

Influence of Different Lubricating Media on Ultrasonic Retrieval Efficiency of Fractured Instruments from Curved Root Canals: An ex vivo study

Dr. Tanushree Saxena¹, Dr. Manish Ranjan^{*2}

¹Postgraduate student, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS) Saveetha University, Chennai- 600077, Tamil Nadu, India
Email ID: 152206002.sdc@saveetha.com

²Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS) Saveetha University, Chennai- 600077, Tamil Nadu, India

*Corresponding Author:

Dr. Manish Ranjan

Email ID: manish@saveetha.com

Cite this paper as: Dr. Tanushree Saxena, Dr. Manish Ranjan, (2025) Influence of Different Lubricating Media on Ultrasonic Retrieval Efficiency of Fractured Instruments from Curved Root Canals: An ex vivo study. *Journal of Neonatal Surgery*, 14 (9s), 1132-1138.

ABSTRACT

Introduction: Ultrasonic retrieval of fractured instruments is a technique-sensitive procedure and may be influenced by the properties of the fluid medium (such as viscosity, lubricity, and surface tension) used during activation. Conventional chelators such as ethylenediaminetetraacetic acid (EDTA) and novel plant-derived alternatives such as soybean oil have been suggested to facilitate retrieval by enhancing lubrication, cavitation, and acoustic streaming. This study aimed to compare the effect of 17% EDTA, soybean oil, and saline on the success rate and efficiency of ultrasonic retrieval of fractured instruments in curved canals.

Materials and Methods: Thirty extracted mandibular molars with mesiobuccal canal curvature of 20°–30° (Schneider's method) were selected. A 4-mm ProTaper Gold F2 fragment was intentionally fractured and confirmed radiographically. Ultrasonic troughing was performed under a dental operating microscope. Teeth were randomly assigned into three groups (n = 10): Group 1 – 17% EDTA, Group 2 – soybean oil, Group 3 – 0.9% saline. Following initial mobility, 2 mL of the assigned fluid was introduced followed by ultrasonic activation along inner curvature. Retrieval time was recorded from first visible mobility until retrieval, with a 30-minute cutoff.

Results: Success rates were 100% for EDTA, 90% for soybean oil, and 80% for saline, with no significant difference ($p > 0.05$). Mean retrieval times were 15.2 ± 1.8 min for EDTA, 14.3 ± 1.7 min for soybean oil, and 24.1 ± 2.3 min for saline with one-way ANOVA showing significant differences ($p < 0.001$). Post hoc analysis confirmed both EDTA ($p < 0.01$) and soybean oil ($p < 0.001$) enabled faster retrieval than saline, while no difference was observed between EDTA and soybean oil.

Conclusion: Both EDTA and soybean oil significantly enhanced the efficiency of ultrasonic retrieval compared with saline, reducing retrieval time without compromising success rates. Further *in vivo* studies are required to validate safety, biocompatibility, and long-term effects.

Keywords: Endodontics, Ethylenediaminetetraacetic Acid, Instrument retrieval, Ultrasonics

1. INTRODUCTION

Instrument fracture remains one of the most challenging iatrogenic complications during root canal therapy and its incidence depends on operator skill, tooth type, instrument design, and canal morphology [1, 2]. The mesiobuccal canal of mandibular molars is particularly prone to separation due to curvature, narrow dimensions, and limited accessibility [2–5]. The presence of a separated instrument may hinder access to the apical canal system that prevents thorough cleaning and shaping, compromises irrigant penetration and may adversely affect long term treatment prognosis [6]. A variety of approaches are available for managing separated instruments, such as bypassing, surgical removal, or orthograde retrieval [7, 8]. Among these, ultrasonic retrieval performed under magnification remains the most widely used modality because of their precision, conservative dentin removal, and high predictability, especially in cases where the fragment is visible [1, 9]. However, despite predictable outcomes in straight or moderately curved canals, success is less certain in severely curved or apically

located fragments. This has led to increased interest in optimizing factors that can influence retrieval success, including the choice of the fluid medium used during ultrasonic activation [1].

