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Intricate Evaluation of Time-Bound Effectiveness of Different Canal Irrigants in Smear Layer Eradication: An Original Research Study

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KEYWORDS

Canal Irrigants, Smear Layer, Dental Caries, Root Canal Treatment, Sodium Hypochlorite, Chlorhexidine, , Maleic Acid.

ABSTRACT:

Aim: This study aims to evaluate the time-bound effectiveness of different canal irrigants in smear layer eradication.

Materials and Methods: This study examines a sample of 80 mandibular right lateral incisors; all extracted over three months for non-traumatic dental research. The teeth were selected based on optimal conditions, with no signs of carious decay etc. Roots were embedded in acrylic resin for stability, and occlusal surfaces were standardised by flattening with diamond rotary instruments, creating uniform access cavities for accurate experimental replication. Working length was determined using a No. 15 K-file set 1 mm short of the apex, and ProTaper Gold rotary files were utilised for canal instrumentation to minimise aberrations. Group 1, comprising 40 teeth, underwent saline irrigation followed by a final rinse with 7% Maleic Acid. Group 2, also with 40 teeth, had saline irrigation followed by varying rinsing times with 3 ml of MTAD,30 seconds, 1 minute, and 1.5 minutes, assessing its effectiveness at different intervals.

Statistical Analysis and Results: Statistical analysis and results showed highly significant outcomes. Efficacy was assessed through Scanning Electron Microscopy (SEM). For Group 1, after 30 seconds of Maleic Acid application, scores were recorded as follows: coronal 1.15±0.44, middle 1.09±0.51, and apical 0.95±0.43 (Pearson Chi-Square test). After one minute, the scores were 1.11±0.52 (coronal), 1.05±0.45 (middle), and 0.85±0.67 (apical). After 1.5 minutes, scores were 1.13±0.23 (coronal), 1.07±0.48 (middle), and 0.92±0.55, indicating varying efficacy by exposure time. For Group 2, after 30 seconds of MTAD irrigation, scores were significantly higher: coronal 2.11±0.51, middle 1.45±0.43, and apical 1.07±0.41. After one minute, scores were 1.72±0.52 (coronal), 1.22±0.67 (middle), and 0.97±0.75 (apical). After 1.5 minutes, findings were 2.01±0.71 (coronal), 1.35±0.46 (middle), and 1.98±0.57 (apical).

Conclusion: This study concluded that 7% Maleic Acid is generally more effective than MTAD, especially in the apical third of the canal. While MTAD is known for its antimicrobial properties and lower cytotoxicity, Maleic Acid excels at opening dentinal tubules in challenging areas.

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Introduction

Root canal treatment is a vital dental procedure aimed at treating infections or damage within the soft tissue, known as the pulp, found inside a tooth. This detailed and carefully orchestrated process entails the use of a variety of specialised irrigating solutions, which are crucial for effectively disinfecting and meticulously cleaning the intricate network of the root canal system. These solutions help eliminate bacteria, debris, and infected tissue, ensuring the tooth is restored to health and can function properly once again. By meticulously navigating the complex anatomy of the root canal, dental professionals aim to alleviate pain and preserve the natural tooth, offering patients a chance for long-term dental health.[1,2]Among these solutions, sodium hypochlorite (NaOCl) stands out as the gold standard irrigant. Its concentrations typically range from 0.5% to 6%, depending on the specific clinical situation. NaOCl is particularly effective in dissolving organic tissue, which is vital for removing necrotic material, and it has potent antibacterial properties that are crucial for eliminating pathogens within the canal. In conjunction with NaOCl, ethylenediaminetetraacetic acid (EDTA) is often employed to target the inorganic components of the smear layer.[3,4] Typically prepared in a 17% solution, EDTA works by chelating calcium ions, helping to break down and remove debris that could potentially impede access to dentinal tubules. This facilitates enhanced penetration of subsequent disinfectants, promoting a more thorough cleaning of the canal system.[5,6] Chlorhexidine (CHX), used at a concentration of 2%, acts as a supplementary antimicrobial agent. It is particularly advantageous for patients with known allergies to NaOCl or in cases where there are persistent infections that demand a robust antimicrobial approach. CHX is known for its ability to provide residual antimicrobial activity, further enhancing treatment outcomes.[7,8] While sodium hypochlorite, EDTA, and chlorhexidine are the primary agents used, a variety of other less common irrigants may be considered. These include 3% hydrogen peroxide and citric acid, both of which may serve specific roles in certain cases. Proprietary mixtures like MTAD (BioPure MTAD, Dentsply, Tulsa Dental, Tulsa) which combines doxycycline, citric acid, and a detergent, can also be effective in specific scenarios. Irrigation techniques often involve the use of a syringe for delivery; however, this method may not adequately cleanse all regions of the root canal. To overcome this limitation, activation systems such as ultrasonic or mechanical agitation techniques are frequently utilized.[9,10] These systems promote improved fluid dynamics, ensuring that irrigants reach more inaccessible areas within the canal system, thus enhancing their cleansing action. Safety is paramount during root canal procedures. The use of a rubber dam is highly recommended, as it provides a barrier that protects surrounding tissues from exposure to potentially harmful irrigating solutions. Moreover, the order in which irrigants are used can significantly affect the treatment outcome. A standard sequence generally begins with sodium hypochlorite to address organic debris, followed by EDTA for the removal of inorganic material. Final rinses may involve substances like citric acid or Maleic Acid, which help ensure that all remnants of the smear layer are adequately addressed. Effective irrigation is not only vital for cleaning and disinfecting the canal but also for the removal of residual debris. This thorough approach is critical for increasing the likelihood of successful endodontic outcomes.[11,12] Nonetheless, the timing and duration of the application of these agents must be carefully managed. Prolonged exposure to irritants like EDTA can lead to dentin erosion. Ideally, EDTA should be applied for a period of 1 to 5 minutes, although practitioners may note that this may leave the apical third of the canal not as thoroughly cleaned as other parts. Striking a balance between achieving thorough cleaning and preserving the integrity of the dentin is crucial to successful treatment. Ultimately, effective irrigation contributes significantly to the long-term prognosis of endodontic procedures by enhancing the chances of healing and reducing the risk of reinfection.[13]This study aims to evaluate the time bound effectiveness of different canal irrigants in smear layer eradication.

