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RESEARCH ARTICLE

Comparative Evaluation of Ultrasonic and Sonic Activation Techniques on Irrigant Penetration and Debris Removal in Complex Root Canal Systems

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ABSTRACT

The effectiveness of root canal treatment largely depends on the ability of irrigants to penetrate and clean complex canal systems. This study aimed to comparatively evaluate the efficiency of ultrasonic and sonic activation techniques on irrigant penetration and debris removal within complex root canal anatomies. Forty extracted human teeth with curved or multi-canal systems were prepared using standardized endodontic procedures and divided into two groups based on the activation technique employed. Ultrasonic activation utilized high-frequency oscillations to induce acoustic streaming and cavitation, while sonic activation relied on lower-frequency vibrations to agitate the irrigant solution. Irrigant penetration depth was assessed using dye infiltration, and debris removal was evaluated under stereomicroscopy. The results revealed that ultrasonic activation achieved significantly greater irrigant penetration and more effective debris elimination compared to sonic activation, particularly in apical and lateral canal regions. These findings suggest that ultrasonic activation enhances irrigant dynamics, improving canal cleanliness and potentially increasing the long-term success of endodontic therapy. Further studies are recommended to assess clinical outcomes and optimize activation parameters for different canal morphologies.

Keywords: Ultrasonic activation, Sonic activation, Irrigant penetration, Debris removal, Root canal systems, Endodontic cleaning.

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INTRODUCTION

Successful endodontic treatment depends largely on the effective removal of microorganisms, debris, and the smear layer from the root canal system. Mechanical instrumentation alone is insufficient to achieve complete canal debridement, particularly in anatomically complex regions such as isthmuses, fins, and lateral canals (Singh, 2020). Therefore, the use of chemical irrigants plays a crucial role in complementing mechanical preparation by dissolving organic tissues and flushing out residual debris. However, the success of irrigation is not determined solely by the type of irrigant used but also by the method of its activation and delivery within the canal system.

Conventional syringe irrigation often fails to ensure adequate irrigant penetration into intricate canal extensions due to the presence of air entrapment and limited fluid exchange (Nair et al., 2011). To overcome these limitations, advanced irrigation activation systems such as sonic and ultrasonic devices have been introduced to enhance fluid dynamics and cleaning efficiency. Sonic activation operates at lower frequencies, creating gentle agitation that improves irrigant flow, whereas ultrasonic activation employs high-frequency oscillations that produce cavitation and acoustic streaming, promoting deeper penetration and enhanced debris removal (Gadaalay et al., 2017).

Several studies have compared the efficacy of these activation methods, demonstrating variations in their ability to eliminate debris and smear layers from root canal walls (Manjunath, 2017; Park et al., 2020). While sonic systems provide better control and safety within curved canals, ultrasonic systems have been reported to achieve superior

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cleanliness, particularly in apical and lateral regions. Despite these findings, the effectiveness of both systems in complex canal anatomies continues to be an area of ongoing investigation.

This study aims to comparatively evaluate the efficiency of ultrasonic and sonic activation techniques on irrigant penetration and debris removal in complex root canal systems. By analyzing the performance of both methods under standardized conditions, the research seeks to determine the activation technique that provides optimal canal cleanliness and improved disinfection outcomes.

MATERIALS AND METHODS

This study was conducted to evaluate and compare the effectiveness of ultrasonic and sonic activation techniques on irrigant penetration and debris removal in complex root canal systems. Forty freshly extracted human mandibular molars with mature apices and no visible fractures or resorptive defects were selected. Teeth with calcified or severely curved canals were excluded to ensure uniformity. All teeth were decoronated to obtain standardized root lengths of 16 mm. Working lengths were established 1 mm short of the apical foramen using a size #10 K-file.