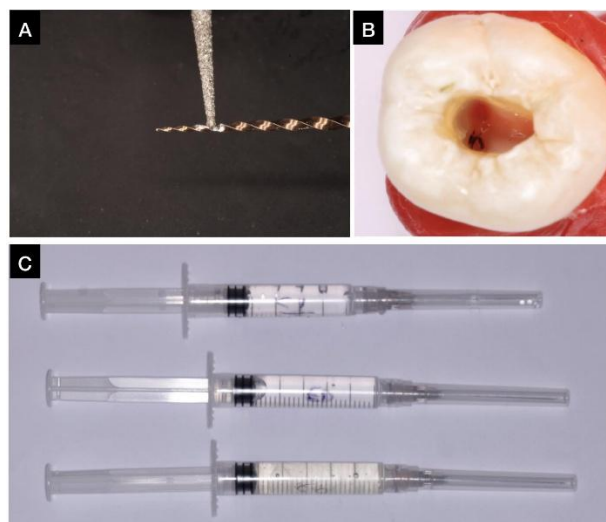
The capacity of a fluid to aid instrument retrieval depends on its lubricity, viscosity, and surface tension [1, 10]. These properties directly influence acoustic streaming and cavitation generated by ultrasonic oscillation [11, 12]. Viscosity determines resistance to flow. While high-viscosity fluids offer enhanced lubrication, they attenuate weak oscillatory shockwaves, requiring higher ultrasonic power and risking tip breakage [11]. Surface tension governs bubble formation and collapse. Lower surface tension promotes cavitation, producing implosions and shear forces that help dislodge fragments [13–15]. Lubricity reduces friction between the separated fragment and dentin walls, minimizing thermal damage and helps in loosening of instruments. Achieving the right balance between lubrication and acoustic activity is therefore critical [1].

Ethylenediaminetetraacetic acid (EDTA, 17%) has long been used as a chelating irrigant in endodontics. It removes the smear layer and reduces dentin hardness, facilitating loosening [16–18]. However, ultrasonic activation of EDTA has been shown to reduce dentin microhardness significantly, potentially predisposing to fracture [13, 19]. Other fluids such as normal saline, glycerin, propylene glycol, and synthetic oil derivatives have also been evaluated [17, 20, 21]. Saline is safe and effective for cooling and debris removal but lacks true lubricating ability due to its high surface tension [17]. On the other hand, viscous synthetic agents such as glycerin or polyethylene glycol provide better lubrication but may suppress cavitation phenomena if used in excess [17, 20]. As a result, interest has shifted toward biocompatible natural oils such as soybean, corn, or olive oil [21, 22]. These agents are inexpensive, readily available, and possess medium viscosity with relatively low surface tension, characteristics that may improve lubrication and cavitation in curved canals while avoiding dentin erosion [14]. Soybean oil in particular has been highlighted as a promising option because of its physicochemical properties and safety profile [1].

Despite the importance of fluid selection, there is little comparative data directly assessing the performance of conventional chelators like EDTA versus natural lubricants such as soybean oil. Addressing this gap may aid in refining retrieval protocols and in developing safer, more predictable strategies for managing separated instruments. The present study was aimed to compare the efficacy of 17% EDTA and soybean oil as lubricating media during ultrasonic retrieval of separated instruments from the mesiobuccal canals of mandibular molars.

2. MATERIALS AND METHODS

Thirty extracted human mandibular molars with fully formed apices and single mesiobuccal canals were selected. Teeth with root resorption, calcifications, cracks, open apices, or evidence of previous endodontic treatment were excluded. Canal curvature was standardized between 20° and 30° using Schneider's method [23]. Teeth were cleaned of debris using an ultrasonic scaler and stored in 0.1% thymol solution (HiMedia Laboratories, India) at 4 °C. Prior to instrumentation, each tooth was mounted vertically in a block of modeling wax up to the cemento-enamel junction to provide stability during ultrasonic retrieval procedures and aid in radiographic confirmation. To create standardized separated fragments, ProTaper Gold F2 rotary files (Dentsply Sirona, Switzerland) were ditched at 4 mm from the tip using a fine diamond bur (Mani Inc., Japan) upto two-third of its thickness (Figure 1A). Standard endodontic access cavities were prepared using Endo Access bur (Dentsply Maillefer, Switzerland) in a high-speed handpiece under water cooling and dental operating microscope (Carl Zeiss OPMI Pico, Germany) (Figure 1B). Canal patency was checked with a size #10 stainless steel K-file (Mani Inc., Japan). The mesiobuccal canal orifice was enlarged with SX rotary instrument (ProTaper Gold, Dentsply Sirona, Switzerland). Notched rotary files were then introduced into the prepared mesiobuccal canals with an endomotor until separation occurred. Periapical radiographs were taken to confirm fragment location in the middle to apical third of the canal.