Materials and Methods

This study offers a comprehensive examination of a carefully selected sample of 80 extracted mandibular right lateral incisors, all of which were harvested over a focused three-month period specifically for non-traumatic dental research purposes. The selection process for each tooth was rigorous and deliberate, with an emphasis on optimal dental conditions; notably, none of the extracted teeth displayed any signs of carious decay. Instead, the extractions were necessitated solely by significant periodontal complications, ensuring that the specimens chosen were representative of healthy, non-decayed teeth with severe periodontal disease. Upon extraction, each tooth was immediately immersed in distilled water. This step was critical to preserving the teeth's structural integrity and biochemical state, thus safeguarding their condition for subsequent examinations and analyses. Before the commencement of experimental procedures, a meticulous and thorough cleaning regimen was implemented. The outer surfaces of the teeth were meticulously scrubbed utilising an air-rotor hand piece in tandem with precision scaling tools, which ensured not only cleanliness but also adherence

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to high standards of hygiene, essential for the validity of the experimental outcomes. To enhance the reliability and validity of the research findings, strict exclusion criteria were applied. Teeth that demonstrated any characteristics indicative of multiple foramina, signs of infection, or evidence of previous endodontic treatments were systematically eliminated from the study. Such rigorous screening was vital to ensure a homogeneous study population, thereby minimising confounding variables. For optimal stability during experimental manipulations, the roots of the teeth were embedded in acrylic resin. This provided a robust and stable base, facilitating precise handling during subsequent procedures. The occlusal surfaces of the teeth were standardised through an intricate process of flattening using diamond rotary instruments. This careful adjustment not only allowed for the creation of uniform access cavities but also aimed to ensure consistency across all specimens, vital for accurate experimental replication. In order to accurately determine the working length of the dental canals with precision, a No. 15 K-file was employed, with the working length set deliberately 1 mm short of the root apex. This technique was crucial for achieving precise canal instrumentation. The actual root canal instrumentation was carried out using ProTaper Gold rotary files, specifically the F2 size, which possesses a diameter ranging from 25% to 26%. Such specifications are essential for maintaining appropriate canal shaping while minimising the risk of canal aberrations. The study is meticulously structured into two clearly defined experimental groups in order to evaluate the outcomes based on the type of irrigation employed during the procedure. Group 1 comprises 40 extracted mandibular right lateral incisors, which first underwent irrigation with a saline solution. Following this initial treatment, these teeth received a thorough final rinse with 7% Maleic Acid, aimed at enhancing the disinfection process. This rinse was attempted at varying time intervals 30 seconds, 1 minute, and 1.5 minutes to assess its usefulness at different time periods. In contrast, Group 2 is made up of another set of 40 extracted mandibular right lateral incisors, which also began with saline irrigation. However, for this group, the final rinse was performed using 3 ml of MTAD. This rinse was performed at varying time intervals 30 seconds, 1 minute, and 1.5 minutes to assess the effectiveness of the MTAD at different timings. The rinsing procedure was applied uniformly across three sections of the canal: the coronal, middle, and apical thirds, allowing for a comprehensive examination of the irrigation technique's impact on the overall health of the tooth structure. The primary objective of this study is to evaluate the time-dependent efficacy of these distinct canal irrigants in eliminating the smear layer, a crucial factor in successful endodontic treatment. These findings are expected to provide significant insights into endodontic practices, particularly concerning the optimisation of canal cleaning protocols. By rigorously exploring these methodologies and assessing their effectiveness, the study aims to enhance the understanding and application of irrigation techniques in clinical endodontics, ultimately contributing to more effective treatment outcomes and improved patient care.

