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Effect of Irrigation Activation Techniques and Gravity on Apical Extrusion in Immature Teeth: An In Vitro Study

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Abstract

Background: This study investigated the effects of irrigation activation techniques (standard needle irrigation, passive ultrasonic irrigation, EndoActivator, and EDDY) and gravity (maxillary vs mandibular position) on apical irrigant extrusion in immature teeth.

Methods: Eight intact maxillary central incisors were prepared to simulate immature teeth with 1.1 mm apical diameters. Root canals were irrigated with 2.5% sodium hypochlorite, 17% Ethylenediaminetetraacetic acid, and distilled water. Each tooth was fixed into a hole prepared in the cap of an Eppendorf tube. To simulate the periodontal ligament, the Eppendorf tubes were filled with 1.5% agar agar, into which the teeth were placed. After the agar had solidified, the weight of the agar-filled Eppendorf tube without the tooth was measured using a microbalance. All 4 activation techniques were applied in both mandibular (vertical) and maxillary (45° inclined) positions. Following activation, the teeth were removed, and the Eppendorf tubes were reweighed. The difference between the final and initial weights was recorded as the amount of apical extrusion. Data were statistically analyzed using the Kruskal–Wallis and Mann–Whitney *U*-tests at a significance level of $P < .05$.

Results: No significant differences were found among the activation techniques or between the mandibular and maxillary positions ($P > .05$).

Conclusion: Although all techniques resulted in irrigant extrusion, neither the activation method nor the tooth position had a statistically significant effect. Clinicians should remain cautious when selecting and applying irrigation protocols in immature teeth to minimize the risk of extrusion.

Keywords: Apical extrusion, EDDY, EndoActivator, gravity, immature teeth, passive ultrasonic irrigation

What is already known on this topic?

- *Immature teeth are prone to irrigant extrusion.*
- *Previous studies have reported inconsistent findings regarding the influence of different irrigation activation techniques.*

What does this study add on this topic?

- *This study demonstrates that irrigant extrusion occurs with all activation techniques in immature teeth.*
- *It also shows that the amount of extrusion is not significantly affected by the activation method or tooth position.*

INTRODUCTION

Traumatic dental injuries during childhood, as well as morphological anomalies such as palatogingival groove, dens invaginatus, and dens evaginatus, may result in pulp necrosis prior to the completion of root development.[1,2] This condition consequently leads to the occurrence of teeth with open apices.[1,2] Endodontic treatment of necrotic teeth presents several challenges; due to the wide canal lumen, thin and fragile dentin walls, and a non-conical canal shape, conventional instrumentation and obturation

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techniques are often inadequate in such cases. Moreover, excessive removal of canal dentin may predispose the tooth to vertical root fracture.[3,4] Therefore, in immature teeth, minimal mechanical instrumentation is recommended, with chemical methods being preferred to achieve effective disinfection.[3-5]

Sodium hypochlorite (NaOCl) is widely used as the primary irrigant in endodontics because of its strong antimicrobial properties and ability to dissolve organic tissue.[6] Apical extrusion of irrigants is a major concern, particularly in immature teeth, because the wide-open apical foramen increases the likelihood of the solution passing beyond the root apex into the periapical tissues.[7-9]Apical extrusion of NaOCl into the apical region may cause acute inflammation, severe pain, and even necrosis in the periapical tissues. Moreover, apical extrusion of NaOCl may damage mesenchymal stem cells located in the apical papilla, thereby compromising the success of regenerative endodontic treatment.[8,10] Considering the clinical consequences of apical extrusion, it is of great importance that irrigation techniques used in immature teeth provide effective disinfection while minimizing the risk of irrigant extrusion beyond the root apex.[10]

To enhance irrigation efficiency, ultrasonic and sonic activation systems have been introduced as adjuncts to standard needle irrigation (SNI).[11-14] Studies investigating the effect of activation techniques on apical extrusion in immature teeth have reported that EDDY may cause greater extrusion than passive ultrasonic irrigation (PUI).[15,16]

In addition to irrigation activation techniques, several other factors are known to influence the amount of apical extrusion, including canal morphology, apical diameter, needle type, and tip position.[17] Among these, gravity may also play a role, as the positioning of the tooth in the maxilla or mandible can affect irrigant flow direction.[7,18] Studies have shown that, when using positive pressure irrigation and PUI, mandibular models exhibit more irrigant extrusion compared with maxillary models.[7] Likewise, Namsoy et al[18]reported that open- and closed-ended needles produced greater extrusion in mandibular positioning than in maxillary or horizontal positioning.

