BMC Oral Health

RESEARCH

Open Access

Pulp tissue dissolution capacities of two hypochlorite-based irrigants at different temperatures: an in vitro study

Damla Erkal[1], Yunus Emre Çakmak[2*], Ana Maria Pistol[3] and Kürşat Er[2]

Abstract

Background Effective removal of pulp tissue is essential for successful root canal treatment. Sodium hypochlorite (NaOCl) is commonly used because of its tissue-dissolving and antimicrobial properties, but its instability and cytotoxicity have led to the exploration of alternatives such as calcium hypochlorite [$Ca(ClO)_2$]. Both irrigants may show enhanced efficacy when heated, yet comparative data under varying temperatures remain limited. This study aimed to evaluate the pulp tissue dissolution capacity of NaOCl and $Ca(ClO)_2$ irrigants at various temperatures.

Methods Standardized bovine pulp tissues (25 mg) were exposed to 3 irrigants [distilled water, 5.25% NaOCl, and 5.25% $Ca(ClO)_2$] each tested at 24 °C, 36 °C, and 60 °C. The samples were irrigated with 2.5 mL of the assigned irrigant, with a total exposure time of 15 min including 3 min of sonic activation (3 × 20 s per cycle × 3 repetitions) and subsequently reweighed to calculate the percentage of tissue dissolution. Statistical analysis included the Shapiro-Wilk test for normality, the Scheirer-Ray-Hare test for overall group comparison, and the Mann-Whitney U test for post hoc analysis.

Results Tissue dissolution significantly varied depending on both irrigant type and temperature ($P < 0.001$). Both hypochlorite-based irrigants showed superior dissolution capacity compared to distilled water, with no significant difference between them ($p = 0.178$). Higher temperatures led to increased dissolution across all groups, with the greatest effect observed at 60 °C.

Conclusion These findings underscore the potential clinical benefits of optimizing irrigant protocols through temperature modulation. $Ca(ClO)_2$ may represent a viable alternative to NaOCl, particularly in scenarios where biocompatibility and chemical stability are prioritized.

Keywords Pulp, Tissue dissolution, Sodium hypochlorite, Calcium hypochlorite

*Correspondence:
Yunus Emre Çakmak
dt.emrecakmak@gmail.com
[1]Department of Endodontics, Faculty of Dentistry, Burdur Mehmet Akif Ersoy University, Burdur, Turkey
[2]Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey
[3]Department of Pedodontics, Faculty of Dental Medicine, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Introduction

Effective pulp tissue dissolution is a fundamental requirement for endodontic irrigants, as it plays a vital role in facilitating thorough canal debridement and enhancing disinfection outcomes. Residual organic tissues within the root canal system not only impede the penetration of intracanal medicaments and sealers but also provide a substrate for microbial survival and proliferation, thereby increasing the risk of persistent infection, postoperative pain, and long-term treatment failure [1]. Therefore, irrigants with potent tissue-dissolving properties are essential for cleaning both the main canal and anatomically complex areas such as isthmuses, lateral canals, and apical deltas.

Sodium hypochlorite (NaOCl) is the most widely used endodontic irrigant, primarily due to its broad-spectrum antimicrobial effect, its ability to dissolve necrotic and vital pulp tissue, and its capacity to eliminate the organic component of the smear layer [2–5]. However, despite these advantages, NaOCl also presents certain drawbacks. Its optimal performance is achieved at higher concentrations, which may increase the risk of cytotoxicity and damage to periapical tissues if extruded beyond the apex [6]. Additionally, NaOCl is chemically unstable and highly sensitive to external factors such as temperature, light exposure, and storage conditions, all of which can compromise its effectiveness by reducing the availability of free chlorine ions responsible for tissue dissolution [5, 6]. Given that an irrigant's dissolving efficacy is directly proportional to its chlorine content [7], these limitations highlight the need for alternative solutions with improved stability and similar efficacy.

Consequently, research continues to explore novel irrigants that can match or exceed the tissue-dissolving performance of NaOCl while offering better biocompatibility and chemical resilience under clinical conditions.

Calcium hypochlorite [$Ca(ClO)_2$] is a white powder that can be dissolved in distilled water and used for industrial sterilization and purifying water treatment. It is relatively stable and has a greater available chlorine content than NaOCl does [8]. Chlorine, an active oxidizer, also allows irreversible inhibition of essential bacterial enzymes [9]. Studies [10–12] have demonstrated the potential of $Ca(ClO)_2$ irrigants to dissolve tissue and antimicrobial action against *E. faecalis*. Additionally, compared with NaOCl, $Ca(ClO)_2$ has favorable effects on viability and induces a low-level inflammatory response [8]. Others have reported that $Ca(ClO)_2$ has a greater percentage of usable chlorine ions than NaOCl does [10, 13] and has a considerable dissolving effect on organic tissue [14]. Furthermore, cytotoxicity studies have shown that $Ca(ClO)_2$ provides more positive results for cell viability and induces a far lower inflammatory response than NaOCl does [15]. On the basis of these findings, $Ca(ClO)_2$ could be a promising root canal irrigant alternative to NaOCl [11].

