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Review Article

Comparasion of irrigant penetration using different irrigation activation techniques in root canals

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Abstract

The ideal irrigation to guarantee the elimination of microorganisms, the removal of debris and enhance the disinfection within the anatomically complex systems of root canals. Conventional needle irrigation is not able to ensure thorough penetration of irrigant into the lateral canals and inaccessible areas, requiring better irrigation activation method. Passive ultrasonic irrigation (PUI) utilizes ultrasonic oscillations to create acoustic streaming and perhaps cavitation to improve flow and to remove debris. Several alternative methods such as the sonic, laser-assisted irrigation and manual dynamic agitation have been explored to improve the distribution of irrigant. The root canal have been designed to enable such a comparison in a controlled setting. The results of irrigant penetration can be assessed by dye visualization, microscopic examination and digital image analysis which can determine the maximum penetration depth, percentage of the lateral canal filled and the percentage of total penetration. However, teeth and models do not completely mimic dentinal permeability and anatomical complexity of natural teeth. This comparative analysis of irrigation activation techniques could aid in the determination of differences in penetration efficiency and future research in finding an optimized endodontic irrigation protocol.

Keywords: Root canal irrigation, Passive ultrasonic irrigation, Irrigant penetration, Sonic activation, Laser-assisted irrigation, Root canals, Endodontics.

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1. Introduction

The success of root canal therapy requires an effective chemomechanical preparation which will enable the elimination of microorganisms, removal of all remnants of organic tissues, and disruption of biofilms in the root canal system.[1] The complex anatomy of the root canals (fins, isthmuses, ramifications, and lateral canals) makes it very challenging to thoroughly clean and disinfect. Anatomical irregularities cannot be completely instrumented with mechanical instruments alone and, therefore, irrigation during endodontic treatment is of critical importance.[2] Thus, the quest for achieving a deeper irrigant penetration in inaccessible areas of the root canal system is still a major goal in modern endodontics.[3]

Sodium hypochlorite is a highly effective endodontic irrigant with antimicrobial properties and organic tissue dissolving properties.[4] The inorganic component of the smear layer can be removed by the use of ethylenediaminetetraacetic acid (EDTA), which provides a better dentinal surface cleanliness.[5] However, effectiveness of these irrigants will depend on factors

such as concentration, volume, contact time, canal anatomy and delivery method.[6] Although the technology of conventional needle irrigation has been developed for a long time, it is still in use due to its simplicity and accessibility.[7] Its effectiveness is limited, however, because of the limited fluid exchange in the apical region and the difficulty of irrigating the narrow lateral canals and some of the more complex anatomical regions.[8] These restrictions have inspired the work on irrigation activation methods that promote better fluid dynamics and irrigant distribution.[9]

Several methods of irrigation activation have been developed to improve the ability of irrigants to penetrate and be effective during endodontic treatment.[10] The oscillating tools used in Sonic activation create fluid movement which facilitates irrigant exchange in the root canal system. Passive ultrasonic irrigation (PUI) involves the use of ultrasonic energy to create acoustic streaming and possibly cavitation which promotes movement of the irrigant and clears debris from inaccessible regions.[11] Laser assisted irrigation technologies produce high-speed fluid flow by utilizing the cavitation effect and growth of bubbles, which may lead to better irrigant distribution in complicated canal anatomies.[12] Another way to improve fluid displacement is by manual dynamic agitation, or repeated movement of a well-fitting gutta-percha cone within the prepared canal.[13] However, due to their various mechanisms of activation, equipment needs, and applicability in the clinic, it is warranted that they be further compared.

The root canal models are used to create a standardized experimental set up to study the penetration of irrigants under controlled conditions.[14] Artificial canals with dimensions and lateral extensions that can be repeated enables assessment of how much the various irrigation techniques can provide solutions into the anatomically difficult regions.[15] These models, used in conjunction with dye-dye visualization and digital image analysis, enable quantitative evaluation of penetration depth and the length of lateral canals irrigated by the irrigant.[16] The results of the models, however, should be used with caution, as it is not possible to mimic the permeability, irregular anatomy and tissue properties of natural teeth with artificial models.