The thirty specimens were randomly assigned to three groups (n = 10 per group) based on the lubricant used during ultrasonic retrieval:

- Group 1: 17% EDTA solution (Prevest DenPro, India)
- Group 2: Pharmaceutical-grade soybean oil (Qualigens Fine Chemicals, India)
- Group 3: 0.9% normal saline (Baxter India Pvt. Ltd., India), used as a control due to its neutral, non-chelating and non-lubricating properties.

All procedures were performed by a single operator under the dental operating microscope with $\times 21$ magnification. The coronal access to the fractured instrument was prepared using a ProTaper Gold finishing file F4 (ISO #40, Dentsply Sirona, Switzerland), which was advanced along the inner wall of the canal to provide direct exposure of the coronal end of the fragment. A 90° semicircular trough was created along the inner wall of the canal, as described by Terauchi et al., using EndoStar Sonic tips ISO 25 (Poldent Co., Poland) attached to an EndoChuck 90 handpiece and powered by an ultrasonic unit (Satelec P5 Newtron, Acteon, France) at low ($\leq 30\%$) power to minimize secondary fracture risk. No lubricant was used during this preparation stage. Saline was used intermittently for debris removal followed by drying with paper points to enhance visibility of the procedure under microscope. Fragment loosening was identified by tactile feedback, transitioning from a sticky resistance to a loose feeling and confirmed by the first visible mobility of the fragment. Once fragment mobility was observed, the canal was filled with the assigned lubricant. A standardized 2 mL volume was delivered in 0.20 mL increments using a 2.5 mL Luer-lock syringe with a 27-gauge needle (Unolok, HMD, India) (Figure 1C). The fluid level was maintained up to at least half the pulp chamber to optimize cavitation and acoustic streaming. Ultrasonic retrieval was then carried out under wet conditions, with the tip placed on the inner curve and activated at a power setting 10–20% higher than in the preparation phase. Troughing and ultrasonic activation were continued with short up-and-down strokes along the inner canal wall, until the fragment was completely dislodged and floated coronally or was ejected out of the canal. The retrieval time was recorded with a digital stopwatch, starting from the point of first visible fragment mobility until complete removal. Each attempt in the retrieval phase was restricted to a maximum of 30 minutes to simulate clinically relevant overall chairside times for retrieval procedures. Retrieval was considered a failure if the fragment could not be removed within this period or if iatrogenic complications occurred, including strip perforation or secondary fracture of the fragment. Observations were recorded by an independent examiner not involved in the retrieval procedure.

All collected data was analyzed using SPSS software version 25.0 (IBM Corp., Armonk, NY, USA). Retrieval time was measured in minutes and seconds, and all values were converted into decimal minutes prior to analysis for uniformity. Descriptive statistics were expressed as mean $\pm$ standard deviation (SD) for retrieval time and as frequencies/percentages for retrieval success/failure. Comparisons of retrieval success rates among the three groups were performed using the chi-square test. Differences in mean retrieval times were assessed with one-way analysis of variance (ANOVA). When ANOVA revealed significant differences, Tukey's post hoc test was used to identify pairwise group differences. The significance threshold was set at $p < 0.05$ for all statistical tests.