Nonetheless, these studies did not specifically address the use of sonic activation systems or the potential influence of gravity on their performance. To the best of the authors' knowledge, this is the first study to investigate the combined effect of irrigation activation techniques and gravity in immature teeth, with particular emphasis on sonic activation systems. Moreover, no prior research has evaluated the effect of the EndoActivator system on apical extrusion in immature teeth. Therefore, this study aimed to compare the effects of SNI, EndoActivator, EDDY, and PUI on NaOCl extrusion in immature teeth positioned in maxillary and mandibular orientations. The null hypothesis stated that neither the irrigation technique nor the tooth position would significantly affect the amount of apical extrusion.

MATERIALS AND METHODS

This study was approved by the Ethics Committee of Clinical Research Ethics Committee of Çanakkale Onsekiz Mart University (approval no.: 2023/07-15, date: May 3, 2023). Written informed consent was obtained from all participants prior to tooth extraction, allowing the use of their extracted teeth for research purposes. Based on a power analysis using data from a previous study,[19] with a 95% confidence level ($1-\alpha$), 95% test power ($1-\beta$), and an effect size of $d=0.629$, the required sample size was determined to be 8 specimens per group.

In this study, 8 intact human maxillary central incisors without caries, restorations, cracks, fractures, or root resorption, confirmed under a dental operating microscope, were used. To prevent damage from activation procedures and to ensure standardization of experimental conditions, the same 8 maxillary incisors were reused across all irrigation groups. The selected teeth were meticulously cleaned of all hard and soft tissue remnants using hand instruments and stored in 5% formalin saline solution until use.

After preparation of the access cavity, the teeth were sectioned to a standardized length of 18 mm from the apex. The root canals were prepared up to an X5 file of the ProTaper Next system according to the manufacturer's instructions. Subsequently, standardized parallel-walled root canals with an apical diameter of 1.1 mm were created using Gates Glidden burs to simulate immature root apices. After each file and Gates Glidden bur change, the canals were irrigated with 2 mL of 2.5% NaOCl. Final irrigation was performed sequentially with 2 mL of 2.5% NaOCl, 2 mL of 17% EDTA, and 2 mL of distilled water.

Each tooth was secured with cyanoacrylate into openings created in the caps of Eppendorf tubes. To simulate periapical tissues, the tubes were filled with a 1.5% agar gel. After the apical portions of the teeth were wrapped with Teflon tape, the teeth were placed into the tubes. Once the gel had set, the teeth were removed, and the Teflon tape was discarded. The weights of the Eppendorf tubes were then measured three times and recorded using an analytical balance with a precision of 0.00001 g (Radwag AS 82/220.R2, Radwag, Poland).[20] Following repositioning of the teeth into the agar gel, irrigation and activation procedures were performed (Figure 1).

Standard Needle Irrigation

Standard needle irrigation was performed with 2 mL of 2.5% NaOCl using a 30-gauge side-vented needle (Steri Irrigation Tips, DiaDent, Netherlands). The needle tip was positioned 2 mm short of the working length, and irrigation was repeated twice with in-and-out motions of the needle.

Figure 1. Experimental setup of a tooth embedded in 1.5% agar gel within an Eppendorf tube to simulate periapical resistance and enable standardized weighing.

Passive Ultrasonic Irrigation

Passive ultrasonic irrigation was performed with 2 mL of 2.5% NaOCl, with the needle tip positioned 2 mm short of the working length. Ultrasonic activation was then applied using a 0.2-mm diameter, 21-mm long tip (ED 60, Woodpecker, Japan) connected to an ultrasonic device (VDW Ultra, VDW, Munich, Germany) set at 30% power. The tip was moved using in-and-out motions for 20 seconds. Irrigation and activation were repeated twice.

EndoActivator

Irrigation was performed with 2 mL of 2.5% NaOCl, with the needle tip positioned 2 mm short of the working length. A medium-sized polymer tip was attached to the EndoActivator device, and activation was applied for 20 seconds using in-and-out motions. Irrigation and activation were repeated twice.

