467.3232188 ± 179.89910506	0.201*	0.053**	0.147**
	Apical	24	415.4572917 ± 173.81083699			
Group 2 (XPF)	Coronal	24	408.2867396 ± 168.66424422	0.155*		
	Apical	24	337.3152917 ± 174.35935126			
Group 3 (EA)	Coronal	24	353.5002396 ± 165.62920850	0.293*		
	Apical	24	309.5255625 ± 173.13355238			
Group 4 (PUI)	Coronal	24	347.6724479 ± 157.66701728	0.496*		
	Apical	24	376.7613125 ± 146.75224250			

**The Mann-Whitney U test (p < 0.05 shows significance), **The One-way ANOVA test (p < 0.05 shows significance). DTPD: Dentinal Tubule Penetration Depth, CNI: Conventional Needle Irrigation, SD: Standard Deviation, XPF: XP-Endo Finisher, EA: EndoActivator, PUI: Passive Ultrasonic Irrigation.*

EA resulted in the highest extrusion. This study, on the other hand, found different results. There was no difference in ADE amount between all irrigation activation techniques in our study. Several factors may be responsible for these discrepancies. Firstly, primary teeth have shorter roots than permanent teeth. Secondly, the more complex root canal anatomy of primary teeth may have impacted the outcome. Finally, using a single-file system may have influenced the amount of debris during root canal preparation in primary teeth. Multiple-file systems are evident when reviewing studies on permanent teeth [6, 22]. As a result of the ease with which single-file systems make root canal treatment easier for the operator, causing less debris extrusion, being approximately 3–4 times faster than conventional procedures, and making the treatment more acceptable to patients by reducing the procedure time, single-file systems are frequently preferred [31]. Therefore, we used the 25/06 One Reci single-file system for root canal preparation in this study. To eliminate the possibility of the file not being able to perform effective preparation in wide canals and to achieve adequate mechanical preparation, it was preferred to use mesiobuccal canals of the mandibular primary second molar teeth, which have narrower and rounder canals than the distal canals [32], were preferred for this research. In addition, the operator also paid attention to the file's contact with the canal walls during preparation. All tips for the activation devices were selected to be smaller than those of the 25/06 One Reci single-file system. This prevents them from contacting the canal walls during activation. Assuring that the root canal form and taper were not affected, preparation was completed.

Another critical aspect evaluated in this study is DTPD. Root canal filling materials should penetrate into dentin tubules, be biocompatible, and have adequate mechanical properties in order to function effectively [4, 33]. As a part of root canal treatment, adequate irrigation is crucial since it allows the root canal filling material to penetrate accessory canals, isthmuses, apical deltas and dentinal tubules [19]. Due to its antibacterial properties, by effectively penetrating the tubules, canal-filling material inhibits bacteria's nourishment and growth by trapping bacteria within the tubules. To fill the root canals, a calcium hydroxide (CaOH)-based filling material (containing iodoform) was used in this study. Despite its favorable properties such as biocompatibility, good antimicrobial activity, favorable pH, flowability, radiopacity and good adaptation to acceptable dimensions, it is commonly used as an intracanal medication in permanent teeth and as a root canal filling material in primary teeth [34, 35]. Moreover, CaOH-based materials penetrate into the dentin tubules, as shown in previous studies [15, 36, 37]. On permanent teeth, there are different results in studies conducted on canal filling activation's effect and filling techniques on DTPD [15, 38]. According to Tadano *et al.* [15] ultrasonic or sonic vibration provides no advantage when using the lentulo spiral alone in DTPD when agitating CaOH-based root canal filling material. Similarly, Demir *et al.* [38] reported that the DTPD of the root canal filling material was independent of the obturation technique. A lentulo spiral driven at low speed for filling the root canals in the present study, a widely used technique for its successful filling results in primary teeth [28]. Various methods are available for assessing the DTPD of root canal filling materials, including scanning electron microscopy, light microscopy, and CLSM [4, 39, 40]. We used CLSM in this study, which has gained popularity recently because of its advantages, such as repeatability and minimal sample manipulation. In addition, CLSM requires no sample processing, such as dehydration, which causes shrinkage of the material, in comparison to Scanning Electron Microscope (SEM) [4]. In contrast, CLSM requires fluorescent dyes to label and differentiate the material from dentinal tubules [4, 15]. According to the literature, 0.1% rhodamine B dye was added to the CaOH-based canal filling material to visualize intratubular penetration; this amount of dye had no effect on the material's physicochemical properties [15].

