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Influence of Sodium Hypochlorite Heating Method, Activation Technique, and Concentration on Organic Tissue Removal in Simulated Internal Resorption Cavities

ABSTRACT

Introduction: This *in vitro* study aimed to evaluate the effects of sodium hypochlorite (NaOCl) heating method, activation technique, and concentration on organic tissue removal from simulated internal resorption cavities. **Methods:** A total of 198 single-rooted resin teeth with simulated internal resorption cavities were included. To simulate organic tissue, the cavities were filled with bovine muscle tissue. Specimens were allocated into 18 groups ($n = 11$) according to heating method (room temperature, intracanal heating, or extracanal heating), NaOCl concentration (5.25% or 2%), and activation technique (standard needle irrigation, passive ultrasonic irrigation, or XP-endo Finisher). Baseline cone-beam computed tomography scans were obtained before irrigation. Following irrigation and activation procedures, residual organic tissue was assessed using cone-beam computed tomography and the percentage of residual organic tissue was calculated. Statistical analysis was performed with the significance level set at $P < .05$. **Results:** XP-endo Finisher resulted in significantly less residual organic tissue than standard needle irrigation under all temperature and concentration conditions. Passive ultrasonic irrigation showed superior tissue removal compared with standard needle irrigation only when 5.25% NaOCl was used with intracanal heating; no significant differences were observed under the other temperature and concentration conditions. Within the XP-endo Finisher groups, heating methods did not significantly influence tissue removal efficacy. In the passive ultrasonic and standard needle irrigation groups, extracanal heating generally yielded greater tissue removal than room temperature. Across all temperature conditions in the passive ultrasonic groups, and in the extracanal heating subgroup of standard needle irrigation, 5.25% NaOCl showed significantly greater tissue dissolution than 2% NaOCl. **Conclusions:** XP-endo Finisher demonstrated superior organic tissue removal regardless of irrigation temperature or NaOCl concentration. When standard needle irrigation or passive ultrasonic irrigation was used, extracanal heating of NaOCl enhanced its tissue-dissolving capacity, whereas increasing NaOCl concentration improved dissolution efficiency primarily in passive ultrasonic irrigation. (*J Endod* 2026;52:1023–1031.)

KEY WORDS

Heating; internal resorption; irrigation activation; sodium hypochlorite; XP-endo Finisher

The primary objective of endodontic treatment is the elimination of microorganisms and necrotic pulp tissue from the root canal system, followed by adequate disinfection and three-dimensional obturation to preserve tooth function¹. However, the complex anatomy of the root canal system, particularly irregular morphological features such as internal resorption cavities, limits the effectiveness of mechanical instrumentation and hinders complete debridement of organic tissue². Consequently,

SIGNIFICANCE

Effective removal of organic tissue from internal resorption cavities is critical for endodontic success. This study provides evidence on how irrigant temperature, concentration, and activation methods influence tissue removal, offering guidance for optimizing clinical irrigation protocols.

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irrigation plays a critical role in compensating for the limitations of mechanical instrumentation and is essential for treatment success³.

Sodium hypochlorite (NaOCl) is the most widely used irrigant in endodontics due to its antimicrobial properties and its ability to dissolve organic tissue^{4,5}. Nevertheless, the efficacy of NaOCl is influenced by both its concentration and temperature. Although higher concentrations provide greater tissue-dissolving capacity, their use is associated with an increased risk of toxicity and must therefore be approached with caution⁶. Heating NaOCl has been proposed as an alternative strategy to enhance its effectiveness, as increasing the temperature of lower-concentration solutions can improve both their antimicrobial activity and tissue-dissolving potential^{7,8}.

Another approach to improving irrigation efficacy involves the use of activation techniques. Standard needle irrigation (SNI) has limited effectiveness because of inadequate irrigant penetration into the apical region⁹. Passive ultrasonic irrigation (PUI) enhances irrigant performance by generating acoustic microstreaming and cavitation within the canal, whereas the XP-endo Finisher (XPF), owing to its flexible design, facilitates irrigant contact in areas inaccessible to conventional mechanical instrumentation¹⁰⁻¹². Comparing the effectiveness of these activation systems in irregular cavities such as those encountered in internal resorption is therefore highly relevant to clinical practice.

Previous *in vitro* studies have investigated organic tissue removal from simulated internal resorption cavities using different irrigation protocols¹³⁻¹⁵. Mechanical activation with XPF has been reported to enhance organic tissue removal compared with both conventional syringe irrigation and passive ultrasonic irrigation¹³. Additionally, devices such as Easy Clean have demonstrated improved organic tissue removal compared with passive ultrasonic irrigation¹⁴. More recent studies have investigated the effects of intracanal-heated sodium hypochlorite in combination with different activation techniques on tissue dissolution¹⁵. However, the available evidence remains limited regarding the combined and comparative effects of sodium hypochlorite heating methods, concentration, and activation techniques on organic tissue removal from simulated internal resorption cavities.

The aim of this study was to evaluate the effectiveness of NaOCl in removing organic tissue from resin tooth models with simulated internal resorption cavities under

different heating methods, activation techniques, and concentrations using cone-beam computed tomography (CBCT). The null hypotheses were that the sodium hypochlorite heating method (H_{01}), activation technique (H_{02}), and concentration (H_{03}) would not significantly affect organic tissue removal from simulated internal resorption cavities.

MATERIALS AND METHODS

The sample size was determined based on a previously published study with a similar methodology¹⁶. A power analysis was performed for variance analysis using statistical software (G*Power 3.1; Heinrich Heine University, Düsseldorf, Germany; F-test family), with an effect size of 0.8059, a significance level of $\alpha = 0.05$, and a power of 95% ($\beta = 0.95$). The minimum required sample size was calculated as $n = 10$ per group. To account for potential procedural errors and specimen loss, 11 teeth were included in each group. Accordingly, a total of 198 teeth were included in the present study.