Temperature activation has been shown to improve chemical reaction rates and thus can amplify their immediate tissue-dissolution capacity and antimicrobial effect, which is the primary goal of root canal treatment (RCT) [16]. Understanding the comparative effectiveness of NaOCl and $Ca(ClO)_2$ at various temperatures provides valuable insights into their practical applications in endodontics.

This study aims to systematically evaluate the dissolution capacity of hypochlorite-based [NaOCl & $Ca(ClO)_2$] irrigants at different temperatures (24 °C, 36 °C, and 60 °C) on pulp tissue, highlighting their chemical mechanisms, clinical implications, and potential advantages. By analyzing literature and experimental findings, this study seeks to contribute to the ongoing discourse on optimizing endodontic irrigation protocols for improved patient outcomes. The null hypothesis of this study was that the type of irrigant [distilled water, NaOCl or $Ca(ClO)_2$] and the variation in temperature (24 °C, 36 °C, or 60 °C) do not significantly affect pulp tissue dissolution.

Materials and methods

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines [17] (Fig. 1). For a visual overview of the experimental protocol and group allocations, refer to Fig. 2.

Sample size calculation

The sample size was estimated based on a power analysis using G*Power 3.1 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany), assuming a significance level of 0.05, a statistical power of 80%, and a large effect size (f = 0.41). As a result, a minimum of 11 samples per group was considered sufficient.

Sample preparation

This study was not considered an animal experiment, as the procedures did not interfere with the animals' premortem condition or the method of slaughter in any form. Freshly extracted bovine mandibular incisors were used to obtain pulp tissues. The crowns were sectioned via a diamond bur, and the pulp tissues were removed under sterile conditions. The samples were stored at -80 °C until use.

Bovine incisors were decoronated at the cementoenamel junction via diamond fissure burs, and the pulp tissues were carefully removed. All pulp tissue was irrigated with distilled water to remove excess blood/blood clots and placed into individual Eppendorf tubes for subsequent treatment procedures. This method allows a standardized and isolated environment to assess the effects

