

Efficacy Of Sonic Irrigation Compared to Ultrasonic Irrigation Techniques: A Systematic Review

DR. GAYATRI PENDSE ¹, DR. RASHMI MISRA ², DR. LALITA GAURI MANDKE³, DR. VASUNDHARA JADHAV⁴, DR. ANKITA KHOSE⁵, DR. KANAKAA DULANI⁶

¹ Professor Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

^{2,3} Professor Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

^{4,6} PG Student Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

⁵ Lecturer Department of Conservative Dentistry and Endodontics, Dy Patil University School of Dentistry, Nerul, Navi Mumbai, Maharashtra, India

Abstract—BACKGROUND: Traditional endodontic treatment incorporates a combination of mechanical debridement using hand or rotary instruments and chemical disinfection through irrigants. Sonic and ultrasonic irrigation techniques represent a significant advancement in endodontic disinfection, utilizing acoustic energy to induce the movement of irrigants within the root canal. **AIM:** The aim of this review is to compares both techniques in terms of bacterial reduction, debris removal, and clinical outcomes to guide evidence-based irrigation protocols. **MATERIALS AND METHOD:** The inclusion and exclusion criteria for selecting studies were established based on the Population, Intervention, Comparison, Outcome, and Study design (PICOS) framework to ensure a structured and rigorous selection process. A narrative synthesis summarized outcomes on bacterial reduction, debris removal, and clinical success. Subgroup analyses were based on tooth type, irrigant used, activation parameters (frequency, duration), and outcome type (clinical vs. microbiological). Data was managed in Microsoft Excel and analyzed using RevMan. **RESULT:** A review of 24 studies on extracted human teeth compared sonic (SI) and ultrasonic irrigation (UI). These papers evaluated smear layer removal, debris clearance, and bacterial reduction. SEM Scanning Electron Microscope evaluations showed that PUI cleans complex anatomy and the apical third more effectively than SI. Additionally, PUI achieved greater reductions in *E. faecalis* (CFU) counts, though neither method completely eradicated the bacteria. **CONCLUSION:** It was concluded that Ultrasonic irrigation cleans, disinfects, and penetrates root canals

more effectively than sonic systems. Evidence indicated that PUI is superior to SI for achieving maximum canal cleanliness, making it the preferred method for complex root canal networks.

Index Terms—Sonic irrigation; Ultrasonic irrigation; Passive ultrasonic irrigation; Irrigant activation; Root canal irrigation; Root canal disinfection; Debris removal; Endodontics.

I. INTRODUCTION

There are high success rate (97%) after 10 years of follow-up and 76% after 30 years, still failures can happen, requiring procedures like retreatment or apical surgery.^[1] The success of endodontic treatment depends on the complete elimination of microorganisms from the root canal system, which remains challenging due to its complex anatomy [1,2]. Persistent bacteria, particularly biofilm-forming species like *Enterococcus faecalis* and *Fusobacterium nucleatum*, are strongly associated with endodontic failure, highlighting the need for irrigation techniques capable of reaching areas beyond mechanical instrumentation [4,5].

Traditional endodontic therapy combines mechanical debridement with chemical irrigation; however, 35–50% of canal surfaces remain untouched, especially in irregular canals, emphasizing the importance of

irrigation for effective disinfection [6–10]. Conventional syringe irrigation commonly uses sodium hypochlorite (NaOCl) for its antimicrobial and tissue-dissolving properties, along with (Ethylenediaminetetraacetic acid) EDTA for smear layer removal and (Chlorhexidine) CHX for substantivity [10–14]. Nevertheless, their efficacy is limited by the delivery method [15].

Conventional syringe irrigation relies on hydraulic pressure but fails to adequately penetrate the apical third, lateral canals, and isthmuses, with efficacy further limited by the vapor lock effect [16–18]. Advanced strategies, including negative pressure systems like EndoVac and side-vented needles, improve irrigant delivery and coverage [19–21]. However, they remain insufficient in achieving effective irrigant activation for optimal biofilm disruption and deep debris removal.

Advanced irrigation methods, including passive ultrasonic irrigation (PUI), apical negative pressure, and laser activation, enhance irrigant efficacy [22–24]. Among these, sonic and ultrasonic activation improve disinfection via acoustic energy and hydrodynamic forces [25,26]. Sonic systems (1–6 kHz) enhance irrigant flow and smear layer removal but have limited cavitation [27–30], whereas ultrasonic systems (25–40 kHz) generate stronger acoustic streaming and cavitation, improving irrigant penetration and bactericidal effectiveness [31].

Ultrasonic devices (e.g., Piezon Master 700, Irrisafe) enhance disinfection through cavitation and micro bubble collapse, improving biofilm disruption, debris removal, and dentinal tubule penetration, though heat generation may cause dentinal damage and post-operative discomfort [25,32–35]. Despite advancements, persistent infection and inconsistent evidence on sonic versus ultrasonic efficacy highlight the need for systematic evaluation [25]. This review compares both techniques in terms of bacterial reduction, debris removal, and clinical outcomes to guide evidence-based irrigation protocols [36].