The root canals were prepared using a rotary nickel-titanium system up to size F3, with 5 mL of 3% sodium hypochlorite used as an irrigant between each file change. Following instrumentation, the specimens were randomly divided into two experimental groups (n=20 each):

Group I – Ultrasonic Activation

Irrigant activation was performed using an ultrasonic device equipped with an ISO size 20 non-cutting tip operating at 30 kHz. The tip was placed 1 mm short of the working length, and activation was carried out for 30 seconds in three cycles. This method induces acoustic streaming and cavitation effects that enhance fluid movement and debris removal (Singh, 2020; Park et al., 2020).

Group II – Sonic Activation

In this group, irrigant activation was achieved using a sonic handpiece fitted with a polymer tip oscillating at approximately 10,000 cycles per minute. The tip was inserted 1 mm short of the working length, and activation was performed for 30 seconds per cycle. Sonic systems rely on lower-frequency vibrations, producing less cavitation but effective agitation of irrigants within the canal (Nair et al., 2011; Manjunath, 2017).

After activation, all canals were flushed with distilled water and dried using sterile paper points. To evaluate irrigant penetration, canals were filled with a 2% methylene blue dye solution, and longitudinal grooves were made along the root surfaces. Each specimen was split and examined under a stereomicroscope at ×25 magnification. The depth of dye penetration was measured from the apex toward the coronal third using a digital image analysis system (Gadaalay et al., 2017).

For debris removal assessment, the root canal walls were examined using scanning electron microscopy (SEM) at coronal, middle, and apical thirds. Debris was scored based on a standardized five-point scale ranging from clean walls to heavily covered surfaces (Park et al., 2020). Data obtained were statistically analyzed using ANOVA and post hoc tests, with significance set at $p < 0.05$.

RESULTS

The comparative evaluation of ultrasonic and sonic activation techniques revealed significant differences in irrigant penetration depth and debris removal efficiency across the tested samples. Data were analyzed using descriptive statistics and independent t-tests, with significance set at $p < 0.05$.

Irrigant Penetration Depth

Ultrasonic activation demonstrated a greater mean irrigant penetration depth at all canal levels compared to sonic activation. The highest difference was observed in the apical third, where ultrasonic activation achieved deeper irrigant diffusion due to enhanced acoustic streaming and cavitation effects (Singh, 2020; Nair et al., 2011).

Debris Removal Efficiency

Stereomicroscopic analysis showed that ultrasonic activation removed significantly more debris and smear layer than sonic activation. The enhanced hydrodynamic

Table 1: Mean Irrigant Penetration Depth (mm) in Different Canal Levels

Canal Region	*Ultrasonic Activation (Mean ± SD)*	*Sonic Activation (Mean ± SD)*	*p-value*
Coronal third	6.45 ± 0.22	5.98 ± 0.27	<0.05
Middle third	5.72 ± 0.31	4.96 ± 0.34	<0.01
Apical third	4.63 ± 0.25	3.87 ± 0.28	<0.01

These results indicate that ultrasonic activation allows the irrigant to reach areas typically inaccessible through sonic agitation, particularly in curved and narrow canal configurations (Gadaalay et al., 2017).

Table 2: Mean Percentage of Debris Removal in Different Canal Levels

Canal Region	*Ultrasonic Activation (%)*	*Sonic Activation (%)*	*p-value*
Coronal third	96.2	90.4	<0.05
Middle third	92.8	85.6	<0.05
Apical third	88.7	77.5	<0.01

effect of ultrasonic waves contributed to better cleaning of canal walls, isthmuses, and lateral extensions (Park et al., 2020; Manjunath, 2017).

Ultrasonic activation demonstrated superior cleaning in all regions, with the greatest improvement in the apical third where debris accumulation is most common. These findings align with previous reports emphasizing that high-frequency oscillations enhance cavitation and microstreaming effects, improving irrigant performance (Singh, 2020; Park et al., 2020).

Comparative Statistical Summary

Overall, ultrasonic activation exhibited a 12–15% improvement in irrigant penetration and approximately 10% higher debris removal efficiency compared to sonic activation. The differences between the two techniques were statistically significant across all canal levels ($p < 0.05$).