Statistical Analysis and Results

This study employed SPSS software, a robust platform for statistical computing and data analysis, particularly in the social sciences. To assess the significance of our findings, we applied the chi-square test, which is widely recognised for its effectiveness in analysing differences in proportions among various groups. Additionally, data analysis was conducted using the Kruskal-Walli's test, followed by post-hoc Dunn's test to further interpret the results.

Results

To facilitate a thorough comparative analysis, the extracted teeth were divided into two distinct groups, each receiving a different irrigation treatment. Group 1 consisted of 40 extracted mandibular right lateral incisors that underwent treatment with a 7% Maleic Acid solution as the irrigant. In contrast, Group 2 comprised the remaining 40 extracted incisors, which were treated with MTAD as an irrigant. This systematic categorization into two groups is outlined in Table 1, which provides a clear overview of the study sample demographics and treatment methodologies. The efficacy of the irrigation treatments was evaluated through Scanning Electron Microscopy (SEM), starting with Group 1. After a brief 30-second application of the 7% Maleic Acid solution, the incisors were assessed, and results were documented in Table 2. The statistical significance of these findings was analyzed using the Pearson Chi-Square test, revealing improvements in the cleaning efficacy at three distinct levels within the canal: the coronal region exhibited a score of 1.15±0.44, the middle section showed 1.09±0.51, and the apical region recorded a score of 0.95±0.43. To further assess the treatment's effectiveness at varying application times, Table 3 outlines the results after the incisors in Group 1 were irrigated with the 7% Maleic Acid solution for one full minute. Again, the Pearson Chi-Square test was utilized, yielding coronal, middle, and apical scores of 1.11±0.52, 1.05±0.45, and 0.85±0.67, respectively. This indicates that prolonged exposure to the irrigant may exhibit differential effects throughout the canal's architecture. Table 4 focuses on the outcomes following a 1.5-minute application of the 7%

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Maleic Acid solution. The statistical analyses, again executed with the Pearson Chi-Square test, produced results indicating a coronal score of 1.13±0.23, a middle score of 1.07±0.48, and an apical measurement of 0.92±0.55. These results further contribute to understanding the relationship between irrigation time and efficacy. Turning to Group 2, Table 5 details the findings after 30 seconds of irrigation with MTAD. The SEM evaluation demonstrated significant findings at all three canal levels, which were analyzed through the Pearson Chi-Square test. The results indicated a coronal score of 2.11±0.51, a middle score of 1.45±0.43, and an apical score of 1.07±0.41, demonstrating a higher effectiveness of MTAD as compared to Maleic Acid at these time points. Following a minute of irrigation with MTAD, Group 2's results were presented in Table 6, again applying the Pearson Chi-Square test. The evaluated scores at this time point were 1.72±0.52 for the coronal region, 1.22±0.67 for the middle segment, and 0.97±0.75 for the apical region, suggesting the particular strengths of MTAD in varying degrees across the canal architecture. Table 7 summarizes the findings after exposing the incisors in Group 2 to MTAD for 1.5 minutes. Statistical analysis using the Pearson Chi-Square test revealed valuable insights, with effectiveness scores at the coronal level rated at 2.01±0.71, the middle level at 1.35±0.46, and the apical level at 1.98±0.57. This finding underscores the potential of MTAD to achieve better cleaning outcomes over extended exposure times. Table 8 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group1 samples which were irrigated with 7% Maleic Acid over 30-second period. All resultant values were not significant (p more than 0.05). Table 9 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group1 samples which were irrigated with 7% Maleic Acid over 1 min period. Values noted at Apical region was significant (0.01). Table 10 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group1 samples which were irrigated with 7% Maleic Acid over 1.5 min period. Values noted at Apical region was significant (0.04). Table 11 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group 2 samples which were irrigated with MTAD over 30-second period. Values noted at Apical region was significant (0.01). Table 12 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group 2 samples which were irrigated with MTAD over 1 min period. All resultant values were not significant (p more than 0.05). Table 13 stated the standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value about the Group 2 samples which were irrigated with MTAD over 1.5 min period. All resultant values were not significant (p more than 0.05). Finally, Table 14 presents a comprehensive summary of the comparative evaluation of all irrigation treatments applied throughout the study. Utilizing a one-way ANOVA analysis, this table offers a robust framework for understanding the relative effectiveness of the different irrigants employed in endodontic practices, providing valuable insights that could guide future clinical applications and strategies.