Resin tooth models were designed based on the morphology of a maxillary central incisor, featuring a standardized access cavity, sealed apical foramina, a canal length of 28 mm with a standardized canal size of ISO 50 and 0.04 taper, and a simulated internal resorption cavity measuring 5 mm in diameter located 5 mm coronal to the root apex (Fig. 1). All geometric features of the resin tooth models, including canal length, apical anatomy, and internal resorption cavity dimensions, were standardized during manufacturing. No mechanical instrumentation or canal preparation was performed before the experimental procedures.

A total of 198 specimens were allocated into 18 subgroups according to 3 heating conditions (room temperature, extracanal heating, and intracanal heating), 3 irrigation activation techniques (standard needle irrigation, passive ultrasonic irrigation, and XPF), and 2 NaOCl concentrations (2% and 5.25%) (Fig. 2).

To simulate organic tissue within the internal resorption cavities, bovine muscle tissue was used. For visualization during CBCT measurements, the tissue was minced into small, homogeneous fragments and mixed with barium sulfate at a weight ratio of 1:20 (ZAG Kimya, Barium Sulfate [Barite] 95.45% Chem Pure 1 kg; ZK.100270.1000, Türkiye). To determine the optimal ratio, preliminary mixtures were prepared at different proportions (1:2, 1:5, 1:10, 1:20, and

1:40) and evaluated using CBCT imaging, after which the most suitable ratio was selected. This process provided sufficient radiopacity of the simulated organic tissue within the resorption cavity. After preparation, the tissue-barium sulfate mixture was loaded into a syringe equipped with a transparent plastic delivery tip commonly used for intracanal paste placement. The mixture was injected into each canal to fill the entire canal space, including the internal resorption cavity, using the same delivery and packing procedure for all specimens to ensure consistent filling conditions. Each specimen was weighed before and after placement of the tissue mixture, and the mean mass of introduced material (0.077 ± 0.011 g) confirmed consistency in the amount of organic tissue introduced into the cavities. All weighing procedures, including preparation of the tissue-barium sulfate mixture and specimen mass measurements, were performed using an analytical balance with a precision of 10^{-4} g. (RADWAG AS 220.R2 Plus, Radom, Poland)

For CBCT imaging (NewTom 5G XL; QR Systems, Verona, Italy), specimens were positioned in groups of 8 within custom-made molds fabricated using C-type silicone impression material (Zeta Plus Intro Kit L, Zhermack SpA, Badia Polesine, Italy), and all scans were acquired using the same molds. Imaging parameters were set at 110 kV, a slice thickness of 0.100 mm, a field of view of 8×8 cm, an exposure time of 9 seconds, and a high-resolution scanning protocol. The images were exported in Digital Imaging and Communications in Medicine format. Prior to irrigation procedures, the amount of organic tissue within the internal resorption cavity was quantified by importing the Digital Imaging and Communications in Medicine files into 3D Slicer software (version 5.4.0; Surgical Planning Laboratory, Harvard University, Boston, MA, USA; Fig. 3). The organic tissue within the internal resorption cavity was reconstructed three-dimensionally, and volume measurements were recorded in cubic millimeters (mm^3) (Fig. 4). Volumetric measurements were performed in 3D Slicer software using semiautomatic threshold-based segmentation of the radiopaque tissue mixture within the standardized internal resorption cavity. Image reconstruction and segmentation procedures were performed by an oral and maxillofacial radiologist with 8 years of experience, followed by manual verification of segmentation boundaries. To assess intrarater reliability, 70 out of the 198 teeth (approximately 35% of the total sample) were randomly re-evaluated by the same examiner after a 2-week interval, and the