3. RESULTS

Overall, retrieval was successful in 27 of 30 specimens (90%). The success rates were highest in Group 1 (EDTA; 100%) followed by Group 2 (soybean oil; 90%) compared to the control (saline; 80%) group (Table 1). Statistical analysis of success proportions by chi-square test revealed no significant difference among the three groups ($p > 0.05$), although saline demonstrated a lower numerical success. When retrieval time was considered, significant differences were observed. The mean retrieval times were expressed in decimal minutes and measured from the first visible mobility of the fragment until complete removal. These were 14.3 ± 1.7 minutes for soybean oil, 15.2 ± 1.8 minutes for EDTA, and 24.1 ± 2.3 minutes for saline. One-way ANOVA confirmed that these differences were statistically significant ($p < 0.001$) (Table 1). Post hoc Tukey analysis confirmed that the saline group required significantly longer retrieval times compared with both EDTA ($p < 0.01$) and soybean oil ($p < 0.001$), while no significant difference was found between EDTA and soybean oil ($p > 0.05$) (Table 2). No procedural complications were recorded in any group. All failures (n = 3) were attributed to exceeding the maximum retrieval time limit of 30 minutes. These findings indicate that, in comparison with the control group (saline), the use of EDTA or soybean oil significantly reduced retrieval time, while both lubricants demonstrated comparable efficiency to each other.

Table 1. Retrieval outcomes across experimental groups.

<i>Group</i>	<i>Success</i>	<i>Failures</i>	<i>Mean retrieval time ± SD (min)*</i>
Group 1 – EDTA	10/10 (100%)	0 (0%)	15.2 ± 1.8
Group 2 – Soybean oil	9/10 (90%)	1 (10%)	14.3 ± 1.7
Group 3 – Saline	8/10 (80%)	2 (20%)	24.1 ± 2.3
Total	27/30 (90%)	3/30 (10%)	17.5 ± 4.8

*Overall ANOVA: $p < 0.001$; Retrieval time measured in decimal minutes from first visible fragment mobility to complete removal (with seconds converted into minute fractions; for example, 15 minutes 30 seconds = 15.50 minutes).

Table 2. Pairwise multiple comparisons of mean retrieval times (Post hoc Tukey's HSD) *

<i>(I) Group</i>	<i>(J) Group</i>	<i>Mean Difference (I-J)</i>	<i>Std. Error</i>	<i>p value</i>	<i>95% CI</i>
EDTA	Soybean oil	0.90	0.65	0.42 (ns)	-0.68, 2.48
EDTA	Saline	-8.90	0.74	<0.01	-10.62, -7.18
Soybean oil	Saline	-9.80	0.72	<0.001	-11.49, -8.11

*Overall ANOVA: $p < 0.001$; Retrieval time measured in decimal minutes from first visible fragment mobility to complete removal (with seconds converted into minute fractions; for example, 15 minutes 30 seconds = 15.50 minutes).

4. DISCUSSION

The effectiveness of a fluid in aiding ultrasonic retrieval of fractured instruments is largely determined by its physical properties, particularly lubricity, viscosity, and surface tension [1, 10]. Viscosity represents a fluid's resistance to flow and shear. Highly viscous solutions tend to absorb weaker ultrasonic shockwaves, thereby requiring greater power settings to produce sufficient hydrodynamic forces for fragment displacement. Although stronger oscillatory forces generated at high ultrasonic power can exert greater pressure on the fragment, this also increases the risk of tip fracture [1, 12]. In general, fluids with both high viscosity and high surface tension dampen acoustic streaming and cavitation but provide superior lubrication, whereas the opposite is true for low-viscosity, low-surface-tension fluid [11]. The efficiency of ultrasonic streaming is also influenced by tip design and power setting [1, 24]. Smaller tips generate weaker streaming, but the velocity of the streaming increases proportionally with power output [10]. Cavitation, another important mechanism, arises when ultrasonic activation produces vapor-filled bubbles in the irrigant. The violent collapse of these bubbles produces localized implosions and shear stresses, which can help detach the fragment from canal walls. Solutions with lower surface tension tend to favor the generation of these shockwaves, enhancing the likelihood of fragment dislodgement through continuous pressure waves [1]. Previous studies have emphasized the importance of fluid characteristics such as viscosity and surface tension in cavitation dynamics. Lower surface tension and optimal viscosity facilitate bubble formation and collapse, thereby generating shear forces capable of mobilizing fragments [1, 14, 25, 26].