II. METHODOLOGY

Study Design: This systematic review was conducted in accordance with PRISMA guidelines [37] and

registered with PROSPERO (CRD420250643233) to ensure transparency and reproducibility.

Review Question

This systematic review was designed to address the following research questions:

1. How does sonic irrigation techniques affect bacterial reduction, debris removal, and overall clinical success?
2. How does ultrasonic irrigation techniques affect bacterial reduction, debris removal, and overall clinical success?
3. How does sonic and ultrasonic irrigation techniques differently affect bacterial reduction, debris removal, and overall clinical success?

Search strategy: A comprehensive literature search was conducted across PubMed/MEDLINE, Embase, Scopus, Web of Science, CENTRAL, Google Scholar, and ClinicalTrials.gov. The strategy used MeSH terms and free-text keywords (e.g., “sonic irrigation,” “ultrasonic irrigation,” “root canal irrigation,” “bacterial reduction,” “debris removal,” “root canal disinfection,” “clinical success,” “endodontic irrigation,” “activation of irrigants,” “passive ultrasonic irrigation”) combined with Boolean operators. Reference lists of included studies and relevant reviews were also screened. No initial language restrictions were applied, but only English-language studies were included.

III. ELIGIBILITY CRITERIA

- **Population (P):** Patients undergoing root canal treatment in permanent teeth, irrespective of age, gender, or systemic health conditions.
- **Intervention (I):** Root canal irrigation performed using sonic irrigation techniques such as EndoActivator, Vibringe, or other sonic activation devices.
- **Comparison (C):** Studies comparing sonic irrigation with ultrasonic irrigation (e.g., Piezon Master 700, Irrisafe tips, NSK Varios, etc.) or conventional syringe irrigation.
- **Outcomes (O):** The primary outcomes assessed will include bacterial load reduction, debris removal efficacy, and clinical success.

Additional outcomes such as post-operative pain, canal cleanliness, and procedural time will also be considered.

- Study Design (S): The review includes randomized controlled trials (RCTs), observational studies (prospective and retrospective), and experimental studies that provide comparative data on the efficacy of these irrigation techniques.

IV. INCLUSION CRITERIA

Studies evaluating sonic and/or ultrasonic irrigation techniques in in-vivo or ex-vivo human teeth models.

- Studies comparing sonic irrigation versus ultrasonic irrigation or either technique versus conventional syringe irrigation.
- Studies reporting quantitative data on bacterial reduction, debris removal, or clinical success.
- Studies with full text available in English language
- No restriction on the date of publication. All studies published from inception to the present will be included.

V. EXCLUSION CRITERIA

In vitro studies conducted on extracted teeth without clinical or microbiological relevance.

- Studies evaluating primary teeth, as their canal morphology differs significantly from permanent teeth.
- Narrative reviews, opinion papers, case reports, and letters to the editor.
- Studies with insufficient data or methodological flaws that prevent meaningful analysis.

Study Selection Process

Study selection was performed in three phases: (1) Title and abstract screening by two independent reviewers, (2) Full-text evaluation of eligible studies with discrepancies resolved through discussion or a third reviewer, and (3) Final inclusion for qualitative and quantitative synthesis. The process was documented using a PRISMA flow diagram. Inter-rater agreement was found to be 0.8.

Data extraction

A standardized form was used to extract data on study characteristics, patient demographics, intervention details (irrigation type, device, activation

time, frequency), comparators, outcomes (bacterial reduction, debris removal, clinical success), and follow-up duration. Data extraction was performed independently by two reviewers, with discrepancies resolved through discussion or a third reviewer.

Risk of bias:

Risk of bias was assessed using RoB 2 for RCTs [38], ROBINS-I for non-randomized studies [39], and the Newcastle-Ottawa Scale for observational studies [40]. Study quality was independently evaluated by two reviewers using the GRADE approach, with disagreements resolved by consensus.

Data Synthesis and Statistical Analysis

A narrative synthesis summarized outcomes on bacterial reduction, debris removal, and clinical success. Subgroup analyses were based on tooth type, irrigant used (NaOCl, EDTA, CHX, MTAD), activation parameters (frequency, duration), and outcome type (clinical vs. microbiological).

VI. RESULT

A total of 24 studies compared sonic (SI) and ultrasonic irrigation (UI) [41–64], with inclusion requiring at least one SI and UI group. Most were in vitro studies (n=22), with two RCTs, and sample sizes ranged from 20 to 240. Studies primarily used extracted human teeth and were conducted across multiple countries, led by Turkey, China, Germany, Italy, and India, between 2003 and 2025. Tooth types varied, including single-rooted premolars, molar roots, and anterior teeth, with some studies using simulated canals; most samples were decoronated and standardized.