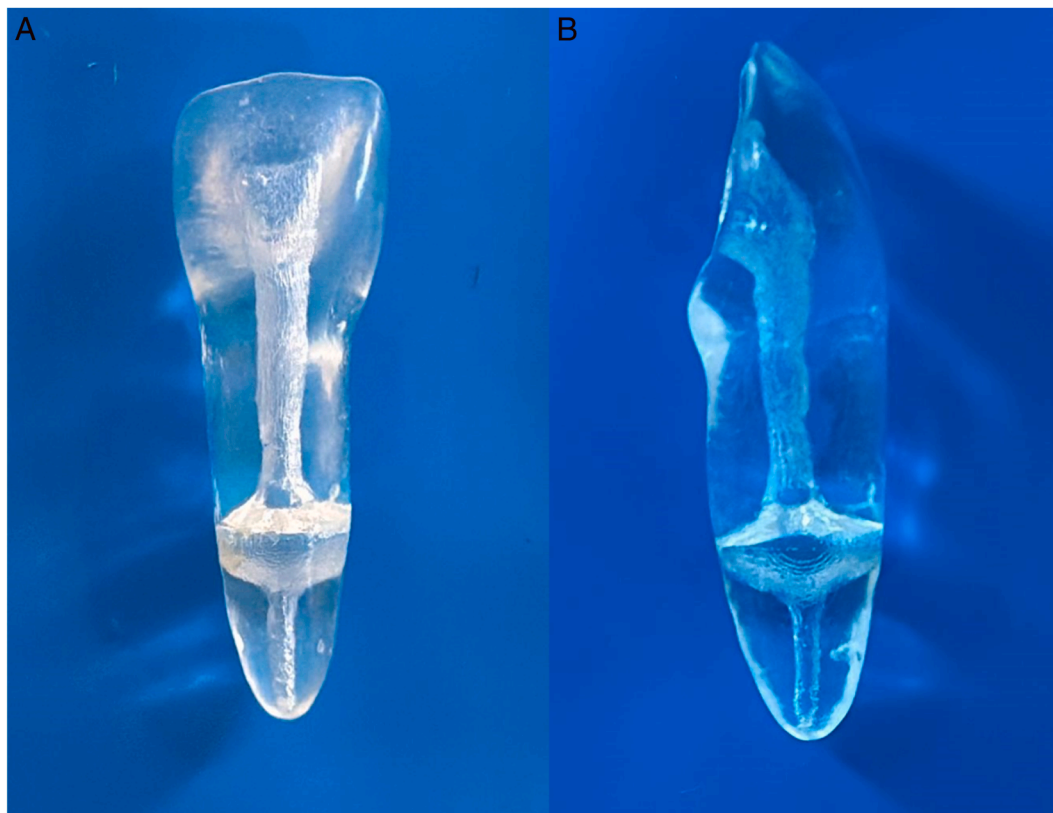


FIGURE 1 – Resin tooth model. (A) Buccal view. (B) Axial view.

intraclass correlation coefficient was calculated to determine measurement consistency over time. (intraclass correlation coefficient = 0.95, 95% CI: 0.66–0.98, $P < .001$).

Irrigation Procedures

Teeth filled with organic tissue were irrigated according to the protocols assigned to their respective groups. Prior to irrigation, the organic tissue within each root canal was

gently instrumented using a size #50 H-file (Perfect Dental, Türkiye).

In the first phase, irrigation procedures were performed using 2% NaOCl (CHLORAXID 2%; Cerkamed, Stalowa Wola,

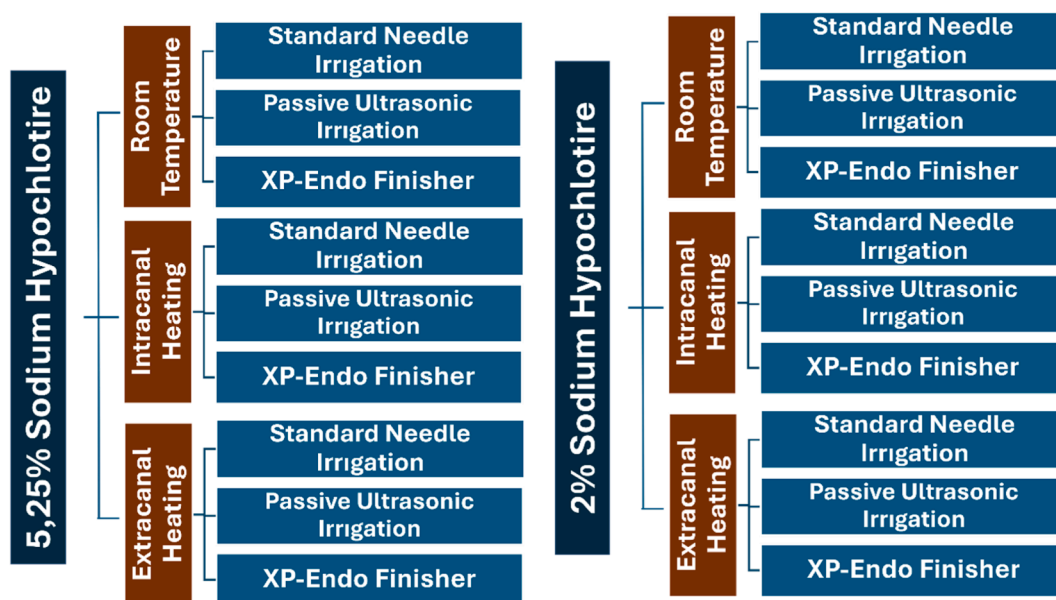


FIGURE 2 – Grouping of the 198 specimens according to NaOCl concentration, heating conditions, and irrigation activation techniques. NaOCl, sodium hypochlorite.