The present *ex vivo* study evaluated the influence of different fluids on the ultrasonic retrieval of fractured instruments from curved root canals. The mean retrieval times were approximately 14 to 15 minutes for EDTA and soybean oil compared with 24 minutes for saline. This difference was statistically significant, indicating that these agents could improve ultrasonic performance. Although overall success rates did not differ statistically, both tested agents consistently achieved faster retrieval times than saline, indicating that their physicochemical properties such as chelating action in the case of EDTA and lubricity in the case of soybean oil enhance fragment displacement once initial loosening has been achieved. These findings

suggest that the incorporation of lubricants can be helpful for reducing chairside time and optimizing clinical efficiency during ultrasonic retrieval. Saline, a routinely used rinse in endodontics was included as a control due to its inert nature, performed less favorably. While it maintains canal hydration and prevents overheating, its high surface tension and lack of lubricity limit cavitation and streaming, prolonging retrieval [1, 12]. Both EDTA and soybean oil, possessing lower surface tension than saline, allowed more efficient dislodgement.

EDTA remains a well-established irrigant in endodontics, combining surface tension-reducing and chelating actions that also help remove inorganic debris, improving visibility and preventing blockage during ultrasonic activation [14]. EDTA chelates calcium ions, which leads to decalcification of dentin [27]. Over time (especially with longer exposure), this can reduce dentin microhardness, weaken intertubular and peritubular structure and thus potentially reduce microhardness and fracture resistance of the root [13, 19, 28]. Furthermore, EDTA lacks inherent antimicrobial activity and must therefore be used in conjunction with sodium hypochlorite to achieve adequate disinfection [17]. However, interactions with NaOCl reduce available free chlorine, diminishing its antibacterial and tissue-dissolving properties [16, 29]. In addition, extrusion of EDTA into periapical tissues has been associated with cytotoxicity and inflammatory responses [30]. Precipitate formation has also been reported when EDTA is combined with chlorhexidine, which may interfere with sealing ability [29]. These limitations underscore the importance of controlled exposure times and judicious selection of irrigant protocols when employing EDTA during ultrasonic retrieval.

Soybean oil, in contrast, represents a novel, biocompatible, inexpensive, and readily available alternative [1]. From a physicochemical standpoint, it has intermediate viscosity and relatively low surface tension (23–32 mN/m), properties that favor both lubrication and cavitation under ultrasonic activation [1, 21, 31]. It exerts no chemical alteration of dentin but functions as a physical lubricant. The lubricating effect reduces direct friction at the dentin–metal interface i.e. between the fractured instrument and dentinal walls, potentially minimizing dentin loss while facilitating coronal displacement of the fragment. Its thermal stability also helps dissipate ultrasonic heat, reducing the risk of tip fracture or thermal injury. While it lacks the chelating effect of EDTA, its purely physical action provides a novel strategy to improve efficiency of ultrasonic retrieval without chemically altering dentin. Similar results with plant-derived oils have been described in other fields where ultrasonic-assisted retrieval or lubrication is required, but their use in endodontics remains largely unexplored. The findings of the present study [21] therefore support further evaluation of edible oils as adjuncts in challenging retrieval cases, especially when prolonged ultrasonic activation is anticipated. However, soybean oil does not remove smear layer or dentin debris and may leave an oily residue if not flushed adequately, which could interfere with subsequent irrigation or obturation.