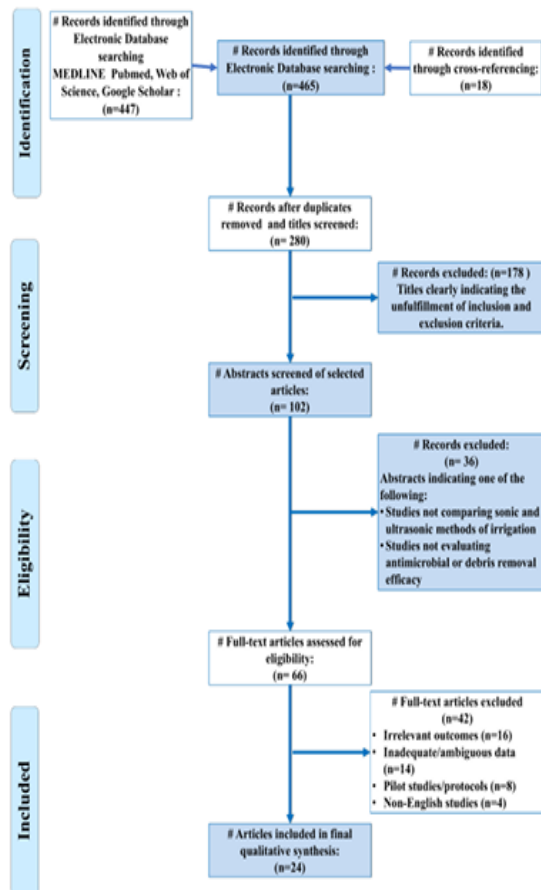


Figure: PRISMA Flow diagram indicating the selection process of the articles in the present systematic review

Irrigation activation methods varied, with passive ultrasonic irrigation (PUI) used in 19 studies and sonic irrigation (SI) in 15 studies, commonly employing devices such as VDW Ultra, P5 Booster, Satelec Acteon (ultrasonic) and EDDY (6000 Hz) (sonic). Activation times ranged from 30 seconds to 3 minutes in multiple cycles. NaOCl (1–5.25%) was the primary irrigant, often followed by 17% EDTA, with some use of CHX or saline; dyes were occasionally used to assess penetration. Sonic devices used polyamide tips (size 20–25), while ultrasonic systems operated at 28–36 kHz using K-files or IrriSafe tips.

Outcomes included smear layer removal (21 studies), debris removal (12 studies), and bacterial reduction (10 studies). SEM-based assessments showed PUI to be more effective than SI, particularly in the apical third and complex areas. Bacterial reduction,

commonly evaluated using *E. faecalis* (CFU), was greater with PUI, although neither technique achieved complete elimination.

Irrigant penetration (9 studies), assessed via CLSM, was greater with PUI due to enhanced acoustic streaming and cavitation. One study reported more stable cavitation with PUI using sonochemiluminescence. In two RCTs, postoperative pain (VAS) was lower with PUI in early phases, with differences diminishing by day 7.

None of the techniques achieved complete bacterial elimination; however, PUI showed superior performance over sonic irrigation across smear layer removal, bacterial reduction, and irrigant penetration, particularly in apical and complex regions. Sonic systems (e.g., EDDY) outperformed conventional syringe irrigation but remained less effective than ultrasonics. Activation protocols typically involved 30–120 seconds (often 3×20 s cycles) with irrigant volumes of 3–12 mL, sometimes followed by saline or distilled water rinses.

Evaluation methods varied, including SEM with blinded calibrated examiners, CLSM with ImageJ analysis, and imaging tools for cavitation assessment; some studies also recorded temperature changes. Limitations included the predominance of in vitro designs, methodological heterogeneity, variable sample sizes, and inconsistent control of factors such as temperature and irrigant neutralization. Few studies assessed patient outcomes, with limited data on postoperative pain, curved canals, and long-term follow-up, restricting clinical applicability.

Risk of Bias Interpretation

All 24 studies were assessed using the QUIN tool [65], evaluating domains such as study design, controls, blinding, standardization, outcome validity, and statistical analysis. Most studies (n=15) showed low risk of bias, demonstrating strong methodological rigor despite often lacking sample size calculations.

Eight studies showed a moderate risk of bias, mainly due to lack of sample size justification and assessor blinding, though overall design, statistical analysis, and outcome measures were acceptable. Sabins et al. (2003) reported a serious risk of bias due to outdated and less rigorous methodology, including absence of blinding, sample size calculation, and control measures [41]. Lack of procedural standardization

reduced confidence in some findings despite the use of validated outcome tools. All studies reported conflict of interest status, supporting transparency. Overall, QUIN assessment indicated acceptable to high methodological quality, with only one study showing serious concerns [65]. These findings support the reliability of the review while highlighting the need for improved sample size estimation and blinding in future in vitro studies.