EDDY

Irrigation was performed with 2 mL of 2.5% NaOCl, with the needle tip positioned 2 mm short of the working length. A size 25.06, 28-mm long polyamide tip (VDW, Germany) was attached to an air scaler (TA-200, Micron, Tokyo, Japan) and operated at the first power setting (within the manufacturer's reported frequency range of 5000-9000 Hz). Activation was applied for 20 seconds with maximum speed using in-and-out motions. Irrigation and activation were repeated twice.

All activation procedures were performed in 2 positions to simulate different jaw positions: a vertical setup to mimic the mandibular position and a custom device angled at 45° to mimic the maxillary position. For the mandibular setup, the teeth were mounted vertically in Eppendorf tubes fixed to glass vials, while for the maxillary setup, a custom-made styrofoam holder was used to stabilize the specimens at a 45° inclination, ensuring standardized positioning across all experiments (Figure 2). After the activation procedures were completed, the teeth were removed from the agar gel, and the Eppendorf tubes were reweighed three times. The difference in weight before and after the procedure, measured in milligrams (mg), was recorded as the amount of irrigant extruded apically.

Statistical Analysis

The normality of data distribution was assessed using the Shapiro–Wilk test, which indicated a non-normal distribution. Accordingly, the Kruskal–Wallis test was used to compare apical extrusion amounts among different irrigation activation techniques, while the Mann–Whitney *U*-test was applied for pairwise comparisons between jaw positions (maxilla and mandible). A significance level of $P < .05$ was considered for all analyses. Statistical analyses were performed using SPSS software (version 20.0; IBM, USA).

RESULTS

The median (minimum-maximum) values of apical extrusion for each group are presented in Table 1. Although median values varied among the groups depending on both tooth position (maxillary vs. mandibular) and activation technique, no statistically significant differences were observed between the activation techniques. Furthermore, apical extrusion did not differ significantly between the maxillary and mandibular positions.

DISCUSSION

In immature teeth, the absence of an apical constriction increases the risk of irrigant extrusion; in fact, as the apical

Figure 2. Experimental setups simulating mandibular (vertical) and maxillary (45° inclined) positions using standardized holders.

diameter enlarges, the likelihood of irrigant passing into the periapical tissues also increases.[9] In studies investigating apical extrusion in immature teeth, apical diameters have typically been prepared between 0.8 and 1.5 mm.[7,15,16,18,21,22] In the present study, the apical diameter was standardized at 1.1 mm to represent an average value within this reported range. While some previous studies used extracted human teeth,[15,16,18,22]others employed 3D-printed teeth,[7,21] highlighting the advantage of standardization.[21] However, to better simulate clinical conditions in terms of dentin wettability, this study utilized extracted human teeth. To ensure standardization, the same 8 teeth were reused across all groups.

Some studies evaluating irrigant extrusion in immature teeth have incorporated cresol purple indicator into agar gel, analyzing color changes caused by extrusion through photographic documentation.[15,21,22] In other studies, the amount of extrusion was assessed using the classical Myers and Montgomery model.[7,18,23] In 1 study, teeth were placed in agar-filled tubes, and the extruded irrigant was quantitatively analyzed using micro-computed tomography.[16] In the present study, apical irrigant extrusion was evaluated by weighing the amount of extruded irrigant in grams using an analytical microbalance. This gravimetric method enabled precise and objective quantification of extrusion volume without reliance on visual interpretation or colorimetric changes. Unlike colorimetric or volumetric assessments, the gravimetric approach employed in this study allows for repeatable and standardized measurements of apically extruded irrigant. However, a limitation of gravimetry is that it only measures the total weight of extruded irrigant, without providing information about its spatial distribution or penetration depth into periapical tissues.[16] In addition, embedding teeth in an agar gel simulated the mechanical resistance of periapical tissues more effectively than traditional open-air or liquid-based models. This approach enhances the clinical relevance of the model by providing a more realistic barrier to irrigant extrusion during activation procedures.

The findings indicate that none of the evaluated irrigation techniques completely eliminated the risk of apical extrusion in immature teeth, underscoring the importance of clinical caution regardless of the method used. Although a tendency toward greater apical extrusion was observed in the mandibular position compared with the maxillary position across all groups, the difference did not reach statistical significance. Thus, the null hypothesis was accepted with respect to both the irrigation activation methods and tooth position. This suggests that, despite potential influences such as gravity, neither positional changes nor the choice of activation technique may significantly affect the amount of irrigant extrusion.