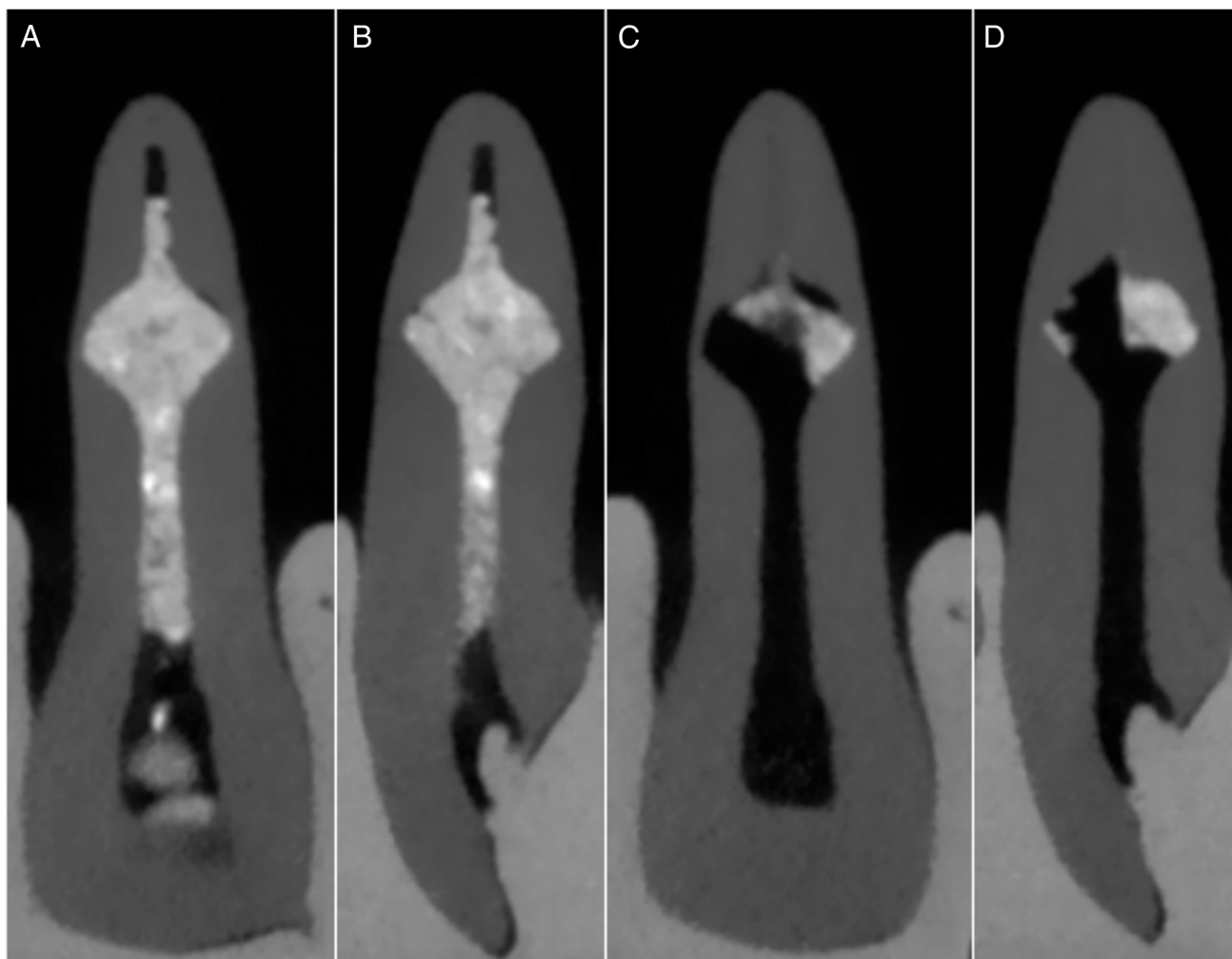


FIGURE 3 – Coronal (*A* and *C*) and sagittal (*B* and *D*) cross-sectional images of root canals filled with organic tissue material, obtained using 3D Slicer software. (*A* and *B*): Before irrigation. (*C* and *D*): After irrigation.

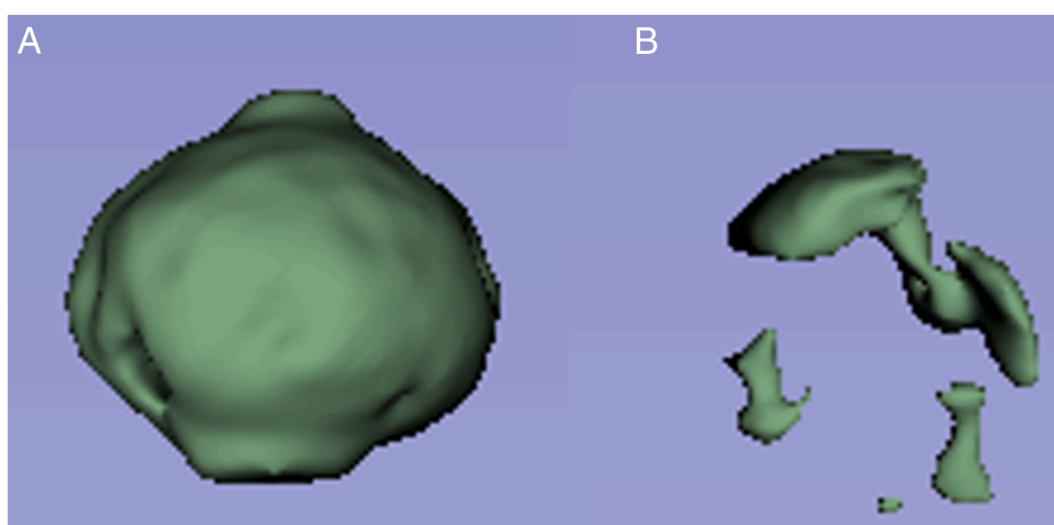


FIGURE 4 – Three-dimensional reconstructed images of organic tissue material within the internal resorption cavity obtained using 3D Slicer software. (*A*) Before irrigation. (*B*) After irrigation.

Poland) under different heating methods and activation techniques, resulting in 9 experimental subgroups.

Irrigation Procedures at Room Temperature (SNI, PUI, and XPF)

Specimens were irrigated with 5 mL of NaOCl solution at room temperature ($23 \pm 1^\circ\text{C}$), which was maintained constant throughout all procedures and monitored using a thermocouple thermometer (UT325; UNI-T, Dongguan, Guangdong, China), using a 31-gauge, double side-vented irrigation needle (Ultradent NaviTip; Ultradent, Utah, USA). The irrigation needle was positioned 1 mm short of the working length and moved gently in an up-and-down motion throughout irrigation. After irrigation, a waiting period of 20 seconds was allowed.

For PUI at room temperature, each 5 mL NaOCl irrigation cycle was followed by ultrasonic activation using an ultrasonic unit (VDW ULTRA; VDW GmbH, Munich, Germany) equipped with an ultrasonic irrigation activation tip (Woodpecker E60 Endo Ultrasonic Tip; China) operated at 30% power for 20 seconds.

For XPF activation at room temperature, each 5 mL NaOCl irrigation cycle was followed by activation using an XPF file (ISO size 25, 0% taper; FKG Dentaire, Switzerland) mounted on an endodontic motor (Woodpecker, Guilin, China) at 1000 rpm and 1 N cm torque. Activation was performed for 20 seconds using 5-mm amplitude in-and-out movements.

For each activation group, the procedures were repeated 3 times to deliver a total irrigant volume of 15 mL per canal. Subsequently, the canals were flushed with 5 mL of distilled water.