VII. DISCUSSION

This systematic review evaluated irrigation activation techniques—ultrasonic, sonic, laser-activated, and conventional—to identify methods that improve canal cleanliness and disinfection [41–64,66, 67]. Across 24 studies (2003–2025) from multiple countries, most were in vitro (23/24), with only one RCT assessing postoperative pain [64]. Research has shifted from syringe irrigation to advanced systems like SWEEPS in recent years. While sample sizes (20–200+) generally supported comparisons, few studies reported power calculations, though standardized canal models aided consistency.

Studies used various teeth—mainly single-rooted premolars, molar roots, and anterior teeth—with standardized canal lengths to reduce variability [41–64]. Tooth selection aligned with study aims, with simple anatomies for penetration analysis and complex morphologies for challenging scenarios; use of extracted teeth improved clinical relevance.

All studies compared activation methods with syringe irrigation. Passive ultrasonic irrigation (PUI), most commonly used (19 studies), enhanced cleaning via micro streaming and cavitation [46, 49, 51]. Sonic systems (15 studies), especially EDDY, improved outcomes over syringe irrigation but were generally less effective than PUI, with advantages in curved canals [44, 45]. Newer systems (e.g., Easydo Activator, Perfect Clean) showed promising early results, though evidence remains limited [59, 62].

Activation protocols typically ranged from 30 seconds to 3 minutes (often 3 cycles of 20–30 seconds) with tips ~1 mm short of working length and irrigant volumes of 3–12 mL. Sodium hypochlorite (1–5.25%) followed by 17% EDTA was standard, with some use of saline or dyes; consistent reporting enabled reliable comparisons [41–64].

Smear layer removal (21 studies), assessed by SEM, showed activation methods outperforming syringe irrigation, with ultrasonics most effective due to stronger acoustic energy and cavitation—especially in coronal and middle thirds, though reduced apically due to limited energy and irrigant exchange [41–64,44,49,52]. Sonic irrigation improved smear layer removal over syringe methods but remained less effective than ultrasonics due to lower frequency and energy limiting micro streaming and cavitation [29, 30]. However, EDDY performed well in simple canals and offered added safety with flexible tips [44,45].

Debris removal (12 studies) showed similar trends, with ultrasonic and sonic systems outperforming syringe irrigation [41–64]. Ultrasonics were particularly effective in complex anatomies and fractured instrument cases, though outcomes depend on proper tip positioning and free movement in curved or narrow canals.

Bacterial reduction (10 studies using *E. faecalis* models) showed no method achieved complete elimination, but ultrasonic activation consistently produced greater CFU reduction than sonic and syringe techniques, due to enhanced NaOCl penetration via acoustic streaming and cavitation [42,50,51]. Erkan et al. (2022) also reported lower postoperative pain with ultrasonic irrigation, likely reflecting improved disinfection [64]. Sonic systems showed moderate, less consistent effects, mainly in coronal and middle thirds.

Irrigant penetration (9 CLSM studies) confirmed the superiority of activation techniques, with passive ultrasonic irrigation achieving the greatest depth and area, followed by sonic systems like EDDY [71]. Ultrasonic activation showed penetration >500 µm, sufficient for biofilm disruption [55,47], while syringe irrigation remained superficial.

An RCT reported the lowest postoperative pain with ultrasonic irrigation at 48 hours and 7 days, likely due to better disinfection and deeper penetration [64]. Overall, activation—especially ultrasonic—outperforms syringe methods, with sonic systems offering moderate benefits and supporting routine clinical use.

Most studies were in vitro, limiting clinical applicability as they do not replicate in vivo conditions such as fluid dynamics, anatomical variability, and host response. Methodological

heterogeneity (tip design, insertion depth, irrigant protocols, evaluation methods), along with limited RCTs and long-term data, restricts generalization. QUIN assessment also identified lack of sample size calculations and inadequate blinding—especially in SEM scoring—raising risks of bias, while inconsistent reporting of activation parameters further contributed to outcome variability [65,72].

Variability in irrigant protocols and canal anatomy introduced significant heterogeneity, limiting generalizability, while the predominance of in vitro studies reduces clinical applicability [41–64]. Despite this, irrigant activation—especially passive ultrasonic—demonstrates clear clinical advantages, with superior smear layer and debris removal, bacterial reduction, and apical penetration compared to syringe methods. Sonic systems provide moderate benefits, particularly in simpler anatomies, with added safety due to flexible tips [44,48,58].

Future research should focus on robust methodology (power analysis, blinding, standardized protocols) and more RCTs to assess long-term effectiveness and cost-benefit. Studies in complex anatomies, diverse populations, and combined activation with novel irrigants are needed to optimize endodontic disinfection.