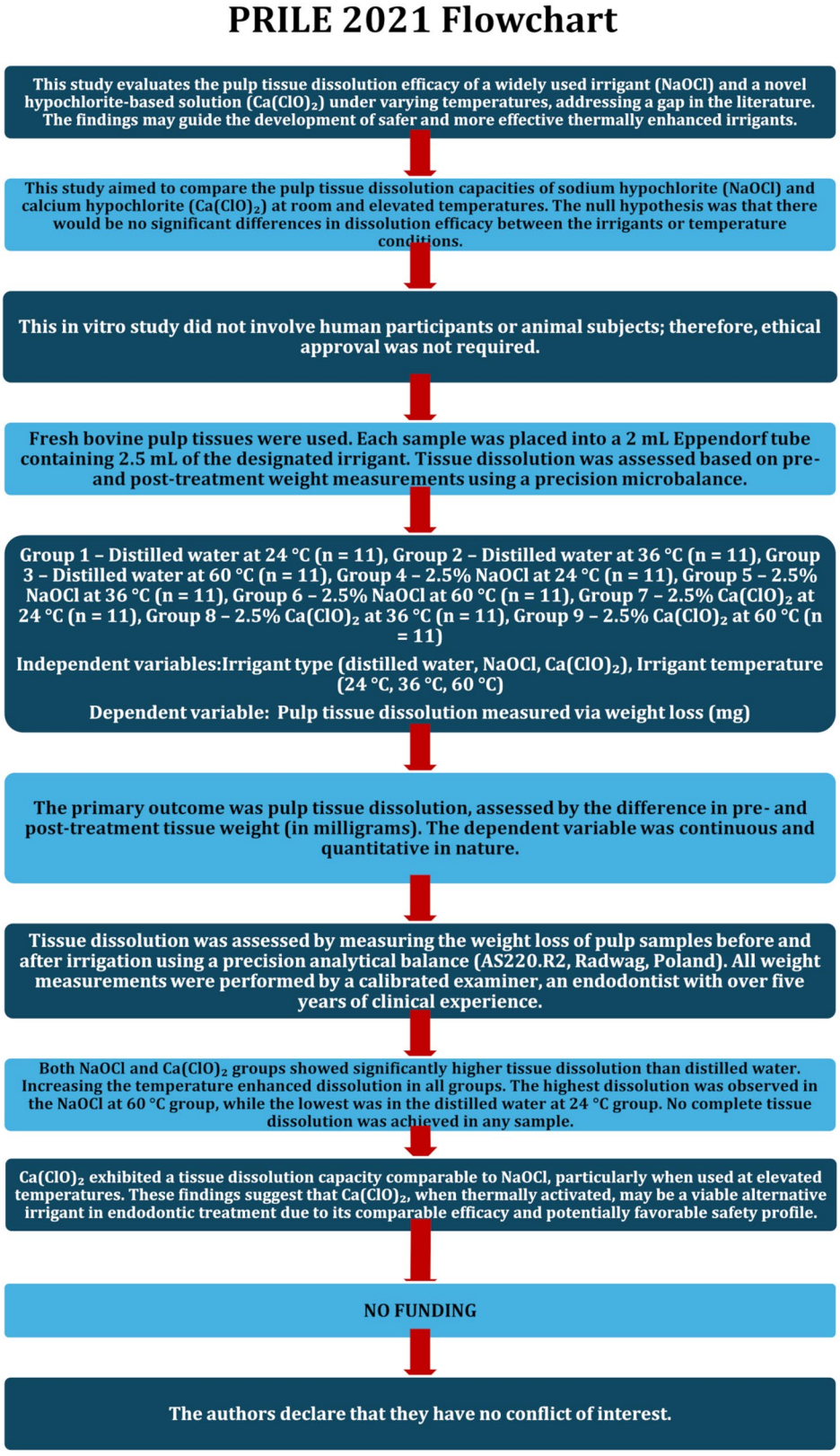


Fig. 1 Preferred reporting items for laboratory studies in endodontology (PRILE 2021) flow chart

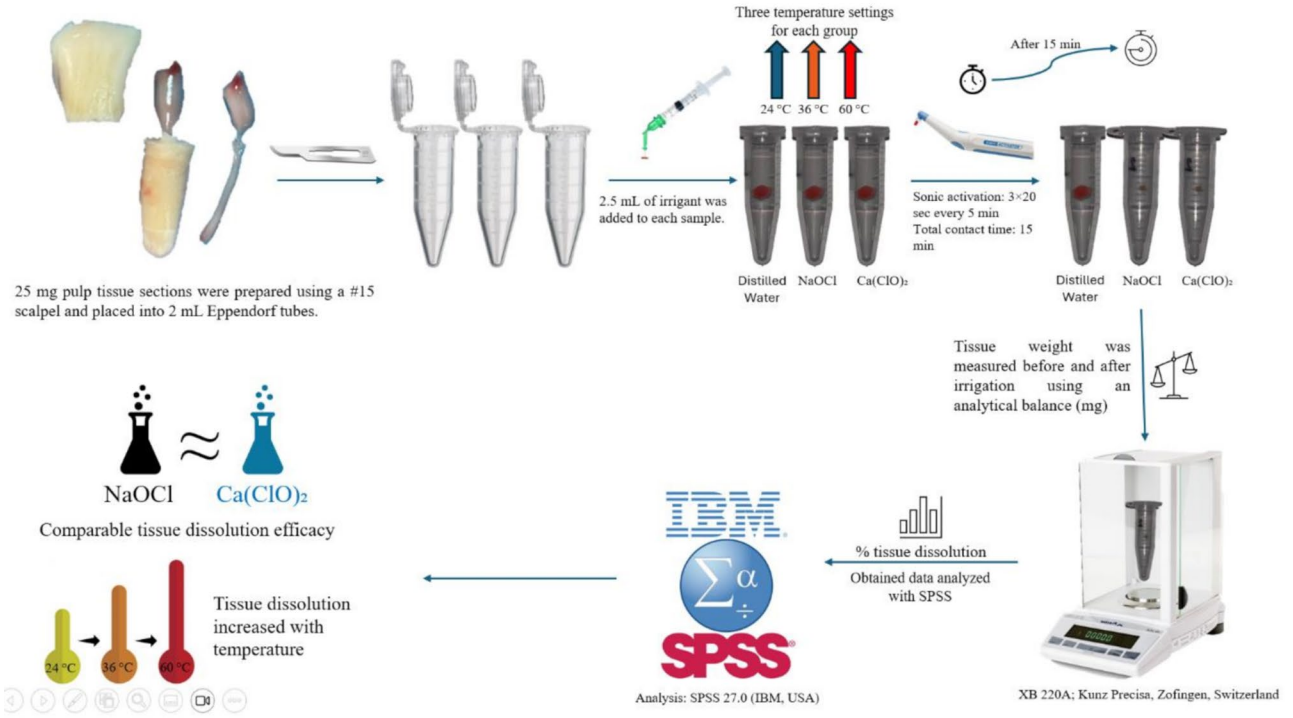


Fig. 2 Graphical abstract. Visual overview depicting standardized pulp tissue exposure to hypochlorite-based irrigants under varying thermal conditions and the resulting dissolution trends

of the tested agents on pulp tissue, minimizing external variables that may arise from dentin cavity preparations.