Irrigation Procedures with Extracanal Heating (SNI, PUI, XPF)

For extracanal heating in the SNI group, 5 mL of NaOCl solution was heated to 60°C using a water bath method within the syringe and delivered to the canal following the same protocol used at room temperature. The temperature of the solution was continuously monitored using a thermocouple thermometer. A 20-second waiting period was allowed after each 5 mL irrigation cycle.

For extracanal heating in the PUI group, the NaOCl solution was heated to 60°C using the same water bath method and activated ultrasonically for 20 seconds following the same protocol as the room temperature PUI group.

For extracanal heating in the XPF group, the NaOCl solution was heated to

60°C and activated for 20 seconds using the same XPF protocol applied in the room temperature group.

In all extracanal heating groups, the procedures were repeated 3 times to achieve a total irrigant volume of 15 mL per canal, followed by the final irrigation with 5 mL of distilled water.

Irrigation Procedures with Intracanal Heating (SNI, PUI, and XPF)

For intracanal heating in the SNI group, canals were irrigated with 5 mL of NaOCl solution using a double side-vented irrigation needle. A heating condenser tip (Duo-Pen Heating Condenser #.06–50; DiaDent, South Korea) attached to a warm vertical compaction device (Duo-Pen; DiaDent, South Korea) was inserted into the root canal and activated for 10 seconds to heat the irrigant within the canal. The heating device was operated at a constant temperature setting of 230°C according to the manufacturer's instructions, and identical device settings and heating durations were applied to all specimens to ensure procedural standardization. A 20-second waiting period was allowed after each heating cycle.

For PUI activation, the heated irrigant within the canal was ultrasonically activated for 20 seconds using the same ultrasonic unit and activation tip employed in the room temperature and extracanal heating groups.

For XPF activation, the heated irrigant was activated for 20 seconds using the XP-Endo Finisher file, following the same protocol as in the other XPF groups.

After repeating the irrigation, intracanal heating, and activation procedures 3 times with 5 mL NaOCl to reach a total volume of 15 mL, all canals were finally irrigated with 5 mL of distilled water.

All procedures performed with 2% NaOCl were repeated identically for the 5.25% NaOCl groups.

Postirrigation, imaging was performed using the same CBCT parameters applied at baseline. The residual organic tissue volume was analyzed using 3D Slicer software, and the percentage of remaining organic tissue within the resorption cavity was calculated by normalizing the residual volume to the initial volume.

Statistical Analysis

Data were analyzed using IBM SPSS statistical software (version 27; SPSS Inc., Chicago, IL, USA). A significance level of $P < .05$ was considered statistically significant. Data distribution was assessed

using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. Due to the multifactorial design and the presence of nonparametric distributions in certain subgroups, a stratified analysis approach was adopted. Simple main-effect analyses were conducted by fixing 2 variables and comparing the third within homogeneous experimental conditions. For groups showing normal distribution and homogeneity of variances, comparisons among 3 groups were performed using one-way analysis of variance followed by post hoc Bonferroni post hoc tests. When data did not meet normality assumptions, comparisons among 3 groups were conducted using the Kruskal–Wallis test; in cases where significant differences were detected, pairwise comparisons were performed using the Dunn–Bonferroni post hoc test. To evaluate the effect of NaOCl concentration, within experimental conditions independent-samples *t* tests were used for normally distributed data, whereas the Mann–Whitney *U* test was applied for non-normally distributed data.

RESULTS

Table 1 presents the descriptive statistics (mean, standard deviation, median, and 25th–75th percentiles) of the percentage of residual organic tissue within the internal resorption cavity following irrigation with 5.25% NaOCl under different activation and heating conditions.

No statistically significant difference was observed between SNI and PUI in terms of residual organic tissue at room temperature or under extracanal heating conditions ($P > .05$). Under both room temperature and extracanal heating conditions, XPF resulted in significantly less residual organic tissue compared with both SNI and PUI ($P < .05$). Under intracanal heating conditions, XPF was significantly more effective than both PUI and SNI; additionally, PUI demonstrated superior tissue removal compared with SNI ($P < .05$).

When the effect of heating methods was evaluated while keeping the activation technique constant, significant differences were observed among heating conditions in the SNI and PUI groups. In the SNI group, no significant difference was found between room temperature and intracanal heating ($P > .05$); however, extracanal heating resulted in a significantly lower percentage of residual tissue compared with the other heating conditions ($P < .05$). In the PUI group, both intracanal and extracanal heating resulted in significantly less residual organic tissue than room temperature ($P < .05$), whereas no significant difference was

TABLE 1 - Comparison of the Percentages of Residual Organic Tissue within the Internal Resorption Cavity Following Irrigation with 5.25% NaOCl Under Different Activation Techniques and Heating Conditions, as Assessed by CBCT

	Room temperature	Intracanal heating	Extracanal heating	P
SNI	44.56 (14.72) 46.95 (30.02–58.4) ^{a,A}	39.81 (10.05) 38.15 (34.86–46.85) ^{a,A}	10.87 (9.50) 10.51 (2.49–16.45) ^{a,B}	<.05*
PUI	27.95 (12.32) 30.69 (15.93–32.51) ^{a,A}	14.04 (8.86) 12.06 (9.11–21.38) ^{b,B}	7.64 (9.61) 2.85 (0.00–13.25) ^{a,B}	<.05*
XPF	3.71 (7.06) 0.00 (0.00–8.79) ^b	0.51 (1.69) 0.00 (0.00–0.00) ^c	1.29 (4.28) 0.00 (0.00–0.00) ^b	>.05 [†]
P	<.05 [†]	<.05 [†]	<.05 [†]	

CBCT, cone-beam computed tomography; NaOCl, sodium hypochlorite; PUI, passive ultrasonic irrigation; SNI, standard needle irrigation; XPF, XP-endo Finisher.