Systematic comparison of irrigation activation techniques may be useful to better understand the relative effectiveness to increase irrigant penetration. The current in vitro study is designed, therefore, to compare irrigant penetration using various techniques of irrigation activation in root canals. It is hypothesized that the amount of irrigant penetration will be significantly different between the techniques evaluated. The results can be used for experimental evidence to select and promote irrigation protocols to enhance endodontic cleaning in complex root canal systems.

2. Review

2.1. Root canal irrigation, an important treatment

The use of root canal irrigation is a crucial part of endodontics which enhances the mechanical instrumentation by aiding in the removal of microorganisms, necrotic tissue, dentinal debris and smear layer. Mechanical preparation alone is ineffective because of the complexity of the root canal system and the presence of lateral canals, isthmuses, fins and apical ramifications. Therefore, the degree of penetration of the irrigant into such inaccessible areas is an important factor in canal disinfection. Sodium hypochlorite with its antimicrobial properties and organic tissue dissolving ability is widely used, while ethylenediaminetetraacetic acid (EDTA) is used to remove smear layer.[17] But these solutions are effective depending on chemical properties, contact time, delivery method and reaching anatomically complex areas.

Table 1: Showing overview of root canal irrigation and its importance

Aspect	Description
Importance of irrigation	An essential component of endodontic treatment that complements mechanical instrumentation.
Primary functions	Removal of microorganisms, necrotic tissue, dentinal debris, and smear layer.
Limitations of mechanical preparation	Complex root canal anatomy, including lateral canals, isthmuses, fins, and apical ramifications, restricts adequate cleaning.
Importance of irrigant penetration	Facilitates irrigation of inaccessible anatomical regions and supports effective canal disinfection.
Sodium hypochlorite (NaOCl)	Provides antimicrobial activity and dissolves organic tissue.
Ethylenediaminetetraacetic acid (EDTA)	Facilitates removal of the inorganic component of the smear layer.
Factors influencing effectiveness	Chemical properties, contact time, delivery technique, and penetration into anatomically complex areas.

2.2. Conventional needle irrigation

The conventional needle irrigation is still widely-used due to its simplicity, low cost and ease of use. The delivery of irrigants is typically dependent on the location of the needles, the depth of insertion, the flow rate of the solution and the size of the canal prepared. However, fluid exchange is less effective in narrow canals and the apical area, especially when the canal is not close to the working length when the needle is positioned. Minimal movement of irrigant can also fail to fill in lateral canals and other irregularities.[18] These restrictions have stimulated the growth of some activation methods which promote better fluid circulation and distribution of irrigant outside the main root canal.

2.3. Sonic irrigation activation

Sonic activation involves vibrating instruments to produce a smooth movement in the root canal system. The resulting hydrodynamic effects promote exchange of irrigant and may aid in cleaning canal irregularities of debris. This is successful when the frequency of oscillation, instrument design, canal dimensions and the operating protocol are followed.[19] In selected experimental models, sonic activation can be used to enhance irrigation water distribution compared to conventional needle irrigation. But, it depends on the parameters of the canal and activation parameters used. Comparisons, therefore, must all be made in a standardised manner to ensure that its relative effectiveness in terms of penetration of lateral extensions are determined.

2.4. Passive ultrasonic irrigation

Passive ultrasonic irrigation (PUI) involves the ultrasonically vibrating device that is placed in the root canal filled with irrigant. The oscillations create acoustic streaming and may under appropriate conditions induce cavitation which will further improve the fluid flow and aid in debris removal. Overall, the technique is designed to enhance the irrigation and to minimize the removal of dentin, since cutting the dentinal walls is not typically done with the instrument.[20] However, it may be affected by the location of the instrument, the curvature of the canal, the space available, the duration of activation, and obstructions. Evaluation of PUI in root canals can be used to assess its efficacy in providing irrigants into lateral canals in an experimental setting.

