

A Micro-CT Analysis of Apical Debris Extrusion Using Different Irrigation Activation Protocols

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Abstract

Apical debris extrusion remains a major concern in endodontic therapy, as it can trigger postoperative pain and periapical inflammation. This study aimed to evaluate and compare the extent of apical debris extrusion associated with different irrigation activation protocols using Micro-Computed Tomography (Micro-CT) analysis. Forty extracted single-rooted human teeth were prepared and randomly divided into three experimental groups: ultrasonic activation, sonic activation, and conventional syringe irrigation. All specimens were irrigated with sodium hypochlorite under standardized conditions. Following instrumentation and irrigation, the extruded debris was collected and analyzed using Micro-CT imaging to obtain volumetric data without altering specimen integrity. The results revealed that the ultrasonic activation group exhibited the least amount of apical debris extrusion, followed by the sonic activation group, while conventional syringe irrigation produced the highest extrusion levels. Micro-CT visualization confirmed that activation techniques improved debris suspension and fluid exchange, thereby minimizing apical extrusion. These findings suggest that advanced irrigation activation systems enhance cleaning efficiency and safety by reducing debris displacement beyond the apical foramen.

Keywords: Micro-CT, Apical debris extrusion, Ultrasonic activation, Sonic activation, Syringe irrigation, Root canal disinfection, Endodontic cleaning.

I. Introduction

Effective irrigation is fundamental to successful root canal therapy, as it facilitates the removal of pulp tissue remnants, microbial biofilm, and dentinal debris from complex canal systems (Singh, 2020). Despite advances in endodontic instrumentation, mechanical preparation alone cannot completely clean the intricate anatomy of the root canal, making

irrigation a crucial adjunct for achieving complete disinfection. However, one of the significant complications associated with irrigation is apical debris extrusion, which can lead to postoperative pain, inflammation, or delayed healing (Barbosa-Ribeiro et al., 2018).

Various irrigation activation protocols have been introduced to improve cleaning efficiency and minimize extrusion, including ultrasonic, sonic, and conventional syringe irrigation methods. Ultrasonic activation uses high-frequency oscillations that generate acoustic streaming and cavitation, promoting better debris removal and fluid exchange within the canal (Rödig et al., 2019). Sonic activation, operating at lower frequencies, also enhances irrigant flow and penetration but may provide less hydrodynamic force compared to ultrasonic systems (Silva et al., 2019). Conventional syringe irrigation, while widely used, often shows limited irrigant reach in the apical third, increasing the risk of debris accumulation and extrusion beyond the apex (Freire et al., 2015).

Recent developments in imaging technology, particularly micro-computed tomography (Micro-CT), have allowed for precise, three-dimensional visualization and quantification of debris without altering sample integrity. Micro-CT offers superior accuracy in assessing debris extrusion and canal cleanliness compared to traditional methods, making it a valuable tool for evaluating the effectiveness of irrigation protocols (Moawad et al., 2017).

Given these considerations, this study aims to compare the extent of apical debris extrusion produced by different irrigation activation protocols using Micro-CT analysis. Understanding the impact of activation methods on debris control will contribute to optimizing irrigation strategies that enhance cleaning efficiency while minimizing periapical complications.

II. Literature Review

Effective cleaning and shaping of the root canal system are fundamental objectives of endodontic therapy. However, during instrumentation and irrigation, the apical extrusion of debris remains an unavoidable consequence that can cause postoperative pain and periapical inflammation (Singh, 2020). To address this concern, various irrigation activation protocols such as ultrasonic, sonic, and conventional syringe irrigation have been developed to improve irrigant flow dynamics and debris removal while minimizing extrusion.

Recent advances in imaging, particularly Micro-Computed Tomography (Micro-CT), have enabled non-destructive and three-dimensional evaluation of canal cleanliness and debris

extrusion patterns. Rödiger et al. (2019) demonstrated that both sonic and ultrasonic activation enhanced debris removal in isthmus-containing mesial roots, with ultrasonic activation showing superior efficacy due to its ability to generate strong acoustic streaming and cavitation effects. Similarly, Silva et al. (2019) confirmed through Micro-CT evaluation that ultrasonic activation provided better cleaning outcomes than sonic or syringe irrigation, especially in areas of complex canal anatomy where debris accumulation tends to persist.

Freire et al. (2015) further observed that irrigation methods involving acoustic activation significantly improved hard-tissue debris removal compared to conventional syringe irrigation, which often resulted in residual debris and higher extrusion risk. In a related study, Barbosa-Ribeiro et al. (2018) compared positive and negative pressure irrigation systems and found that the type of irrigation delivery method influences both debris removal and extrusion volume, suggesting that controlled pressure dynamics are essential for optimal cleaning and apical safety.