According to Terauchi et al [1], EDTA can expedite retrieval in straighter canals by enhancing cavitation and removing debris generated during ultrasonic activation due to its low surface tension and chelating ability. In contrast, its low viscosity may limit lubrication in severely curved canals ($>30^\circ$), making fragment dislodgement less efficient. Both solutions reduce friction and promote cavitation, and their combined use could offer complementary benefits by balancing chelation and lubrication in moderately curved canals ($20\text{--}30^\circ$). Additionally, surface tension generally decreases as temperature rises. From these relationships, fluids with moderate viscosity and low surface tension such as soybean or corn oil may be particularly advantageous when using higher ultrasonic power for retrieval in severely curved canals ($>30^\circ$). By contrast, EDTA, with its low surface tension, is more suitable for use at moderate power in canals with less curvature ($<30^\circ$) [1]. These findings underscore the clinical need to supplement ultrasonics with fluids that offer additional mechanical or chemical advantages. Terauchi and colleagues [1, 32] reported that most visible, short fragments (<4.6 mm) can be removed with ultrasonics within seconds, whereas longer fragments in curved canals require more time. The retrieval times in the present study (14–24 minutes) reflect the increased complexity of severely curved canals, consistent with other *ex vivo* investigations on ultrasonic retrieval efficiency. These findings support the incorporation of lubricants during ultrasonic retrieval to reduce chairside time and improve clinical efficiency. However, the study has certain limitations. Being an *ex vivo* investigation, clinical variables such as patient-related anatomical variations, canal fluid dynamics, and operator fatigue could not be replicated. The sample size was limited, and failures were assessed only up to 30 minutes. Longer observational windows might alter success rates but would reduce clinical applicability. Additionally, only one plant-derived oil was tested. Further comparisons with other vegetable oils of different viscosities may reveal optimal lubricants for ultrasonic retrieval. Future studies should also assess the thermal behavior of lubricants under ultrasonic activation and their potential impact on dentin microstructure, using advanced imaging such as nano-CT. Finally, *in vivo* studies are needed to evaluate safety, patient tolerance, and biocompatibility of such lubricants before recommending their clinical use.

5. CONCLUSION

The *ex vivo* study demonstrated that the use of lubricating agents significantly enhances the efficiency of ultrasonic retrieval of fractured instruments. Both EDTA and soybean oil reduced retrieval times compared with saline, reflecting the importance of viscosity and surface tension in promoting cavitation, acoustic streaming, and lubrication. Although success rates were similar across groups, the efficiency advantage is crucial in chairside practice, where prolonged attempts increase operator fatigue and risk of iatrogenic damage. Further studies in larger samples and *in vivo* conditions are needed to validate these findings, explore biocompatibility, and determine whether combinations of lubricants can optimize retrieval outcomes in

challenging clinical scenarios.

CONFLICT OF INTEREST: Authors declare no conflict of interest.