Pulp tissue standardization

Following thawing at room temperature for approximately 1 h, the pulp tissues were sectioned into smaller fragments via a sterile #15 surgical blade (B. Braun, Melsungen, Germany). Each fragment was carefully trimmed to obtain approximately 25 mg of tissue. To ensure precision and reproducibility, each sample was weighed 3 times via a high-sensitivity analytical balance (XB 220 A; Kunz Precisa, Zofingen, Switzerland), and the average of these measurements was recorded as the initial weight for further analysis.

Preparation of irrigants, irrigation procedure and grouping

The study included 3 irrigants: distilled water (control), 5.25% NaOCl, and 5.25% $Ca(ClO)_2$. These irrigants were tested at 3 temperatures: 24 °C (room temperature), 36 °C, and 60 °C. The granulated form of $Ca(ClO)_2$ (Superkim, Torbalı, Izmir, Turkiye) was used to prepare the irrigant. The preparation mixture was weighed prior to the study, and distilled water was added to achieve a weight/volume (w/v) ratio. The resulting mixture was agitated for 30 min and filtered through paper, and a 5.25% irrigant was obtained. The other used irrigant was 5.25% NaOCl (Cerkamed, Nisko, Poland).

The specimens were randomly allocated into nine experimental groups ($n = 11$ per group) using a computer-generated randomization table, based on the type of irrigant and the temperature condition. The irrigants used at 36 °C and 60 °C were preheated via a digital water bath (Fisher Scientific, Loughborough, UK), and their temperatures were verified immediately prior to application with a digital thermometer (DT-03, Epinox, Istanbul, Turkiye) to ensure consistency. Each pre-weighed pulp tissue sample was immersed in 2.5 mL of the designated irrigant within a sterile Eppendorf tube. All samples were subjected to a standardized irrigation and activation protocol to ensure procedural consistency across experimental groups.

All samples were subjected to a standardized irrigation and activation protocol to ensure procedural consistency across experimental groups. This protocol consisted of three consecutive 5-minute cycles. In each cycle, the sample was first passively immersed in the irrigant for 3 min, followed by a 2-minute activation phase using the EndoActivator system (Dentsply Maillefer, Ballaigues, Switzerland). The activation phase was structured as 1 min of sonic agitation (3 × 20 s), interspersed with 1 min of rest intervals (3 × 20 s). After each cycle, the used irrigant was completely aspirated and replaced with a fresh solution. This procedure was repeated three times per sample, resulting in a total exposure time of 15 min. Before final weighing, excess moisture was gently blotted

from the tissue using a sterile cotton pellet to ensure accurate measurement.

The total exposure time of 15 min was selected based on previous studies [18, 19], which demonstrated that this duration is sufficient for effective pulp tissue dissolution and antimicrobial efficacy of NaOCl, without causing significant damage to surrounding structures.

The experimental groups were as follows:

Group 1 (Distilled water at 24 °C): Samples in this group were irrigated with distilled water at room temperature. The standardized irrigation and activation protocol was applied.
Group 2 (Distilled water at 36 °C): Distilled water was preheated to 36 °C in a water bath prior to application. All samples were treated following the standardized protocol.
Group 3 (Distilled water at 60 °C): In this group, distilled water was preheated to 60 °C. Irrigation and activation were performed according to the standardized protocol.
Group 4 (NaOCl at 24 °C): Sodium hypochlorite maintained at 24 °C was used as the irrigant. The standardized irrigation and activation protocol was applied to all specimens.
Group 5 (NaOCl at 36 °C): NaOCl was preheated to 36 °C to simulate intraoral conditions. All procedures were performed in accordance with the standardized protocol.
Group 6 (NaOCl at 60 °C): NaOCl was preheated to 60 °C and applied to the specimens. Standardized irrigation and activation were performed.
Group 7 [$Ca(ClO)_2$ at 24 °C]: A freshly prepared 5.25% $Ca(ClO)_2$ solution at room temperature was used. All samples were treated using the standardized protocol.
Group 8 [$Ca(ClO)_2$ at 36 °C]: The $Ca(ClO)_2$ solution was preheated to 36 °C. Irrigation and sonic activation followed the standardized procedure.
Group 9 [$Ca(ClO)_2$ at 60 °C]: In the final group, $Ca(ClO)_2$ was preheated to 60 °C. All samples underwent treatment with the standardized irrigation and activation protocol.