VIII. CONCLUSION

This review found passive ultrasonic irrigation superior to sonic systems for root canal cleaning, with better smear layer and debris removal, deeper apical penetration, and greater bacterial reduction. These benefits stem from higher frequency and energy generating stronger acoustic streaming and cavitation. Sonic systems improved outcomes over syringe irrigation but were less effective in deep and curved canals. Overall, PUI is preferred for optimal disinfection, especially in complex anatomies, though further clinical trials are needed.

REFERENCES

- [1] Bhatt M, Seth T, Chaudhary S, Rajguru K, Khalane CS, Chib AS, Gupta S. Nonsurgical Retreatment of Endodontically Treated Teeth: A Prospective Cohort Study on Success Rates and Quality of Life. *Cureus*. 2025 Jul 28;17(7):e88886.
- [2] Versiani MA, Martins JN, Ordinola-Zapata R. Anatomical complexities affecting root canal preparation: a narrative review. *Aust Dent J*. 2023 Jun;68(Suppl 1):S5–23.
- [3] Džanković A, Korać S, Tahmišćija I, Hadžiabdić N. Endodontic challenges arising from root canal morphology. In: Džanković A, editor. *Human Teeth – The Hardest Substance of the Human Body*. Rijeka: IntechOpen; 2024. p. 1 20.
- [4] Colaco AS. Extreme resistance of *Enterococcus faecalis* and its role in endodontic treatment failure. *Prog Med Sci*. 2018;2(1):9–13.
- [5] Gomes BPFA, Bronzato JD, Almeida-Gomes RF, Pinheiro ET, Sousa ELR, Jacinto RC. Identification of *Fusobacterium nucleatum* in primary and secondary endodontic infections and its association with clinical features by using two different methods. *Clin Oral Investig*. 2021 Nov;25(11):6249–58. doi:10.1007/s00784-021-03923-7.
- [6] Elizabeth MS. Hand instrumentation in root canal preparation. *Endod Top*. 2005 Mar;10(1):163–7.
- [7] Venghat S, Hegde M, Shetty C. Irrigants used in endodontics. *Int J Curr Microbiol Appl Sci*. 2014;3(3):126–32.
- [8] Siqueira JF Jr, Rôças ID, Marceliano-Alves MF, Pérez AR, Ricucci D. Unprepared root canal surface areas: causes, clinical implications, and therapeutic strategies. *Braz Oral Res*. 2018 Oct 18;32:e65.
- [9] Mohammadi Z, Jafarzadeh H. The oval shaped root canal: a clinical review. *S Afr Dent J*. 2015 Jun;70(5):200–4.
- [10] Bukhari S, Babaeer A. Irrigation in endodontics: a review. *Curr Oral Health Rep*. 2019 Dec;6(4):367–76.
- [11] van der Sluis LW, Verhaagen B, Macedo R, Versluis M. The role of irrigation in endodontics. In: Olivi G, DiVito E, editors. *Lasers in Endodontics: Scientific Background and Clinical Applications*. Cham: Springer; 2016. p. 45–69.
- [12] Mohammadi Z. Sodium hypochlorite in endodontics: an update review. *Int Dent J*. 2008 Dec;58(6):329–41.
- [13] Mohammadi Z, Shalavi S, Jafarzadeh H. Ethylenediaminetetraacetic acid in endodontics. *Eur J Dent*. 2013 Sep;7(Suppl 1):S135–42.