Data are presented as mean (standard deviation) and median (25th–75th percentiles).

Lowercase letters indicate statistically significant differences among activation techniques within the same column, whereas uppercase letters indicate statistically significant differences among heating conditions within the same row ($P < .05$).

*One-way ANOVA.

[†]Kruskal–Wallis test.

detected between intracanal and extracanal heating ($P > .05$). In contrast, within the XPF group, low residual tissue values were observed under all heating conditions, and no statistically significant differences were detected among the heating methods ($P > .05$).

Table 2 presents the descriptive statistics (mean, standard deviation, median, and 25th–75th percentiles) of the percentage of residual organic tissue within the internal resorption cavity following irrigation with 2% NaOCl under different activation and heating conditions.

No statistically significant difference was detected between SNI and PUI in terms of residual organic tissue under any heating condition ($P > .05$). In contrast, XPF resulted in significantly less residual organic tissue than both SNI and PUI across all heating conditions ($P < .05$).

When the effect of heating methods was evaluated while keeping the activation

technique constant, no significant differences were observed among heating conditions in the SNI and XPF groups ($P > .05$). In the PUI group, no statistically significant difference was found between intracanal and extracanal heating ($P > .05$); however, both heating methods resulted in significantly less residual organic tissue compared with room temperature ($P < .05$).

When the effect of NaOCl, concentration on organic tissue removal was evaluated under different activation and heating conditions, no statistically significant difference was observed between 2% and 5.25% NaOCl when SNI was applied at room temperature or with intracanal heating ($P > .05$). In contrast, under extracanal heating conditions, 5.25% NaOCl was significantly more effective than 2% NaOCl ($P < .05$).

In the PUI groups, 5.25% NaOCl resulted in significantly less residual organic

tissue than the lower concentration under all heating conditions ($P < .05$).

In the XPF groups, no statistically significant differences were detected between NaOCl concentrations under any of the heating conditions ($P > .05$).

DISCUSSION

In previous *in vitro* studies on internal resorption, resorption cavities have commonly been created by longitudinally sectioning teeth, followed by cavity preparation in each half using burs or acid demineralization techniques^{13,17}. However, these approaches present notable limitations, including difficulties in achieving standardization and dentin loss during sectioning process. Therefore, resin tooth models were preferred in the present study, as they allowed the creation of resorptive cavities with identical location, volume, and morphology across all specimens. Incisor teeth are the most frequently affected by internal root resorption, with lesions typically localized in the middle or apical third of the root¹⁸. To closely simulate the clinical scenario, resin tooth models with apically positioned internal resorption cavities were used in the present study.

Various organic tissues, including rat dermal tissue¹⁹, porcine palatal mucosa²⁰, and bovine muscle tissue^{5,14} have been used in previous studies investigating the tissue-dissolving capacity of NaOCl. Bovine muscle tissue has also been widely used in studies evaluating organic tissue removal from internal resorption cavities^{14,15,18}. Due to its similarity to pulp tissue, ease of availability, homogeneous structure, and ability to be standardized in size and weight¹⁴, bovine muscle tissue was selected in the present study to simulate organic tissue within the internal resorption cavity.

Most previous studies evaluating organic tissue removal from internal resorption cavities have relied on gravimetric analysis^{14,18}. While this method allows quantitative assessment by comparing tissue weights before and after irrigation, the present study employed CBCT, enabling nondestructive three-dimensional volumetric analysis and detailed evaluation of both the amount and spatial distribution of residual tissue. CBCT has been reported as a reliable and minimally invasive tool for analyzing complex morphologies such as internal resorption²¹.

To enhance the visibility of organic tissue in CBCT imaging, a tissue mixture containing barium sulfate was prepared. Although barium sulfate improves

TABLE 2 - Comparison of the Percentages of Residual Organic Tissue within the Internal Resorption Cavity Following Irrigation with 2% NaOCl under Different Activation Techniques and Heating Conditions

	Room temperature	Intracanal heating	Extracanal heating	P
SNI	43.03 (17.56) 49.12 (36.71–53.80) ^a	38.81 (21.85) 45.78 (24.12–46.86) ^a	27.34 (13.53) 24.75 (13.26–43.15) ^a	>.05*
PUI	56.31 (18.19) 52.27 (47.85–69.02) ^{a,A}	40.96 (9.97) 43.95 (33.24–48.74) ^{a,B}	27.23 (9.70) 26.09 (20.88–34.07) ^{a,B}	<.05*
XPF	7.16 (10.61) 0.00 (0.00–14.79) ^b	0.91 (2.21) 0.00 (0.00–0.00) ^b	1.56 (3.6) 0.08 (0.00–0.72) ^b	>.05 [†]
P	<.05 [†]	<.05 [†]	<.05 [†]	

NaOCl, sodium hypochlorite; PUI, passive ultrasonic irrigation; SNI, standard needle irrigation; XPF, XP-endo Finisher. Data are presented as mean (standard deviation) and median (25th–75th percentiles).

Lowercase letters indicate statistically significant differences among activation techniques within the same column, whereas uppercase letters indicate statistically significant differences among heating conditions within the same row ($P < .05$).

*One-way ANOVA.

[†]Kruskal–Wallis test.

radiographic visibility due to its high X-ray absorption, increasing its proportion reduces the volume of organic tissue. Therefore, a preliminary study was conducted to determine the minimum barium sulfate concentration required for homogeneous visualization, and a weight ratio of 5% (1:20) was selected.

This study evaluated the effects of irrigant concentration, heating method, and activation technique on organic tissue dissolution during irrigation. Based on the results, all null hypotheses were rejected, indicating that irrigant concentration, heating method, and activation technique significantly influenced organic tissue removal.