Table 1 Mean ± standard deviation of tissue weight reduction (%), according to irrigant and temperature conditions

Groups	24 °C Mean ± SD	36 °C Mean ± SD	60 °C Mean ± SD
Distilled Water	14.28 ± 7.29^{bB}	13.41 ± 4.60^{aB}	24.58 ± 9.54^{aB}
NaOCl	81.65 ± 5.38^{bA}	88.36 ± 3.72^{aA}	96.36 ± 2.41^{aA}
$Ca(ClO)_2$	73.47 ± 10.73^{bA}	89.68 ± 4.16^{aA}	90.78 ± 6.06^{aA}

**a, b: Different lowercase letters in the same column indicate statistically significant differences between temperatures ($p < 0.05$). ***A, B: Different uppercase letters in the same row indicate statistically significant differences between irrigants ($p < 0.05$)

Each sample was weighed three times using the same precision balance, and the mean value was recorded. The percentage of pulp dissolution was calculated via the following formula:

$$\text{Dissolution } (\%) = [\,(\text{Initial Weight} - \text{Final Weight})\,/\,\text{Initial Weight}] \times 100$$

Blinding and operator standardization

All irrigation and activation procedures were performed by 2 experienced endodontists, each with over 5 years of clinical expertise. A digital stopwatch (Neval Digital Stopwatch, Istanbul, Turkey) was used to measure the total contact time of the irrigants. The operator responsible for irrigant activation was blinded to the group allocations to reduce procedural bias. In contrast, the examiner who recorded the duration of each irrigation cycle was aware of the group assignments, as this information was necessary for accurate timekeeping and protocol adherence.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was used to assess the normality of the data distribution, and Levene's test was used to assess the homogeneity of variance. As the data did not meet parametric assumptions, nonparametric tests were applied. Group comparisons were made via the Scheirer-Ray-Hare test, and post hoc analysis was performed via the Mann–Whitney U test. $P < 0.05$ was considered statistically significant.

Results

Statistical analysis revealed significant differences in pulp dissolution rates among the different irrigant and temperature groups ($P < 0.001$). Post hoc analysis indicated that the distilled water group presented a significantly lower dissolution capacity than both the NaOCl and $Ca(ClO)_2$ groups did ($P < 0.001$), whereas no statistically significant difference was found between the NaOCl and $Ca(ClO)_2$ groups ($P = 0.178$). The temperature comparisons revealed significant differences between all the tested temperatures (24 °C vs. 36 °C, 24 °C vs. 60 °C, and 36 °C vs. 60 °C), with higher temperatures resulting in increased dissolution ($P < 0.05$). A significant interaction was also found between the type of irrigant and temperature ($P < 0.001$). The mean and standard deviation values of each group are summarized in Table 1. The statistical results of pairwise comparisons between irrigants and temperatures are presented in Tables 2 and 3, respectively, including *p*-values and effect size estimations to convey the magnitude of differences.

Table 2 Mann-Whitney U post hoc test results for pairwise comparisons between the irrigant groups

Comparison	U Statistic	*p* value	Effect Size (*r*)
Distilled water vs. $Ca(ClO)_2$	0.0	< 0.001	0.986
Distilled water vs. NaOCl	0.0	< 0.001	0.921
$Ca(ClO)_2$ vs. NaOCl	439.0	0.178	0.289

Table 3 Mann-Whitney U post hoc test results for pairwise comparisons between temperature groups

Comparison	U Statistic	*p* value	Effect size (*r*)
24 °C vs. 36 °C	362.0	0.020	0.604
24 °C vs. 60 °C	296.0	0.001	0.725
36 °C vs. 60 °C	376.0	0.031	0.574

Discussion

The null hypothesis was rejected, as significant differences were observed in tissue dissolution capacities among the tested irrigants and across different temperature conditions. Post hoc analysis revealed that both hypochlorite-based irrigants [NaOCl and $Ca(ClO)_2$] exhibited significantly greater dissolution than distilled water did, and increasing the temperature significantly increased the dissolution capacity in all the groups.

The elimination of microorganisms, toxic byproducts, and organic/inorganic debris from the root canal system is essential for the success of RCT. The residual necrotic/vital pulp tissue remaining in the canal following treatment can adversely affect the prognosis and may lead to persistent infection. Therefore, the complete removal and dissolution of organic tissue is of vital importance for the long-term success of RCT.

This study evaluated the pulp tissue dissolution capacities of 2 commonly used endodontic irrigants, NaOCl and $Ca(ClO)_2$, at different temperatures via a standardized bovine pulp tissue model. The results demonstrated that both hypochlorite-based irrigants presented significantly greater tissue dissolution capacities than did the control group (distilled water).