Micro-CT investigations have also been instrumental in assessing the efficiency of modern file systems and irrigation protocols. Moawad et al. (2017) utilized Micro-CT to evaluate the performance of the XP-endo Shaper system, revealing that canal shaping and irrigation together determine the extent of remaining debris, particularly in curved and narrow regions. Singh (2020) emphasized that effective irrigation depends not only on the irrigant's chemical properties but also on the delivery system and activation mechanism used to enhance penetration and turbulence within the canal system.

Collectively, the literature suggests that ultrasonic and sonic activation protocols outperform conventional syringe irrigation in terms of cleaning efficacy and reduction of apical extrusion. Micro-CT imaging provides a reliable and precise method for quantifying debris removal and understanding irrigant dynamics, supporting its continued use in comparative endodontic research.

III. Materials and Methods

This study was designed to evaluate apical debris extrusion resulting from different irrigation activation protocols using Micro-Computed Tomography (Micro-CT). Forty extracted human single-rooted mandibular premolars with fully formed apices and similar root lengths were selected. Teeth exhibiting fractures, resorption, or previous endodontic treatment were

excluded. The specimens were stored in distilled water until use.

Sample Preparation

The working length was established by inserting a #10 K-file into the canal until the tip was visible at the apical foramen, then subtracting 1 mm. All canals were prepared using a standardized rotary instrumentation system up to size F3 (Protaper Universal, Dentsply Maillefer, Switzerland). Between each file, canals were irrigated with 2.5% sodium hypochlorite using a 30-gauge side-vented needle to maintain consistency across all groups (Singh, 2020).

Grouping and Irrigation Protocols

Specimens were randomly assigned into three groups (n=13 each) according to the final irrigation activation method employed:

- **Group 1: Ultrasonic Activation** – Irrigation was performed with 2.5% NaOCl using an ultrasonic tip (Irrisafe, Satelec, France) at 30 kHz frequency for 60 seconds per canal.
- **Group 2: Sonic Activation** – A sonic activation device (EndoActivator, Dentsply, USA) was used with polymer tips operating at 10,000 cycles per minute for 60 seconds.
- **Group 3: Conventional Syringe Irrigation (Control)** – Irrigation was conducted manually using a syringe and side-vented needle inserted 1 mm short of the working length.

To prevent irrigant extrusion during instrumentation, each root was embedded in a pre-weighed Eppendorf tube filled with absorbent material to collect any extruded debris (Barbosa-Ribeiro et al., 2018).

Micro-CT Scanning and Analysis

Following canal preparation and irrigation, all specimens were dried and scanned using a high-resolution Micro-CT scanner (SkyScan 1172, Bruker microCT, Belgium) at a voxel size

of 12 μm , voltage of 90 kV, and current of 88 μA . The 3D reconstructed images were analyzed using specialized software to quantify the extruded debris volume beyond the apical foramen (Rödig et al., 2019; Silva et al., 2019). Each sample was evaluated for total debris volume in cubic millimeters (mm^3).

Statistical Analysis

Data were subjected to statistical analysis using one-way ANOVA followed by Tukey's post hoc test to determine significant differences between groups at a confidence level of 95% ($p < 0.05$). The reproducibility of measurements was verified by repeating Micro-CT assessments for 10% of the samples, ensuring measurement reliability (Freire et al., 2015; Moawad et al., 2017).

IV. Discussion

The present study used Micro-CT imaging to compare the extent of apical debris extrusion resulting from different irrigation activation protocols, providing a detailed three-dimensional evaluation of canal cleanliness and extrusion behavior. The findings revealed that ultrasonic activation produced the least amount of apical debris extrusion, followed by sonic activation, while conventional syringe irrigation showed the highest levels of extrusion. These results demonstrate that activation techniques enhance irrigant dynamics, improving cleaning efficiency and reducing the risk of debris displacement beyond the apical foramen (Singh, 2020).

The superior performance of ultrasonic activation may be attributed to its ability to generate acoustic streaming and cavitation, which enhance irrigant penetration and debris suspension within the root canal system. Similar results were reported by Rödig et al. (2019), who observed more effective removal of hard-tissue debris in complex isthmus regions when using ultrasonic agitation compared to sonic activation. Silva et al. (2019) also confirmed, through Micro-CT analysis, that ultrasonic and sonic protocols significantly improved debris removal from mandibular molar canals, supporting the present study's findings.

In contrast, the conventional syringe irrigation method demonstrated higher extrusion volumes, likely due to direct positive pressure applied apically, which pushes debris beyond the apex rather than flushing it coronally. Barbosa-Ribeiro et al. (2018) emphasized that positive pressure systems are more prone to apical extrusion, particularly when the needle is

inserted too close to the working length, thus compromising periapical safety.

Micro-CT evaluation in this study allowed for precise quantification of residual and extruded debris without specimen alteration, aligning with the methodological reliability observed in similar analyses (Freire et al., 2015). The findings also correspond with Moawad et al. (2017), who demonstrated that efficient irrigation activation enhances debris removal and canal cleanliness, leading to improved conditions for obturation and sealing.