It has been reported that the tissue-dissolving capacity of NaOCl increases with concentration^{5,7,19}, although higher concentrations may also increase tissue toxicity²². In the present study, when the effect of concentration was evaluated under SNI, no significant differences were observed at room temperature or with intracanal heating. In contrast, under extracanal heating conditions, higher NaOCl concentration resulted in significantly greater organic tissue removal. This finding may be attributed to the irrigant entering the canal at a higher initial temperature, potentially enhancing its tissue-dissolving capacity during the early phase of irrigation.

In the PUI groups, 5.25% NaOCl demonstrated significantly greater tissue dissolution than 2% NaOCl across all temperature protocols, supporting the importance of irrigant concentration in determining chemical effectiveness⁵. In contrast, no significant differences between concentrations were observed in any heating condition within the XPF groups. This effect may be related to the high elasticity and expansion capacity of the nickel-titanium XPF instrument, which enhances mechanical contact with canal walls and facilitates physical removal of tissue in areas inaccessible to the irrigant alone²³. Consequently, the reduced chemical activity of lower-concentration NaOCl may have been compensated for by the mechanical action of XPF. In addition, the continuous expansion and movement of the instrument may enhance irrigant circulation and debris mobilization within irregular resorption cavities, further contributing to tissue removal efficiency.

Heating is known to enhance the tissue-dissolving capacity of NaOCl^{5,7,8,24}. Increased temperature reduces solution viscosity and accelerates the diffusion of free chlorine ions, thereby significantly enhancing dissolution kinetics^{5,7}. Studies using

standardized bovine pulp samples have demonstrated that tissue dissolution rates increase significantly as NaOCl temperature rises⁸. Similarly, Stojičić et al⁵ reported that temperature positively contributes to tissue dissolution, while Arslan et al²⁴ showed that extracanal heating to approximately 60 °C resulted in superior tissue dissolution compared with cooled or room-temperature solutions.

In the present study, no significant differences were observed between temperature protocols when 2% NaOCl was used with SNI, whereas extracanal heating was more effective when 5.25% NaOCl was applied. These findings indicate that the method of heat application plays a critical role. During intracanal heating, irrigant was delivered at room temperature, and the heating probe may reduce the fluid volume and allowed rapid cooling, thereby limiting exposure to elevated temperatures. In addition, displacement of irrigant by the heating tip may reduce the effective volume of solution available for tissue dissolution, potentially limiting the chemical action of NaOCl within the resorption cavity. In contrast, extracanal heating enables the continuous delivery of preheated irrigant, resulting enhanced tissue dissolution. Deepa et al²⁵ similarly reported that continuous heating was more effective than preheating alone, supporting the present findings. Consistent with the present study, Saryılmaz et al¹⁵ reported no significant differences between room-temperature NaOCl and intracanal-heated NaOCl in internal resorption models. In contrast, Jaiswal et al²⁶ reported superior performance associated with intracanal heating. These discrepancies may be attributed to differences in tissue type, vitality status, and outcome measures used (time-based vs volumetric analyses).

In the PUI groups, no significant differences were observed between intracanal and extracanal heating; however, both heating methods were significantly more effective than room temperature. This finding aligns with the concept that heating provides greater benefit when combined with activation rather than used alone²⁷. Similarly, Stojičić et al⁵ reported that activation could enhance tissue dissolution by up to 300%, with agitation exerting a greater effect than temperature alone. The absence of differences among heating conditions in the XPF groups further suggests that organic tissue removal efficacy depends more on the mechanical properties of XPF than on irrigant temperature. In the present study, although heated irrigants were used, the actual

intracanal temperature achieved during irrigation was not measured and likely decreased due to thermal buffering. Therefore, the potential influence of temperature variations on the metallurgical behavior of the XPF instrument cannot be definitively determined, and future studies addressing this aspect would provide further clarification.

Across all heating and concentration conditions, XPF demonstrated greater organic tissue removal than PUI and SNI, in agreement with previous reports on simulated internal resorption models^{13,15}. Ulusoy et al¹³ reported that XPF was superior to PUI, whereas Saryılmaz et al¹⁵ reported no significant difference between these techniques. The discrepancy may be related to differences in tooth models, material properties, and methodological design. Previous *in vitro* studies evaluating bovine muscle tissue removal from simulated internal resorption cavities have reported no significant differences between PUI and SNI^{14,15}. The present findings are consistent with these reports. In contrast, Ulusoy et al¹³ reported superior efficacy of PUI, possibly due to differences in ultrasonic devices, power settings, or the use of additional chelating agents such as EDTA or HEBP.

The limitations of this *ex vivo* study include the absence of biological factors such as periodontal ligament circulation which may limit direct simulation to clinical conditions. The organic tissue model used also does not fully mimic the biomechanical properties and adhesion behavior of necrotic pulp tissue, which may influence the clinical performance of irrigation activation techniques. Furthermore, standardized resin models may not fully replicate the irregular anatomy or complex microstructural and surface characteristics of dentin in clinical conditions. Future studies employing experimental models in which internal resorption cavities can be created without tooth sectioning, thereby preserving natural dentinal structure, may provide findings that are better reflect of clinical conditions and further improve the translational relevance of tissue removal assessments. Additionally, the use of higher-resolution imaging modalities, such as microcomputed tomography, may provide additional validation of volumetric assessment methods in internal resorption models.

CONCLUSION

Regardless of the heating method, XPF was the most effective activation

technique for organic tissue removal at both concentrations. Overall, no statistically significant differences were observed between SNI and PUI under any heating condition at either concentration. When PUI was employed, the combined use of higher NaOCl concentration with either intracanal or extracanal heating may yield improved outcomes, whereas for SNI, the combination of higher

concentration and extracanal heating may be more effective.