Although NaOCl is considered the gold standard irrigant in endodontics due to its strong tissue-dissolving capacity, it has been reported that NaOCl is chemically unstable and that external factors such as temperature, light, and storage conditions can affect the availability of chlorine ions, potentially reducing its disinfecting efficacy [18]. In contrast, $Ca(ClO)_2$ has been shown to contain more free chlorine ions and to be more chemically stable than NaOCl is [10]. Furthermore, in a cytotoxicity study, Blattes et al. [15] compared the cytotoxic effects of $Ca(ClO)_2$ and NaOCl both in vitro using 3T3 fibroblasts and in vivo by assessing the inflammatory response in rats. $Ca(ClO)_2$ promoted favorable in vitro cell viability and induced only minimal levels of inflammation. These findings suggest that $Ca(ClO)_2$ could be considered a potential alternative to NaOCl, particularly in terms of its chemical stability, minimal inflammatory response, and greater availability. In our study, $Ca(ClO)_2$ exhibited similar effectiveness under the tested conditions, and no statistically significant difference was found between the 5.25% NaOCl and 5.25% $Ca(ClO)_2$ groups in terms of tissue dissolution capacity.

In their study, Moorer and Wesselink [20] reported that the tissue dissolution capacity of irrigants used in RCT may vary depending on concentration. In the present study, both $Ca(ClO)_2$ and NaOCl irrigants were tested at the same concentration (5.25%). The results demonstrated that within the same temperature group, the 2 irrigants exhibited statistically similar pulp tissue dissolution effects.

Sonic activation systems have been demonstrated to enhance debridement efficacy in root canal systems. Studies [21–23] utilizing first-generation EndoActivator systems have shown significantly improved debridement effectiveness compared with conventional syringe irrigation. In accordance with these findings, our study employed the EndoActivator for irrigant agitation. The intermittent irrigation technique was selected for this investigation because of its superior control over the activation tip depth and irrigant volume during application.

Previous studies [16, 24–26] have reported that heating NaOCl significantly enhances both its tissue-dissolving capacity and antimicrobial efficacy. In the present study, the temperature-dependent increase in pulp tissue dissolution observed across all experimental groups is consistent with earlier literature suggesting that thermal activation improves the performance of irrigants. For both hypochlorite-based irrigants, the highest dissolution rates were recorded at 60 °C. This finding can be attributed to the increased molecular activity and improved diffusion capacity of the irrigant at elevated temperatures, which accelerate protein denaturation and subsequently accelerate tissue degradation. The positive impact of temperature on irrigant efficiency may offer considerable clinical benefits, particularly in cases involving complex root canal anatomies where effective debridement is essential. Within this context, thermally activated irrigation protocols can be considered a valuable clinical approach, especially in scenarios where the elimination of persistent infections and enhanced tissue dissolution are critical to achieving successful endodontic outcomes.

In this study, a total exposure time of 5 min was allocated and divided into three 5 min periods, with no significant differences observed between groups when irrigants of identical temperature and concentration were used. Similarly, Dutta & Saunders [10] reported that both NaOCl and $Ca(ClO)_2$ irrigants demonstrated comparable tissue dissolution effects after just 5 min of exposure. Few studies [10, 14] have evaluated the tissue dissolution

capacity of $Ca(ClO)_2$, and our investigation revealed a similar trend to these prior findings.

Tissue dissolution assessment protocols reported in the literature vary substantially depending on multiple factors, including the source of tissue, duration of irrigant exposure, frequency of irrigant replenishment, and the use of activation methods [14, 27]. In the present study, bovine pulp tissue was selected due to its close morphological and histological resemblance to human dental pulp. Methodological strengths– such as standardized tissue weights, the use of a standardized in vitro model (based on Eppendorf tubes), and the implementation of a sonic activation protocol– contribute to the internal validity of the findings.

Nevertheless, several limitations should be acknowledged. The in vitro design may not fully replicate clinical conditions, particularly in terms of anatomical complexity and the buffering capacity of dentin. Moreover, the static nature of the irrigation setup does not mimic the dynamic fluid flow encountered in vivo. Tissue dissolution was evaluated solely based on weight loss, which may not capture changes in microstructure or biochemical composition.

An additional limitation is the absence of a control group without activation. The use of sonic agitation has likely enhanced the irrigant's tissue-dissolving capacity and may have influenced the thermal distribution, thereby potentially obscuring the isolated effects of the irrigant type and temperature. Future studies should incorporate non-activated control groups to better delineate the independent contributions of chemical and thermal variables. These limitations underscore the need for further investigations to enhance the clinical relevance of the findings. Future studies should incorporate non-activated control groups and assess the long-term effects of different irrigants on dentin structure and biocompatibility. Additionally, evaluating calcium hypochlorite in anatomically simulated root canals may help clarify its potential for clinical use.