- [14] Gomes BPFA, Vianna ME, Zaia AA, Almeida JF, Souza-Filho FJ, Ferraz CC. Chlorhexidine in endodontics. *Braz Dent J.* 2013;24(2):89–102.
- [15] Boutsoukakis C, Arias-Moliz MT. Present status and future directions—irrigants and irrigation methods. *Int Endod J.* 2022 May;55(Suppl 3):588–612.
- [16] Teja KV, Ramesh S, Battineni G, Vasundhara KA, Jose J, Janani K. The effect of various in-vitro and ex-vivo parameters on irrigant flow and apical pressure using manual syringe needle irrigation: systematic review. *Saudi Dent J.* 2022 Feb;34(2):87–99.
- [17] Tay FR, Gu LS, Schoeffel GJ, Wimmer C, Susin L, Zhang K, et al. Effect of vapor lock on root canal debridement by using a side-vented needle for positive-pressure irrigant delivery. *J Endod.* 2010 Apr;36(4):745–50.
- [18] Farmand P. Effects of irrigation and agitation on apical vapor lock: an ex-vivo study [dissertation]. Vancouver: University of British Columbia; 2019.
- [19] Tonini R, Salvadori M, Audino E, Sauro S, Garo ML, Salgarello S. Irrigating solutions and activation methods used in clinical endodontics: a systematic review. *Front Oral Health.* 2022;3:838043. doi:10.3389/froh.2022.838043. 20. Health. 2022 Jan 31;3:838043.
- [20] Palazzi F, Giardino L, Mohammadi Z, Rengo S, Riccitiello F. Debridement effectiveness of two different techniques using negative pressure irrigation system. *G Ital Endod.* 2012 Nov;26(3):117–27.
- [21] Loroño G, Zaldívar JM, Arias A, Dorado S, Jimenez-Octavio JR. Influence of needle design and irrigation depth in the presence of vapor lock: a computational fluid dynamics analysis in human oval roots with apical ramification. *Int J Numer Methods Biomed Eng.* 2023;39(8):e3742. doi:10.1002/cnm.3742.
- [22] Van der Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. *Int Endod J.* 2007 Jun;40(6):415–26.
- [23] Pawar R, Alqaied A, Safavi K, Boyko J, Kaufman B. Influence of an apical negative pressure irrigation system on bacterial elimination during endodontic therapy: a prospective randomized clinical study. *J Endod.* 2012 Sep;38(9):1177–81.
- [24] Olivi G. Laser use in endodontics: evolution from direct laser irradiation to laser-activated irrigation. *J Laser Dent.* 2013;21(2):58–71.
- [25] Mozo S, Llena C, Forner L. Review of ultrasonic irrigation in endodontics: increasing action of irrigating solutions. *Med Oral Patol Oral Cir Bucal.* 2012 May 1;17(3):e512–6.
- [26] Josic U, Mazzitelli C, Maravic T, Fidler A, Breschi L, Mazzoni A. Biofilm in endodontics: in vitro cultivation possibilities, sonic-, ultrasonic- and laser assisted removal techniques and evaluation of the cleaning efficacy. *Polymers (Basel).* 2022 Mar 25;14(7):1334.
- [27] Jiang LM, Verhaagen B, Versluis M, van der Sluis LW. Evaluation of a sonic device designed to activate irrigant in the root canal. *J Endod.* 2010 Jan;36(1):143–6.
- [28] Uroz-Torres D, González-Rodríguez MP, Ferrer-Luque CM. Effectiveness of the EndoActivator system in removing the smear layer after root canal instrumentation. *J Endod.* 2010 Feb;36(2):308–11.
- [29] Macedo R, Verhaagen B, Rivas DF, Versluis M, Wesselink P, van der Sluis L. Cavitation measurement during sonic and ultrasonic activated irrigation. *J Endod.* 2014 Apr;40(4):580–3.
- [30] Nusstein JM. Sonic and ultrasonic irrigation. In: Basrani B, editor. *Endodontic Irrigation: Chemical Disinfection of the Root Canal System.* Cham: Springer; 2015. p. 173–97.
- [31] Jiang LM, Verhaagen B, Versluis M, Langedijk J, Wesselink PR, van der Sluis LW. The influence of the ultrasonic intensity on the cleaning efficacy of passive ultrasonic irrigation. doi:10.1016/j.joen.2011.02.002. *J Endod.* 2011 May;37(5):688–92.
- [32] Tomson PL, Lea SC, Lumley PJ, Walmsley AD. Performance of ultrasonic retrograde systems. *J Endod.* 2006;32(12):1027. doi:10.1016/j.joen.2006.12.027.
- [33] Sartiono E, Iskandar B, Sudhana W. Root canal cleaning effectiveness with passive ultrasonic irrigation: a comparative in vitro study between Irrisafe and EndoUltra tip. *Sci Dent J.* 2021 Sep;5(3):122–7. 34.
- [34] Arathi G, Rajakumaran A, Divya S, Malathi N, Saranya V, Kandaswamy D. Comparison of