Table 1. Median (Minimum-Maximum) Values of Apical Irrigant Extrusion (in mg) for Different Irrigation Activation Techniques in Maxillary and Mandibular Positions

Position	PUI	EndoActivator	EDDY	SNI	*P*
Maxillary	11.4 (0.25-37.8)	12.7 (0.89-23.92)	9.3 (2.0-27.9)	9.4 (5.4-18.4)	.353
Mandibular	16.1 (5.9-62.3)	16.1 (1.4-28.7)	8.7 (0.7-68.1)	14.7 (0.3-32.5)	.686
P	.195	.328	.645	.645	

PUI, passive ultrasonic irrigation; SNI, standard needle irrigation.

Consistent with these results, Abat et al[21] reported no significant difference in apical extrusion between EDDY and conventional syringe irrigation when evaluating EDDY, Shock wave–enhanced emission photoacoustic streaming (SWEEPS) , XP-Endo Finisher, and SNI, with irrigation tips placed 2 mm short of the working length. Similarly, another study found no significant differences among SNI, PUI, XP-Endo Finisher, and Easy Clean in immature teeth, further supporting the findings of the present study.[22] However, Karasu et al[15] demonstrated that EDDY produced greater extrusion than PUI when extrusion was quantified as pixel-based color change, and Dos Reis et al[16]likewise reported more extrusion with EDDY than with needle irrigation or ultrasonic activation. Karasu et al[15] (2022) and Dos Reis et al[16] (2020) both observed greater extrusion with EDDY than with PUI or needle irrigation, whereas the present study found no significant differences among the techniques. These discrepancies may be attributed to methodological variations. First, different quantification methods were employed: pixel-based colorimetric assessment or volumetric micro–computed tomography analysis may be more sensitive to subtle fluid penetration but also more susceptible to interpretation bias, whereas the gravimetric approach used in the present study provides direct and objective measurement of extruded irrigant volume. Secondly, in the present study, the device used for EDDY activation was operated at the first power setting. In contrast, Karasu et al[15] (2022) did not specify the power setting of their device, while Dos Reis et al[16] (2020) employed a different device. In addition, the ultrasonic tip types and power settings used in these studies also differed from those in the present investigation. These variations in device type and power specification may have influenced the hydrodynamic behavior of the activation systems and contributed to the discrepancies in extrusion outcomes across studies.

Regarding tooth position, significantly higher extrusion with open- and closed-ended needles has been reported in the mandibular position compared with the maxillary and horizontal positions.[18] Sharma et al[7] similarly reported greater extrusion in the mandible than in the maxilla with both PUI and SNI. In contrast, the present study did not demonstrate a significant effect of tooth position on extrusion. A possible explanation is that the Myers and Montgomery model[23] used in previous studies does not simulate periapical tissue resistance, whereas the agar gel system employed in the present study was designed to approximate such resistance.

From a clinical perspective, these findings indicate that irrigant extrusion remains a potential risk in immature teeth regardless of the activation technique or tooth position. Clinicians should therefore exercise caution during irrigation procedures in regenerative endodontics to minimize the risk of damage to periapical tissues and apical papilla stem cells.

While agar gel provides a useful means of simulating periapical resistance, it cannot replicate dynamic biological processes such as blood perfusion or irrigant absorption. Moreover, the inherent limitations of in vitro models in reflecting clinical reality must be acknowledged as limitations of the present study. Future studies incorporating dynamic fluid movement models or in vivo simulations could provide further insights into the real-time behavior of irrigant extrusion under clinical conditions.

CONCLUSION

In immature teeth, irrigant extrusion remains a potential risk irrespective of the activation technique employed or the patient's positional orientation. Although not statistically significant, a tendency toward greater apical extrusion was observed in the mandibular position compared with the maxillary position, underscoring the need for careful consideration in clinical practice.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethical committee approval was received from the Clinical Research Ethics Committee of Çanakkale Onsekiz Mart University (Approval No.: 2023/07-15; Date: 03.05.2023).

Informed Consent: Written informed consent was obtained from the patients/patient who agreed to take part in the study.

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