2.5. Laser-assisted irrigation

Other methods to improve irrigant movement in the root canal system have been studied, including laser-assisted irrigation. Some laser systems create the rapid formation and collapse of vapor bubbles that can cause fluid displacement which can help irrigants penetrate anatomically complex areas.[21] This effect is governed by the laser wavelength, pulse energy, delivery configuration and activation protocol. Laser assisted techniques show promise in improving the fluid dynamics, but comparisons with conventional, sonic, and ultrasonic techniques need carefully controlled experimental conditions to be able to compare differences in penetration, and valid interpretation.

2.6. Root canal models and penetration assessment

Irrigation technique can be on root canal models to create an environment that is reproducible to assess technique. Artificial canals with standardized lateral extensions enable comparisons of irrigant penetration, with dimensions of the canal, irrigant volume and activation time being controlled.[22] The degree of penetration can be determined by dye visualization, microscope or digital image analysis. These outcomes that are relevant are Maximum penetration depth, Percentage of lateral canal depth filled and Percentage of completed penetrations. But the artificial models are not true to the dentinal permeability, irregular anatomy and the characteristics of tissues in natural teeth. For these reasons, the conclusions they draw are experimental evidence only, not direct proof of clinical efficacy.

Table 2: Characteristics of conventional needle irrigation

S. No.	Parameter	Description
1	Technique	Delivery of irrigant into the root canal using an irrigation needle.
2	Advantages	Simple, economical, and easy to use.
3	Needle positioning	Influences irrigant delivery and distribution within the canal.
4	Insertion depth	Determines the proximity of the needle tip to the working length.
5	Flow rate	Affects fluid movement and irrigant exchange.
6	Canal dimensions	Narrow canals may restrict irrigant circulation.
7	Apical irrigation	Fluid exchange may be limited in the apical region.
8	Lateral canal penetration	May be inadequate in lateral canals and anatomical irregularities.

Table 2 Continued…

9	Major limitation	Restricted irrigant distribution beyond the main root canal.
10	Clinical implication	Supports the development of activation techniques to improve fluid circulation and irrigant penetration.

Table 3: Characteristics of passive ultrasonic irrigation (PUI)

S. No.	Parameter	Description
1	Technique	Uses an ultrasonically vibrating instrument positioned in an irrigant-filled root canal.
2	Working principle	Ultrasonic oscillations generate acoustic streaming and may induce cavitation under suitable conditions.
3	Fluid dynamics	Enhances irrigant movement and fluid exchange within the root canal system.
4	Debris removal	Facilitates the removal of debris from inaccessible canal regions.
5	Dentin preservation	Typically performed without intentional cutting of dentinal walls.
6	Instrument positioni	Influences the effectiveness of irrigant activation.
7	Canal anatomy	Canal curvature and available space may affect instrument oscillation and fluid movement.
8	Activation duration	Influences the extent of irrigant activation.
9	Potential limitations	Obstructions and restricted canal space may reduce effectiveness.
10	Experimental evaluation	Root canal models can assess irrigant penetration into lateral canals under controlled conditions.

Table 4: Root canal models and irrigant penetration assessment

S. No.	Parameter	Description
1	Purpose of models	Provide a reproducible environment for evaluating irrigation techniques.
2	Canal design	Artificial canals with standardized lateral extensions facilitate comparative assessment.
3	Controlled variables	Canal dimensions, irrigant volume, and activation duration.
4	Penetration assessment methods	Dye visualization, microscopic examination, and digital image analysis.
5	Maximum penetration depth	Measures the greatest distance reached by the irrigant.
6	Percentage of lateral canal depth filled	Quantifies the proportion of lateral canal length penetrated by the irrigant.
7	Complete penetration rate	Measures the percentage of lateral canals completely filled with irrigant.
8	Advantages	Standardization, reproducibility, and controlled comparison of irrigation techniques.
9	Limitations	Does not fully reproduce natural dentinal permeability, anatomical irregularities, or tissue characteristics.
10	Interpretation of findings	Provides experimental evidence but does not directly establish clinical efficacy.