In conclusion, this study evaluated the effectiveness of irrigation and activation techniques under controlled laboratory conditions. Nevertheless, further *in vivo* studies and long-term clinical follow-up studies are required to elucidate the influence of anatomical variability and biological factors in clinical practice.

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The authors deny any conflicts of interest related to this study.

REFERENCES

1. Siqueira Junior JF, das Rôças IN, Marceliano-Alves MF, et al. Unprepared root canal surface areas: causes, clinical implications, and therapeutic strategies. *Braz Oral Res* 2018;32(Suppl 1):1–19.
2. Patel S, Saberi N. The ins and outs of root resorption. *Br Dent J* 2018;224:20–1.
3. Haapasalo M, Endal U. Internal inflammatory root resorption: the unknown resorption of the tooth. *Endod Top* 2008;14:60–79.
4. Cunningham WT, Joseph SW. Effect of temperature on the bactericidal action of sodium hypochlorite endodontic irrigant. *Oral Surg Oral Med Oral Pathol* 1980;50:569–71.
5. Stojicic S, Zivkovic S, Qian W, et al. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. *J Endod* 2010;36:1558–62.
6. Radcliffe CE, Potouridou L, Qureshi R, et al. Antimicrobial activity of varying concentrations of sodium hypochlorite on the endodontic microorganisms *Actinomyces israelii*, *A. naeslundii*, *Candida albicans* and *Enterococcus faecalis*. *Int Endod J* 2004;37:438–46.
7. Sirtes G, Waltimo T, Schaetzle M, et al. The effects of temperature on sodium hypochlorite short-term stability, pulp dissolution capacity, and antimicrobial efficacy. *J Endod* 2005;31:669–71.
8. Rossi-Fedele G, De Figueiredo JAP. Use of a bottle warmer to increase 4% sodium hypochlorite tissue dissolution ability on bovine pulp. *Aust Endod J* 2008;34:39–42.
9. Burleson A, Nusstein J, Reader A, et al. The *in vivo* evaluation of hand/rotary/ultrasound instrumentation in necrotic, human mandibular molars. *J Endod* 2007;33:782–7.
10. Gu LS, Kim JR, Ling J, et al. Review of contemporary irrigant agitation techniques and devices. *J Endod* 2009;35:791–804.
11. Ozdemir O, Hazar E, Kocak S, et al. Kök Rezorpsiyonları. *J Int Dent Sci* 2019;5:38–44.
12. Silva EJNL, Belladonna FG, Zuolo AS, et al. Effectiveness of XP-endo Finisher and XP-endo Finisher R in removing root filling remnants: a micro-CT study. *Int Endod J* 2018;51:86–91.
13. Ulusoy OI, Savur G, Alacam T, et al. The effectiveness of various irrigation protocols on organic tissue removal from simulated internal resorption defects. *Int Endod J* 2018;51:1030–6.
14. Monteiro LPB, de Sousa SEM, de Castro RF, et al. Mechanical activation with Easy Clean device enhanced organic tissue removal from simulated internal root resorption in a laboratory evaluation. *BMC Oral Health* 2023;23:385.
15. Sariyilmaz O, Bayindir E, Sariyilmaz E, et al. The impact of intracanal heating and irrigation solution activation on organic tissue removal from internal resorption cavities: an *in vitro* study. *Türk Klin J Dent Sci* 2025;31:59–66.
16. Koc S, Er K, Hajgulyeva G, et al. Pulp tissue dissolution capacities of different irrigation agitation techniques in artificial internal resorption cavities. *Eur Oral Res* 2024;58:64–9.
17. Ozden I, Sazak Ovecoglu H. Evaluation of filling quality of obturation techniques in internal resorption cavities created with a novel methodology. *Bezmialem Sci* 2024;12:71–7.
18. Çalışkan M, Turkun M. Prognosis of permanent teeth with internal resorption: a clinical review. *Dent Traumatol* 1997;13:75–81.
19. Abou-Rass M, Oglesby SW. The effects of temperature, concentration, and tissue type on the solvent ability of sodium hypochlorite. *J Endod* 1981;7:376–7.

20. Estevez R, Conde AJ, Valencia de Pablo O, et al. Effect of passive ultrasonic activation on organic tissue dissolution from simulated grooves in root canals using sodium hypochlorite with or without surfactants and EDTA. *J Endod* 2017;43:1161–5.
21. Patel S, Ricucci D, Durak C, et al. Internal root resorption: a review. *J Endod* 2010;36:1107–21.
22. Gernhardt CR, Eppendorf K, Kozlowski A, et al. Toxicity of concentrated sodium hypochlorite used as an endodontic irrigant. *Int Endod J* 2004;37:272–80.
23. FKG Dentaire SA. XP-endo Finisher Product Brochure. La Chaux-De-Fonds, Switzerland: FKG Dentaire SA; 2024.
24. Arslan AR. Effect of decreased temperature on the tissue dissolution ability of sodium hypochlorite: an *in vitro* study. *Turk Endod J* 2024;9:16–20.
25. Deepa VL, Vanga HR, Kadali N, et al. Effect of prewarming and continuous warming on tissue dissolving ability of Triton versus Twin Kleen: an *in vitro* study. *J Conserv Dent* 2024;27:100–4.
26. Jaiswal S, Gupta S, Nikhil V, et al. Effect of intracanal and extracanal heating on pulp dissolution property of continuous chelation irrigant. *J Conserv Dent* 2021;24:544–8.
27. Iandolo A, Abdellatif D, Amato M, et al. Dentinal tubule penetration and root canal cleanliness following ultrasonic activation of intracanal-heated sodium hypochlorite. *Aust Endod J* 2020;46:204–9.