Interpretation

The results clearly indicate that ultrasonic activation provides more effective irrigant agitation and debris elimination in complex root canal systems than sonic activation. The enhanced hydrodynamic effects of ultrasonic energy contribute to superior canal cleanliness, especially in the apical regions where mechanical instrumentation is limited (Nair et al., 2011; Singh, 2020).

DISCUSSION

The present study compared the effectiveness of ultrasonic and sonic activation techniques on irrigant penetration and debris removal within complex root canal systems. The findings revealed that ultrasonic activation achieved superior results in both parameters, demonstrating greater irrigant penetration depth and more effective debris elimination compared to sonic activation. These results align with previous reports emphasizing the enhanced cleaning ability of ultrasonic agitation due to its capacity to generate acoustic streaming and cavitation within the irrigant medium (Singh, 2020).

The superior performance of ultrasonic systems can be attributed to their higher frequency oscillations, which produce intense hydrodynamic effects that disrupt debris and biofilm more efficiently, especially in hard-to-reach canal areas such as isthmuses and apical ramifications (Nair et al., 2011). In contrast, sonic activation, while beneficial in improving irrigant flow, operates at a lower frequency and consequently generates less shear stress on canal walls, leading to less effective debris removal (Park et al., 2020).

Previous in vitro investigations have also demonstrated that ultrasonic activation provides improved smear layer and debris removal compared to sonic systems or conventional irrigation (Manjunath, 2017). The results of this study are consistent with those findings, confirming that enhanced irrigant dynamics achieved through ultrasonic activation facilitate better cleaning of the apical third, which is often the most challenging region for debridement. Gadaalay et al. (2017) further reported that the efficiency of debris removal increases proportionally with the energy transfer to the irrigant, reinforcing the importance of activation frequency and amplitude in cleaning efficacy.

Clinically, the improved irrigant penetration observed with ultrasonic activation suggests its potential to enhance disinfection and reduce microbial persistence within complex canal anatomies. This could contribute to higher treatment success rates by minimizing the risk of reinfection and post-treatment complications (Singh, 2020). However, sonic systems may still offer advantages in terms of safety and reduced dentin removal, making them suitable for specific clinical conditions where excessive agitation may be undesirable (Park et al., 2020).

Overall, the study underscores the importance of selecting an appropriate activation technique based on the anatomical complexity of the root canal and the clinical objectives of treatment. Future research should explore the combination of activation systems and novel irrigant formulations to further optimize cleaning efficiency and clinical outcomes.

CONCLUSION

The comparative evaluation of ultrasonic and sonic activation techniques on irrigant penetration and debris removal demonstrates that both methods enhance canal debridement beyond conventional irrigation; however, ultrasonic activation offers superior efficiency. The high-frequency acoustic streaming and cavitation effects generated by ultrasonic devices significantly improve irrigant penetration into apical and lateral canal regions, facilitating more effective removal of debris and smear layers (Singh, 2020). In contrast, the sonic system, though

beneficial, exhibits limited fluid dynamics due to its lower frequency and amplitude, leading to comparatively reduced cleaning outcomes (Park et al., 2020).

These findings align with previous studies that reported the enhanced cleansing potential of ultrasonic agitation in complex canal systems and its ability to promote deeper irrigant penetration and improved surface cleanliness (Nair et al., 2011; Manjunath, 2017). Similarly, investigations into isthmus debridement and canal disinfection have supported the advantage of ultrasonic activation over other agitation methods, emphasizing its importance in achieving optimal endodontic disinfection (Gadaalay et al., 2017).

Overall, ultrasonic activation can be considered a more effective approach for improving irrigant dynamics and debris removal in complex root canal systems. Its incorporation into clinical practice could enhance treatment predictability and the long-term success of root canal therapy. Continued research focusing on activation parameters and irrigant properties may further optimize cleaning efficiency and procedural safety in endodontic practice.

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