FUNDING: None

REFERENCES

- [1] Terauchi Y, Ali WT, Abielhassan MM. Present status and future directions: Removal of fractured instruments. *Int Endod J* 2022; 55 Suppl 3: 685–709.
- [2] Fan Y, Gao Y, Wang X, et al. Expert consensus on management of instrument separation in root canal therapy. *Int J Oral Sci* 2025; 17: 46.
- [3] Alomairy KH. Evaluating two techniques on removal of fractured rotary nickel-titanium endodontic instruments from root canals: an in vitro study. *J Endod* 2009; 35: 559–562.
- [4] Iqbal MK, Kohli MR, Kim JS. A retrospective clinical study of incidence of root canal instrument separation in an endodontics graduate program: a PennEndo database study. *J Endod* 2006; 32: 1048–1052.
- [5] Karobari MI, Veeraraghavan VP, Nagarathna PJ, et al. Predictive analysis of root canal morphology in relation to root canal treatment failures: a retrospective study. *Front Dent Med* 2025; 6: 1540038.
- [6] Spili P, Parashos P, Messer HH. The impact of instrument fracture on outcome of endodontic treatment. *J Endod* 2005; 31: 845–850.
- [7] Madarati AA, Hunter MJ, Dummer PMH. Management of intracanal separated instruments. *J Endod* 2013; 39: 569–581.
- [8] Nevares G, Cunha RS, Zuolo ML, et al. Success rates for removing or bypassing fractured instruments: a prospective clinical study. *J Endod* 2012; 38: 442–444.
- [9] Plotino G, Pameijer CH, Grande NM, et al. Ultrasonics in endodontics: a review of the literature. *J Endod* 2007; 33: 81–95.
- [10] Ahmad M, Pitt Ford TR, Crum LA. Ultrasonic debridement of root canals: an insight into the mechanisms involved. *J Endod* 1987; 13: 93–101.
- [11] Zhang C, Guo X, Royon L, et al. Acoustic streaming generated by sharp edges: The coupled influences of liquid viscosity and acoustic frequency. *Micromachines (Basel)* 2020; 11: 607.
- [12] Mozo S, Llena C, Forner L. Review of ultrasonic irrigation in endodontics: increasing action of irrigating solutions. *Med Oral Patol Oral Cir Bucal* 2012; 17: e512–6.
- [13] Kaul M, Nanda Z, Reddy K, et al. A comparative evaluation of the effect of various chelating agents on the microhardness of root canal dentin: An in vitro study. *Endodontology* 2023; 35: 234–237.
- [14] Mansoorkhani HA, Mahmoudi F. The importance of surface tension in endodontic irrigation: A review study. *Archives of Dental Research* 2023; 12: 76–80.
- [15] Sowmya MR, Teja KV, Solete P, et al. Efficacy of sonic and ultrasonic activation on irrigant penetration in different tapered preparations: An in vitro study. *Endodontology* 2024; 36: 370–375.
- [16] Zehnder M. Root canal irrigants. *J Endod* 2006; 32: 389–398.
- [17] Haapasalo M, Shen Y, Wang Z, et al. Irrigation in endodontics. *Br Dent J* 2014; 216: 299–303.
- [18] Rao PD, Sandeep AH, Madhubala MM, et al. Comparative evaluation of effect of nisin-incorporated ethylenediamine tetraacetic acid and MTAD on endodontic biofilm eradication, smear layer removal, and depth of sealer penetration. *Clin Oral Investig* 2023; 27: 7247–7259.
- [19] Calt S, Serper A. Time-dependent effects of EDTA on dentin structures. *J Endod* 2002; 28: 17–19.
- [20] Cruz EV, Kota K, Huque J, et al. Penetration of propylene glycol into dentine. *Int Endod J* 2002; 35: 330–336.
- [21] Sahasrabudhe SN, Rodriguez-Martinez V, O'Meara M, et al. Density, viscosity, and surface tension of five vegetable oils at elevated temperatures: Measurement and modeling. *Int J Food Prop* 2017; 1–17.
- [22] Nagy-Bota MC, Man A, Santacroce L, et al. Essential oils as alternatives for root-canal treatment and infection control against *Enterococcus faecalis*—A preliminary study. *Appl Sci (Basel)* 2021; 11: 1422.
- [23] Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol* 1971; 32: 271–275.
- [24] Koulogiannis A, Walmsley AD, Angeli P, et al. Ultrasonic irrigation flows in root canals: effects of ultrasound power and file insertion depth. *Sci Rep* 2024; 14: 5368.

- [25] Poggio C, Ceci M, Beltrami R, et al. Viscosity of endodontic irrigants: Influence of temperature. *Dent Res J (Isfahan)* 2015; 12: 425–430.
 - [26] Wu W, Chen Y, Tong C, et al. The effect of ultrasonic tip working length on fluid dynamics in the root canal during the irrigation procedure: a computational fluid dynamics study. *BMC Oral Health* 2025; 25: 266.
 - [27] Elbahary S, Haj-Yahya S, Khawalid M, et al. Effects of different irrigation protocols on dentin surfaces as revealed through quantitative 3D surface texture analysis. *Sci Rep* 2020; 10: 22073.
 - [28] Purayil T, Jalan P, Ballal N, et al. Comparative evaluation of various chelating agents on the microhardness of root canal dentin: An in vitro study. *Saudi Endod J* 2021; 11: 19.
 - [29] Rossi-Fedele G, Doğramaci EJ, Guastalli AR, et al. Antagonistic interactions between sodium hypochlorite, chlorhexidine, EDTA, and citric acid. *J Endod* 2012; 38: 426–431.
 - [30] Farhad Mollashahi N, Saberi E, Karkehabadi H. Evaluation of cytotoxic effects of various endodontic irrigation solutions on the survival of stem cell of human apical papilla. *Iran Endod J* 2016; 11: 293–297.
 - [31] Singh A, Umeda T, Kobayashi I. Formulation and characterization of soybean oil-in-water emulsions stabilized using gelatinized starch dispersions from plant sources. *Molecules*; 29. Epub ahead of print 23 April 2024. DOI: 10.3390/molecules29091923.
 - [32] Terauchi Y, Sexton C, Bakland LK, et al. Factors affecting the removal time of separated instruments. *J Endod* 2021; 47: 1245–1252.
-