2.7. Research gap

There are a number of techniques developed for irrigation activation to enhance irrigant distribution, but differences in the relative effectiveness of these techniques could exist depending on the experimental model, activation parameters, and methods used to assess the outcome.[23] The geometry of the canal, the irrigant used, the depth of insertion of the needles and the duration of activation may also create variations between studies. Standardized root canals could be used in a controlled comparison to minimize some of these methodological differences. This investigation may yield quantitative data for the relative penetration of traditional needle irrigation, laser irrigation, passive ultrasonic irrigation and sonic activation.

3. Discussion

Influencing the effectiveness of endodontic irrigation is the penetration of irrigants into root canals, especially in the anatomically complex areas that are not accessible to mechanical instrumentation.[24] Given the complexity of the irrigation system, different activation techniques could enhance irrigant distribution by modifying fluid dynamics, enabling solution exchange, and encouraging irrigant penetration into laterals that are extended beyond the main canal.[25] Traditional needle irrigation is simple and cost-effective, but may be less effective due to limited flow of fluid in the lateral canals and the apex.[26] Passive ultrasonic irrigation may result in acoustic streaming and possibly cavitation, which could promote fluid exchange in the complex anatomy of a canal, while oscillatory motions generated by sonic activation could improve irrigant displacement. Rapid bubble formation and fluid displacement with laser could also enhance penetration, but will depend on the laser parameters and delivery technique. The variation of penetration between these techniques should be considered in the context of the standardized geometry of the canal, the volume of irrigant, the time of activation and the method of measurement used in the current study.[27] Dye-based visualization and digital image analysis can give quantitative estimation of penetration depth; however, the penetration of the dye does not necessarily mean that the antimicrobial activity was effective and/or that the tissue was dissolved in clinical conditions.[28] Moreover, root canals provide reproducibility but do not completely mimic the complexity of anatomical structures, dentinal permeability, and biological conditions in natural teeth.[29] Thus the results must be viewed in the context of the limitations of the experimental model used. Further studies with extracted human teeth, standard irrigation protocols and complementary evaluations of debris removal and microbial reduction are recommended to determine the clinical significance of the differences in irrigant penetration and to help identify the best activation method for endodontics.

4. Conclusion

To sum up, the irrigant penetration is one of the key factors to ensure good disinfection of the root canal, especially in complex anatomical areas. Different irrigation activation techniques can improve irrigant distribution over traditional needle irrigation. root canal models can give a standardized approach to evaluate penetration under controlled experimental conditions. But, better penetration does not always mean better antimicrobial activity or clinical results. These results should be confirmed with in vitro human teeth and microbiological evaluations to determine the clinical significance of the various techniques of tooth irrigation activation.

List of Abbreviations

PUI: Passive Ultrasonic Irrigation;
EDTA: Ethylenediaminetetraacetic Acid;
NaOCl: Sodium Hypochlorite;
CLSM: Confocal Laser Scanning Microscopy;
SEM: Scanning Electron Microscopy

Author Contributions

Manasa Bhavana: Conceptualization, literature review, methodology, data curation, investigation, writing—original draft preparation, and writing—review and editing. The author approved the final version of the manuscript.

Ethical Approval

Ethical approval was not required.

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Conflict of Interest

None.