- penetrating depth of chlorhexidine and chitosan into dentinal tubules with and without the effect of ultrasonic irrigation. *J Oral Maxillofac Pathol.* 2019 Sep;23(3):389-92. doi:10.4103/jomfp.JOMFP_188_18.
- [35] İnce-Yusufoğlu S, Keskin NB, Uslu G, Helvacioğlu-Yiğit D. Effect of EDDY and manual dynamic activation techniques on postoperative pain in non-surgical retreatment: a randomized controlled trial. *BMC Oral Health.* 2023 Jan 3;23(1):3. doi:10.1186/s12903-022-02702-4.
- [36] Chubb DWR. A review of the prognostic value of irrigation on root canal treatment success. *Aust Endod J.* 2019 Apr;45(1):5-11. doi:10.1111/aej.12348.
- [37] Tugwell P, Tovey D. PRISMA 2020. *J Clin Epidemiol.* 2021 Jun;134:A5-6. doi:10.1016/j.jclinepi.2021.04.008.
- [38] Flemyng E, Moore THM, Boutron I, Higgins JPT, Hróbjartsson A, Nejtgaard CH, Dwan K. Using Risk of Bias 2 to assess results from randomised controlled trials: guidance from Cochrane. *BMJ Evid Based Med.* 2023 Aug;28(4):260-6. doi:10.1136/bmjebm-2022-111952.
- [39] Sterne JAC, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ.* 2016 Oct 12;355:i4919.
- [40] Wells GA, Shea B, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of non randomised studies in meta-analyses. [Internet]. Ottawa: Ottawa Hospital Research Institute; [cited 2025 May 24].
- [41] Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. *J Endod.* 2003 Oct;29(10):674-8.
- [42] Tardivo D, Pommel L, La Scola B, Camps J. Antibacterial efficiency of passive ultrasonic versus sonic irrigation. *Odontostomatol Trop.* 2010 Mar;33(129):29-35.
- [43] Roedig T, Sedghi M, Konietzschke F, Lange K, Ziebolz D, Hülsmann M. Efficacy of syringe irrigation, RinsEndo® and passive ultrasonic irrigation in removing debris from irregularities in root canals with different apical sizes. *Int Endod J.* 2010 Jul;43(7):581-9. doi:10.1111/j.1365-2591.2010.01701.x.
- [44] Arslan H, Akcay M, Capar ID, Ertas H, Ok E, Uysal B. Efficacy of needle irrigation, EndoActivator, and photon-initiated photoacoustic streaming technique on removal of double and triple antibiotic pastes. *J Endod.* 2014 Sep;40(9):1439-42. doi:10.1016/j.joen.2014.02.020.
- [45] Macedo RG, Robinson JP, Verhaagen B, Walmsley AD, Versluis M, Cooper PR, van der Sluis LW. A novel methodology providing insights into removal of biofilm-mimicking hydrogel from lateral morphological features of the root canal during irrigation procedures. *Int Endod J.* 2014 Nov;47(11):1040-51. doi:10.1111/iej.12258.
- [46] Conde AJ, Estevez R, Loroño G, Valencia de Pablo Ó, 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 Oct;50(10):976-82. doi:10.1111/iej.12715.
- [47] Neuhaus KW, Liebi M, Stauffacher S, Eick S, Lussi A. Antibacterial efficacy of a new sonic irrigation device for root canal disinfection. *J Endod.* 2016 Dec;42(12):1799-803. doi:10.1016/j.joen.2016.08.024.
- [48] Plotino G, Grande NM, Mercade M, Cortese T, Staffoli S, Gambarini G, Testarelli L. Efficacy of sonic and ultrasonic irrigation devices in the removal of debris from canal irregularities in artificial root canals. *J Appl Oral Sci.* 2019 Jan 7;27:e20180045. doi:10.1590/1678-7757-2018-0045.
- [49] Rödiger T, Zimmermann F, Konietzschke F, Sydow HG, Wiegand A. Comparison of the antibacterial efficacy of sonic- and two ultrasonic-activated irrigation techniques in reducing intracanal *Enterococcus faecalis* populations. *Quintessence Int.* 2018 Oct;49(9):767-73.
- [50] Donnermeyer D, Wyrsh H, Bürklein S, Schäfer E. Removal of calcium hydroxide from artificial grooves in straight root canals: sonic activation using EDDY versus passive ultrasonic irrigation and XP-endo Finisher. *J Endod.* 2019