Conclusion

This study demonstrated that both 5.25% NaOCl and $Ca(ClO)_2$ achieved comparable pulp tissue dissolution efficacy under standardized in vitro conditions, with no statistically significant difference observed between the two irrigants. Elevated temperatures (up to 60 °C) significantly enhanced the tissue-dissolving capacity of both irrigants, underscoring the clinical potential of thermal activation for optimizing irrigant performance. Given its lower cost, ease of handling, and reduced cytotoxicity risk compared to NaOCl, $Ca(ClO)_2$ may represent a promising alternative for endodontic irrigation, particularly when combined with thermal enhancement.

Abbreviations

$Ca(ClO)_2$	Calcium hypochlorite
NaOCl	Sodium hypochlorite
sec	Second

Acknowledgements

Not applicable.

Author contributions

Damla Erkal conceptualized and designed the study. Yunus Emre Çakmak conducted the experimental procedures, and Damla Erkal performed the statistical analyses. Kürşat Er interpreted the data and drafted the initial version of the manuscript. The manuscript was written collaboratively by Damla Erkal, Yunus Emre Çakmak, and Ana Maria Pistol. Kürşat Er reviewed and approved the final version. All authors have read and agreed to the published version of this manuscript. Yunus Emre Çakmak is designated as the corresponding author and is responsible for all correspondence related to this submission.

Funding

The authors received no specific funding for this work.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was not considered an animal experiment, as the procedures did not interfere with the animals' premortem condition or the method of slaughter in any form; therefore, ethical approval was not deemed necessary.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 9 May 2025 / Accepted: 29 June 2025
Published online: 05 July 2025

References

1. Wu MK, Dummer PMH, Wesselink PR. Consequences of and strategies to deal with residual posttreatment root canal infection. Int Endod J. 2006;39(5):343–56. https://doi.org/10.1111/j.1365-2591.2006.01092.x
2. Koc S, Er K, Hajguliyeva G, Osmanlı Z, Jabbarova L, Karayilmaz H. Pulp tissue dissolution capacities of different irrigation agitation techniques in artificial internal resorption cavities. Eur Oral Res. 2024;58(2):64–9. https://doi.org/10.26650/eor.20241048313
3. Neelakantan P, Cheng C, Mohanraj R, Sriraman P, Subbarao C, Sharma S. Antibiofilm activity of three irrigation protocols activated by ultrasonic, diode laser or er: YAG laser in vitro. Int Endod J. 2015;48(6):602–10. https://doi.org/10.1111/iej.12354
4. Conde A, Estevez R, Loroño G, Valencia de Pablo O, Rossi-Fedele G, Cisneros R. Effect of sonic and ultrasonic activation on organic tissue dissolution from simulated grooves in root canals using sodium hypochlorite and EDTA. Int Endod J. 2017;50(10):976–82. https://doi.org/10.1111/iej.12717
5. Zehnder M. Root canal irrigants. J Endod. 2006;32(5):389–98. https://doi.org/10.1016/j.joen.2005.09.014
6. Christensen CE, McNeal SF, Eleazer P. Effect of lowering the ph of sodium hypochlorite on dissolving tissue in vitro. J Endod. 2008;34(4):449–52. https://doi.org/10.1016/j.joen.2008.01.001
7. Gordon TM, Damato D, Christner P. Solvent effect of various dilutions of sodium hypochlorite on vital and necrotic tissue. J Endod. 1981;7(10):466–9. https://doi.org/10.1016/S0099-2399(81)80308-1
8. Iglesias JE, Pinheiro LS, Weibel DE, Montagner F, Grecca FS. Influence of surfactants addition on the properties of calcium hypochlorite solutions. J Appl Oral Sci. 2019;27:e20180157. https://doi.org/10.1590/1678-7757-2018-0157