References

1. Neelakantan P, Romero M, Vera J, Daood U, Khan AU, Yan A, Cheung GSP. Biofilms in Endodontics-Current Status and Future Directions. *Int J Mol Sci*. 2017;18(8):1748. https://doi.org/10.3390/ijms18081748
2. Jayakumar S, Sridhar D, John BM, Arumugam K, Ponnusamy P, Pulidindi H. Biofilm in Endodontic Infection and its Advanced Therapeutic Options - An Updated Review. *J Pharm Bioallied Sci.* 2024;16(Suppl 2):S1104-S1109. https://doi.org/10.4103/jpbs.jpbs_394_23
3. Liu H, Wang X, Wang Z, Shen Y. Evaluation of bacterial biofilm, smear layer, and debris removal efficacy of a hydrodynamic cavitation system with physiological saline using a new ex vivo model: a CLSM and SEM study. *BMC Oral Health.* 2025;25(1):95. https://doi.org/10.1186/s12903-025-05463-y
4. Tomson PL, Adams N, Kavanagh D, Virdee SS. Non-surgical endodontics: contemporary biomechanical preparation of the root canal system. *Br Dent J.* 2025;238(7):478–86. https://doi.org/10.1038/s41415-025-8599-1
5. Iandolo A, Abdellatif D, Mancino D, Rolin G, Coussens C, Louvrier A, et al. In vitro experimental study comparing continuous and intermittent irrigation protocols: influence of sodium hypochlorite volume and contact time on tissue dissolution. *Restor Dent Endod.* 2025;50(4):e36. https://doi.org/10.5395/rde.2025.50.e36
6. Zou X, Zheng X, Liang Y, Zhang C, Fan B, Liang J, et al. Expert consensus on irrigation and intracanal medication in root