- Mar;45(3):322-6.
doi:10.1016/j.joen.2018.12.003
- [51] Galler KM, Grubmüller V, Schlichting R, Widbiller M, Eidt A, Schuller C, et al. Penetration depth of irrigants into root dentine after sonic, ultrasonic and photoacoustic activation. doi:10.1111/iej.13108. *Int Endod J*. 2019 Aug;52(8):1210–7.
- [52] Pedullà E, Genovese C, Messina R, La Rosa GRM, Corsentino G, Rapisarda S, et al. Antimicrobial efficacy of cordless sonic or ultrasonic devices on *Enterococcus faecalis*-infected root canals. *J Investig Clin Dent*. 2019 Nov;10(4):e12434. doi:10.1111/jicd.12434.
- [53] Hoedke D, Kaulika N, Dommisch H, Schlafer S, Shemesh H, Bitter K. Reduction of dual-species biofilm after sonic- or ultrasonic-activated irrigation protocols: a laboratory study. *Int Endod J*. 2021 Dec;54(12):2219–28. doi:10.1111/iej.13618.
- [54] Salas H, Castrejon A, Fuentes D, Luque A, Luque E. Evaluation of the penetration of CHX 2% on dentinal tubules using conventional irrigation, sonic irrigation (EDDY) and passive ultrasonic irrigation (PUI) techniques: an in vitro study. *J doi:10.4317/jced.57065. Clin Exp Dent*. 2021 Jan;13(1):e37–42.
- [55] Uslu G, Gündoğar M, Üngör M, Özyürek T, Erkan E, Keskin NB. Investigation of the effectiveness of sonic, ultrasonic and new laser-assisted irrigation activation methods on smear removal and tubular penetration. *Lasers Med Sci*. 2023 Jan;38(1):30. doi:10.1007/s10103-022-03697-8
- [56] Vatanpour M, Toursavadjouhi S, Sajjad S. Comparison of three irrigation methods: SWEEPS, ultrasonic, and traditional irrigation, in smear layer and debris removal abilities in the root canal, beyond the fractured instrument. *Photodiagnosis Photodyn* doi:10.1016/j.pdpdt.2021.102707. *Ther*. 2022 Mar;37:102707.
- [57] Liu C, Li Q, Yue L, Zou X. Evaluation of sonic, ultrasonic, and laser irrigation activation systems to eliminate bacteria from the dentinal tubules of the root canal system. *J Appl Oral Sci*. 2022;30:e20220199. doi:10.1590/1678-7757 2022-0199.
- [58] Assadian H, Fathollahi S, Pourhajibagher M, Solimei L, Benedicenti S, Chiniforush N. Effectiveness of activated sodium hypochlorite irrigation by shock wave-enhanced emission photoacoustic streaming, sonic and ultrasonic devices in removing *Enterococcus faecalis* biofilm from root canal system. *J Clin Med*. 2024;13(20):6278. doi:10.3390/jcm13206278. 59.
- [59] Bao P, Liu H, Yang L, Zhang L, Yang L, Xiao N, et al. In vitro efficacy of Er:YAG laser-activated irrigation versus passive ultrasonic irrigation and sonic-powered irrigation for treating multispecies biofilms in artificial grooves and dentinal tubules: an SEM and CLSM study. *BMC Oral Health*. 2024;24(1):261.
- [60] Gonçalves BF, Reddy D, Machado R, Soares Júnior PC, Ignácio SA, Fernandes Couto DA, et al. Smear layer removal comparing conventional irrigation, passive ultrasonic irrigation, EndoActivator System, and a new sonic device (Perfect Clean System) by scanning electron microscopy: an ex vivo study. *PLoS* doi:10.1371/journal.pone.0314940. *One*. 2024;19(12):e0314940.
- [61] Wigler R, Srour Y, Wilchfort Y, Metzger Z, Kfir A. Debris and smear layer removal in curved root canals: a comparative study of ultrasonic and sonic irrigant activation techniques. doi:10.3390/dj12030051. *Dent J (Basel)*. 2024;12(3):51.
- [62] Zhang SH, Gao ZR, Zhou YH, Tan L, Feng Y, Ye Q, et al. Comparison of Easydo Activator, ultrasonic and needle irrigation techniques on sealer penetration and smear layer removal in vitro. *BMC Oral Health*. 2024;24(1):56. doi:10.1186/s12903-023-03833-y.
- [63] Meena A, Sharma N, Sinha DJ, Singh S, Dhawan A, Verma N. Comparative evaluation of side-vented needle, air sonic, and ultrasonic irrigation techniques on sodium hypochlorite penetration into tubules of dentin in root canal: an in vitro study. *Endodontology*. 2025;37(1):80–4.
- [64] Erkan E, Gündoğar M, Uslu G, Özyürek T. Postoperative pain after SWEEPS, PIPS, sonic and ultrasonic-assisted irrigation activation techniques: a randomized clinical trial.

- doi:10.1007/s10266-022-00729-3. 65.
Odontology. 2022;110(4):786–94.
- [65] Sheth VH, Shah NP, Jain R, Bhanushali N, Bhatnagar V. Development and validation of a risk-of-bias tool for assessing in vitro studies conducted in dentistry: the QUIN. *J Prosthet* doi:10.1016/j.prosdent.2023.06.010. 66. *Dent*. 2024;131(6):1038–42.
- [66] Plotino G, Cortese T, Grande NM, Leonardi DP, Di Giorgio G, Testarelli L, et al. New technologies to improve root canal disinfection. *Braz Dent J*. 2016;27(1):3–8.
- [67] Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: a review. *Oral Surg Oral Med Oral Pathol Oral* doi:10.1067/moe.2002.128962. *Radiol Endod*. 2002;94(6):658–66.
- [68] Saeidnia S, Manayi A, Abdollahi M. From in vitro experiments to in vivo and clinical studies; pros and cons. *Curr Drug Discov Technol*. 2015;12(4):218–24.
- [69] Alamoudi RA. The smear layer in endodontic: to keep or remove—an updated overview. *Saudi Endod J*. 2019;9(2):71–81.
- [70] Akyuz Ekim SN, Erdemir A. Comparison of different irrigation activation techniques on smear layer removal: an in vitro study. *Microsc Res Tech*. 2015;78(3):230–9.
- [71] Uzunoglu-Özyürek E, Karaaslan H, Türker SA, Özçelik B. Influence of size and insertion depth of irrigation needle on debris extrusion and sealer penetration. *Restor Dent Endod*. 2018;43(1):e3.
- [72] El Abed S, Ibensouda SK, Latrache H, Hamadi F. Scanning electron microscopy (SEM) and environmental SEM: suitable tools for study of adhesion stage and biofilm formation. In: Kazmiruk V, editor. *Scanning Electron Microscopy*. London: IntechOpen; 2012.