9. Estrela C, Estrela CR, Barbin EL, Spano JC, Marchesan MA, Pecora JD. Mechanism of action of sodium hypochlorite. Braz Dent J. 2002;13(2):113–7. https://doi.org/10.1590/s0103-64402002000200007
10. Dutta A, Saunders WP. Comparative evaluation of calcium hypochlorite and sodium hypochlorite on soft–tissue dissolution. J Endod. 2012;38(10):1395–8. https://doi.org/10.1016/j.joen.2012.06.020
11. Ozturk O, Genc Sen O. Evaluation of pulp tissue dissolving efficiency of sodium and calcium hypochlorite solutions activated by ultrasonics and laser: an in vitro study. BMC Oral Health. 2024;24(1):1046. https://doi.org/10.1186/s12903-024-04852-z
12. de Almeida AP, Souza MA, Miyagaki DC, Dal Bello Y, Cecchin D, Farina AP. Comparative evaluation of calcium hypochlorite and sodium hypochlorite associated with passive ultrasonic irrigation on antimicrobial activity of a root canal system infected with *Enterococcus faecalis*: an in vitro study. J Endod. 2014;40(12):1953–7. https://doi.org/10.1016/j.joen.2014.08.025
13. Carlotto IB, Luisi SB, Kopper PMP, Grecca FS, Montagner F. Calcium hypochlorite solutions: evaluation of surface tension and effect of different storage conditions and time periods over pH and available chlorine content. J Endod. 2016;42(4):641–5. https://doi.org/10.1016/j.joen.2016.01.006
14. Taneja S, Mishra N, Malik S. Comparative evaluation of human pulp tissue dissolution by different concentrations of chlorine dioxide, calcium hypochlorite and sodium hypochlorite: an in vitro study. J Conserv Dent. 2014;17(6):541–5. https://doi.org/10.4103/0972-0707.144590
15. Blattes GB, Mestieri LB, Böttcher DE, Fossati AC, Montagner F, Grecca FS. Cell migration, viability and tissue reaction of calcium hypochlorite based-solutions irrigants: an in vitro and in vivo study. Arch Oral Biol. 2017;73:34–9. https://doi.org/10.1016/j.archoralbio.2016.08.037
16. Govindaraju L, Shruthi ST, Gopal R, Jenarthanan S, Rajendran MR. Does the increase in temperature of sodium hypochlorite have enhanced antimicrobial efficacy and tissue dissolution property? A systematic review and meta-regression. J Conserv Dent Endod. 2024;27(7):675–84. https://doi.org/10.4103/JCDE.JCDE_110_24
17. Nagendrababu V, Murray PE, Ordinola-Zapata R, Peters OA, Rôças IN, Siqueira JF Jr, et al. PRILE 2021 guidelines for reporting laboratory studies in endodontology: a consensus-based development. Int Endod J. 2021;54:1482–90.
18. Mohammadi Z. Sodium hypochlorite in endodontics: an update review. Int Dent J. 2008;58(6):329–41. https://doi.org/10.1111/j.1875-595X.2008.tb00354.x
19. Slutzky-Goldberg I, Maree M, Liberman R, Heling I. Effect of sodium hypochlorite on dentin microhardness. J Endod. 2004;30(12):880–2. https://doi.org/10.1097/01.don.0000128748.05148.1e
20. Moorer WR, Wesselink PR. Factors promoting the tissue dissolving capability of sodium hypochlorite. Int Endod J. 1982;15(4):187–96. https://doi.org/10.1111/j.1365-2591.1982.tb01277.x
21. Akcay M, Arslan H, Mese M, Durmus N, Capar ID. Effect of photon-initiated photoacoustic streaming, passive ultrasonic, and sonic irrigation techniques on dentinal tubule penetration of irrigation solution: a confocal microscopic study. Clin Oral Investig. 2017;21(7):2205–12. https://doi.org/10.1007/s00784-016-2013-y
22. Zeng C, Hu P, Egan CP, Bergeron BE, Tay F, Ma J. Bacteria debridement efficacy of two sonic root canal irrigant activation systems. J Dent. 2024;140:104770. https://doi.org/10.1016/j.jdent.2023.104770
23. Zeng C, Everett J, Sidow S, Bergeron BE, Tian F, Ma J, Tay FR. In vitro evaluation of efficacy of two endodontic sonic-powered irrigant agitation systems in killing single-species intracanal biofilms. J Dent. 2021;115:103859. https://doi.org/10.1016/j.jdent.2021.103859
24. Sirtes G, Waltimo T, Schaetzle M, Zehnder M. The effects of temperature on sodium hypochlorite short-term stability, pulp dissolution capacity, and antimicrobial efficacy. J Endod. 2005;31(9):669–71. https://doi.org/10.1097/01.don.0000153846.62144.d2
25. Stojicic S, Zivkovic S, Qian W, Zhang H, Haapasalo M. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. J Endod. 2010;36(9):1558–62. https://doi.org/10.1016/j.joen.2010.06.021
26. Yared G, Al Asmar Ramli G. Antibacterial ability of sodium hypochlorite heated in the canals of infected teeth: an ex vivo study. Cureus. 2020;12(2):e6975. https://doi.org/10.7759/cureus.6975
27. Niewierowski RS, Scalzilli LR, Morgental RD, de Figueiredo JAP, Vier-Pelisser FV, de Borba MG, Ghisi AC. Bovine pulp tissue dissolution ability of irrigants associated or not to ultrasonic agitation. Braz Dent J. 2015;26(5):537–40. https://doi.org/10.1590/0103-6440201300243

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.