canal therapy. *Int J Oral Sci.* 2024;16(1):23. https://doi.org/10.1038/s41368-024-00280-5
7. Tungsawat P, Arunrukthavorn P, Phuntusuntorn P, Opatragoon S, Sirirangsee P, Inklub S. Comparison of the Effect of Three Irrigation Techniques and Root Canal Preparation Size on Sodium Hypochlorite Penetration into Root Canal Dentinal Tubules. *Int J Dent.* 2021;2021:6612588. https://doi.org/10.1155/2021/6612588
8. Boutsioukis C, Arias-Moliz MT. Present status and future directions - irrigants and irrigation methods. *Int Endod J.* 2022;55 Suppl 3(Suppl 3):588–612. https://doi.org/10.1111/iej.13739
9. Asthana G, Manglani S, Tamuli R. Improving fluid dynamics during root canal irrigation. *J Conserv Dent Endod*. 2025;28(6):595–7. https://doi.org/10.4103/JCDE.JCDE_223_25
10. AbuMostafa A, Almarshad M, Alharith D, Alabdulkareem M, Alqahtani A, Alhawsawi B, et al. Effect of Various Root Canal Irrigation Techniques on Root Dentin Mechanical Properties: An In Vitro Study. *Int J Dent*. 2026;2026:2445546. https://doi.org/10.1155/ijod/2445546
11. Sevencan CG, Akça S. Comparative evaluation of irrigant activation devices for removal of calcium hydroxide from artificial isthmuses connecting curved canals in 3D-printed resin molar models. *BMC Oral Health*. 2026;26(1):1811. https://doi.org/10.1186/s12903-026-09761-x
12. Kumar RS, Ankola A, Peerzade M, Sankeshwari R, Hampiholi V, Khot AP, et al. Comparative Efficacy of Different Irrigant Activation Techniques for Irrigant Delivery Up to the Working Length of Mature Permanent Teeth: A Systematic Review and Meta-Analysis. *Eur Endod J.* 2023;8(1):1–19. https://doi.org/10.14744/eej.2022.87587
13. Bansal S, Maiti N, Gowda T, Sinha RR, Behera SSP, Chatterjee R. Penetration depth of different irrigants in lateral canalsPenetration depth of different irrigants in lateral canals. *Bioinformation*. 2025;21(4):797–800. https://doi.org/10.6026/973206300210797
14. Boutsioukis C, Arias-Moliz MT, Chávez de Paz LE. A critical analysis of research methods and experimental models to study irrigants and irrigation systems. *Int Endod J*. 2022;55 Suppl 2(Suppl 2):295–329. https://doi.org/10.1111/iej.13710
15. Talib AQ, Al-Huwaizi HF. Assessment of the Effect of Different Irrigation Protocols on the Penetration of Irrigation Solution into Lateral Canals (In Vitro Study). *Eur Endod J*. 2024;9(2):146–53. https://doi.org/10.14744/eej.2023.29494
16. Awaida A, El Hachem R, Issa A, Kallasy M, Zogheib C, Hage W. The action of different irrigant activation methods on engineered endodontic biofilm: an *in vitro* study. *Biomater Investig Dent.* 2025;12:43065. https://doi.org/10.2340/biid.v12.43065
17. Kumar RS, Ankola AV, Sankeshwari RM, Hebbal M, Hampiholi V, Kumar SL, et al. Effectiveness of various irrigant activation techniques on the penetration of sodium hypochlorite into lateral canals of mature permanent teeth: A systematic review and meta-analysis. *Saudi Dent J*. 2023;35(1):1–23. https://doi.org/10.1016/j.sdentj.2022.12.004
18. Montaser OK, Fayyad DM, Abdelsalam N. Efficacy of different irrigant activation techniques for cleaning root canal anastomosis. *BMC Oral Health.* 2023;23(1):142. https://doi.org/10.1186/s12903-023-02835-0
19. Degirmencioglu D, Erşahan Ş, Hepsenoglu YE, Erkan E, Gundogar M, Sagir K. The influence of cavity configuration and irrigation activation on root canal smear removal-an *in vitro* study. *PeerJ*. 2025 ;13:e19678. https://doi.org/10.7717/peerj.19678
20. Fidan ME, Erdemir A. Effect of different irrigation activation techniques on irrigation penetration into the lateral canals. Odontology. 2023;111(1):132–41. https://doi.org/10.1007/s10266-022-00729-1
21. Gomes BPFA, Aveiro E, Kishen A. Irrigants and irrigation activation systems in Endodontics. *Braz Dent J*. 2023;34(4):1–33. https://doi.org/10.1590/0103-6440202305577
22. Antony DPS, Solete P, Jeevanandan G, Syed AA, Almahdi S, Alzhrani M, et al. Effect of Various Irrigant Activation Methods and Its Penetration in the Apical Third of Root Canal-In Vitro Study. *Eur J Dent.* 2023;17(1):57-61. https://doi.org/10.1055/s-0041-1742122
23. 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. https://doi.org/10.3389/froh.2022.838043. Erratum in: *Front Oral Health.* 2022;3:876265. https://doi.org/10.3389/froh.2022.876265
24. Su Z, Li Z, Shen Y, Bai Y, Zheng Y, Pan C, et al. Characteristics of the Irrigant Flow in a Lateral Canal Under Two Typical Laser-Activated Irrigation Regimens. *Lasers Surg Med.* 2020. https://doi.org/10.1002/lsm.23317
25. Imad Al-Ghurairi H, Al-Huwaizi H. Effect of Irrigation with Zirconia Microparticles Combined with Different Activation Techniques on Smear Layer Removal: An Ex Vivo Study. *Dent J (Basel).* 2026;14(8):497. https://doi.org/10.3390/dj14080497
26. Susila A, Minu J. Activated Irrigation vs. Conventional non-activated Irrigation in Endodontics - A Systematic Review. *Eur Endod J*. 2019;4(3):96–110. https://doi.org/10.14744/eej.2019.80774
27. Naladkar K, Chandak M, Sarangi S, Agrawal P, Jidewar N, Suryawanshi T, et al. Breakthrough in the Development of Endodontic Irrigants. *Cureus.* 2024;16(8):e66981. https://doi.org/10.7759/cureus.66981
28. Atav A, Zanza A, Gunes A, Testarelli L, Galli M, Erda Q, et al. Recent innovations in endodontic irrigation and effects on smear layer removal: an ex-vivo study. *Clin Oral Investig.* 2025;29(6):309. https://doi.org/10.1007/s00784-025-06387-1
29. Panda B, Panda S, Hota S, Dass D, Arya A, Marwaha J. Effect of Different Irrigation Activation Techniques on Smear Layer Removal in Root Canal Treatment. *J Pharm Bioallied Sci*. 2025;17(Suppl 4):S3099-S3101. https://doi.org/10.4103/jpbs.jpbs_1175_25