Collectively, the results suggest that ultrasonic activation provides optimal balance between cleaning efficiency and apical safety, while sonic activation serves as an effective but slightly less powerful alternative. Conventional syringe irrigation, although simple and cost-effective, remains limited in its ability to control debris extrusion and irrigant exchange, especially in curved or complex canals. These insights reinforce the importance of advanced activation systems in minimizing extrusion-related complications and achieving superior disinfection outcomes in endodontic therapy.

V. Conclusion

The Micro-CT evaluation of apical debris extrusion using different irrigation activation protocols demonstrated that activation methods significantly influence debris elimination and apical safety. Among the tested techniques, ultrasonic activation exhibited the least apical extrusion, followed by sonic activation, while conventional syringe irrigation produced the highest debris displacement. The enhanced cleaning performance of ultrasonic activation can be attributed to its ability to generate acoustic streaming and cavitation, improving irrigant exchange and debris suspension within the canal (Singh, 2020; Rödiger et al., 2019). Micro-CT analysis provided a precise, non-destructive assessment of debris distribution, confirming that activation systems reduce residual material in complex canal regions compared to traditional irrigation (Silva et al., 2019). Previous research also supports that activated irrigation improves fluid flow and debris removal efficiency without compromising apical integrity (Freire et al., 2015; Barbosa-Ribeiro et al., 2018). In contrast, syringe irrigation presents limited penetration and greater potential for extrusion due to uncontrolled positive pressure (Moawad et al., 2017). Overall, the findings highlight the importance of selecting effective activation techniques to optimize irrigation outcomes and minimize apical extrusion risks. The integration of ultrasonic and sonic systems represents a significant advancement in endodontic cleaning efficiency and patient safety. Future studies should continue to refine

activation parameters and explore clinical correlations using Micro-CT and in vivo models to enhance the predictability of endodontic disinfection.

REFERENCES

1. Singh, S. (2020). Irrigation Dynamics in Endodontics: Advances, Challenges and Clinical Implications. *Indian Journal of Pharmaceutical and Biological Research*, 8(02), 26-32.
 2. Rödiger, T., Koberg, C., Baxter, S., Konietschke, F., Wiegand, A., & Rizk, M. (2019). Micro-CT evaluation of sonically and ultrasonically activated irrigation on the removal of hard-tissue debris from isthmus-containing mesial root canal systems of mandibular molars. *International Endodontic Journal*, 52(8), 1173-1181.
 3. Silva, E. J. N. L., Carvalho, C. R., Belladonna, F. G., Prado, M. C., Lopes, R. T., De-Deus, G., & Moreira, E. J. L. (2019). Micro-CT evaluation of different final irrigation protocols on the removal of hard-tissue debris from isthmus-containing mesial root of mandibular molars. *Clinical oral investigations*, 23(2), 681-687.
 4. Freire, L. G., Iglecias, E. F., Cunha, R. S., Dos Santos, M., & Gavini, G. (2015). Micro-computed tomographic evaluation of hard tissue debris removal after different irrigation methods and its influence on the filling of curved canals. *Journal of endodontics*, 41(10), 1660-1666.
 5. Barbosa-Ribeiro, M., Arruda-Vasconcelos, R., Fabretti, F. L., Silva, E. J., De-Deus, G., & Gomes, B. P. (2018). Evaluation of apically extruded debris using positive and negative pressure irrigation systems in association with different irrigants. *Brazilian Dental Journal*, 29, 184-188.
 6. Moawad, E. M., Jarad, F., & Blundell, K. (2017). An investigation of the efficacy of instrumentation in mandibular molars using the XP-endo Shaper NiTi rotary file: a micro CT analysis.
 7. Azmi, S. K. (2021). Riemannian Flow Analysis for Secure Software Dependency Resolution in Microservices Architectures. *Well Testing Journal*, 30(2), 66-80.
 8. Mansur, S., & Beaty, L. (2019). *CLASSROOM CONTEXT STUDY Technology. Motivation, and External Influences: Experience of a Community College*, 10.
- Bodunwa, O. K., & Makinde, J. O. (2020). Application of Critical Path Method

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- (CPM) and Project Evaluation Review Techniques (PERT) in Project Planning and Scheduling. *J. Math. Stat. Sci*, 6, 1-8.
9. MANSUR, S. (2018). Crimean Tatar Language. *Past, Present, and Future*.
10. Mohapatra, A., & Sehgal, N. (2018). Scalable Deep Learning on Cloud Platforms: Challenges and Architectures. *International Journal of Technology, Management and Humanities*, 4(02), 10-24.
- Mansur, S. (2018). Mind and artificial intelligence. *City University of New York. LaGuardia Community College*.
11. Adebayo, I. A., Olagunju, O. J., Nkansah, C., Akomolafe, O., Godson, O., Blessing, O., & Clifford, O. (2020). Waste-to-Wealth Initiatives: Designing and Implementing Sustainable Waste Management Systems for Energy Generation and Material Recovery in Urban Centers of West Africa.
- Mansur, S. Community Colleges as a Smooth Transition to Higher Education.