In studies examining the effects of irrigation activation techniques for DTPD on permanent teeth, varying results have been obtained. Koruk *et al*. [21] found that PUI enhanced DTPD more than CNI and EA. In contrast, Zand *et al*. [5] reported that PUI penetrated better in both coronal and apical regions than CNI and XPF. Additionally, XPF showed greater DTPD in the coronal region and similar DTPD in the apical region than CNI in the same study. Conversely, in a study by Keles *et al*. [17], XPF showed higher DTPD than PUI and EA. This study, however, did not compare CNI with the new techniques. According to the cumulative results of several studies, DTPD appears to be the lowest in the CNI groups when compared to the new techniques [9, 10]. Additionally, EA and XPF often perform similarly, with XPF occasionally being more effective [17, 20]. In the same way, XPF and PUI often yield similar results, with PUI being more effective on occasion [5, 17, 21].

This study investigated DTPD in both the coronal and apical regions. After various irrigation techniques and root canal filling materials on permanent teeth, DTPD has consistently decreased from the coronal to the apical region, typically attributed to several factors, including a reduction in tubule density and diameter in the apical region and increased irregularities in the apical region relative to the cervical region [41]. Toward the cementum, tubule density and distribution decrease [41]. As reported in studies on permanent teeth, our study observed an increase in maximum DTPD from the apical to the coronal region. However, the mean DTPD did not differ between the apical and coronal regions. This may be related to primary teeth' differing root canal structures and dentin structures such as thinner dentin thickness, greater peritubular dentin thickness, and straighter dentinal tubule direction than permanent teeth [12, 13]. Additionally, in the present study, only distilled water and NaOCl were used during root canal preparation, since EDTA is rarely used in primary tooth root canal treatments. This may have resulted in a thinner smear layer. Thus, further research is needed to explore the impact of different irrigation solutions on primary teeth, since removing debris and the smear layer could enhance canal filling material penetration into dentinal tubules.

The technical variables in this study were all equal. This study was limited by the use of extracted teeth, which may have contributed to variations. This limitation was overcome by taking radiographs of the tooth from two different directions and excluding teeth with variations [42]. Sample selection was randomized to minimize selection bias and specimen heterogeneity. Furthermore, vital teeth extracted for orthodontic treatment, without root resorption, were used in this study. When transferring research results to the clinic, consideration must be given to physiological infection-induced root resorption. To gain a more comprehensive understanding of these irrigation techniques, additional clinical and experimental investigations are warranted to consider differences such as the resorption and apical opening conditions of primary teeth canal filling materials, and irrigation solutions used.

5. Conclusions

Within the limitations of the study, XPF, EA and PUI irrigation activation techniques caused similar amounts of ADE to CNI during primary teeth root canal treatment. Similarly, DTPD of the root canal filling material did not differ in any irrigation activation techniques.

AVAILABILITY OF DATA AND MATERIALS

All data generated or analyzed during this study are included in this published article.

AUTHOR CONTRIBUTIONS

MA, ÜŞE and SK—material preparation, data collection, and analysis. MA, ÜŞE—written the first draft of the manuscript. ÜŞE and SK—edited the first draft of the manuscript. All authors read and approved the final manuscript. All authors contributed to the study conception and design.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All procedures performed in the study were in accordance with the Ethics Committee of the Kocaeli University (Approval No: GOKAEK-2022/217) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The parents signed informed consent regarding publishing their children's data.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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