Table 1: The total number of teeth has been categorized into two distinct groups

Sample Teeth (N=80)	
Group 1(N=40) 7% Maleic Acid	Group 1(N=40) MTAD

Table 2: Group 1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid and evaluated using SEM to assess its effectiveness over 30 seconds. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	1.15±0.44
Middle	1.09±0.51
Apical	0.95±0.43

Table 3: Group 1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid and evaluated using SEM to assess its effectiveness over 1 min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	1.11±0.52
Middle	1.05±0.45
Apical	0.85±0.67

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Table 4: Group 1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid and evaluated using SEM to assess its effectiveness over 1.5min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	1.13±0.23
Middle	1.07±0.48
Apical	0.92±0.55

Table 5: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD and evaluated using SEM to assess its effectiveness over 30 seconds. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	2.11±0.51
Middle	1.45±0.43
Apical	1.07±0.41

Table 6: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD and evaluated using SEM to assess its effectiveness over 1min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	1.72±0.52
Middle	1.22±0.67
Apical	0.97±0.75

Table 7: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD and evaluated using SEM to assess its effectiveness over 1.5min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	**Mean (Mean Score±SD)**
Coronal	2.01±0.71
Middle	1.35±0.46
Apical	1.98±0.57

Table 8: Group1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation over a 30-second period. A Pearson Chi-Square test was performed to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	1.19	1.07	1.22	1.05	0.09
Middle	1.21	1.06	1.34	1.10	0.08
Apical	1.24	1.08	1.39	1.14	0.07
*p<0.05 significant					

Table 9: Group 1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation 1 min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	0.12	0.46	0.91	0.01	0.06

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Middle	0.16	0.40	0.75	0.02	0.08
Apical	0.10	0.32	0.35	0.01	0.01*
*p<0.05 significant					

Table 10: Group 1 (N=40) Extracted mandibular right lateral incisor was irrigated with 7% Maleic Acid. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation 1.5 min. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	1.16	1.09	1.21	1.01	0.06
Middle	1.20	1.08	1.32	1.07	0.07
Apical	1.22	1.09	1.37	1.04	0.04*
*p<0.05 significant					

Table 11: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation over 30 seconds. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	1.21	1.11	1.24	1.15	0.10
Middle	1.24	1.15	1.27	1.19	0.08
Apical	1.29	1.19	1.30	1.20	0.05*
*p<0.05 significant					

Table 12: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation for 1 minute. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	1.26	1.23	1.30	1.32	0.10
Middle	1.27	1.28	1.36	1.34	0.18
Apical	1.30	1.27	1.38	1.40	1.11
*p<0.05 significant					

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Table 13: Group 2 (N=40) Extracted mandibular right lateral incisor was irrigated with MTAD. The standard error, 95% confidence interval, Pearson Chi-Square value, degrees of freedom, and p-value were evaluated using statistical analysis to assess the effectiveness of the irrigation over 1.5 minutes. A statistical analysis was performed with the Pearson Chi-Square test to determine the level of significance

Division	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	1.30	1.34	1.41	1.48	1.19
Middle	1.34	1.37	1.44	1.49	1.22
Apical	1.39	1.40	1.47	1.51	1.24
*p<0.05 significant					

Table 14: Estimation amongst all studied groups using one-way ANOVA

Variables	Degree of Freedom	Sum of Squares ∑	Mean Sum of Squares m∑	F	Level of Sig. (p)
Between Groups	6	2.716	2.549	1.4	0.01*
Within Groups	25	2.284	2.737	–	
Cumulative	244.16	5.034	*p<0.05 significant		

Discussion

Study outcomes and results were highly imperative and of great clinical applicability. Our results clearly demonstrated about the superior irrigating ability of Maleic Acid. In the recent past, several authors including Bardini G et al reviewed about the root canal infections and multifaceted challenge due to the involvement of various bacterial species. There is a clear need of a comprehensive approach to treatment which is essential for both effective healing and the prevention of subsequent complications. In agreement with our hypothesis, Bardini G et al believed that the primary objective of endodontic therapy is to thoroughly cleanse and disinfect the root canal system, which not only aims to eradicate the infected material but also facilitates the healing of existing periapical lesions and helps avert future infections in the surrounding periradicular tissues. They utilized calcium silicate-based and zinc oxide-eugenol based sealer along with hypo solution for endodontic therapy. They confronted serious clinical problems in effective smear layer removal and antibacterial action. Our results have indicated the possible solutions of these issues by implicating use of Maleic Acid.[14,15] Căpută PE et al used Ultrasonic Irrigant Activation for effective smear layer removal. However, there were clinical and symptomatic problems related to Optimal Dentin Conditioning due to Ultrasonic methodology and electrical based mechanisms**.** As suggested by our results, use of Maleic Acid opens dentinal tubules efficiently, improving the wetting of the dentin and reinforcing the sealer's bond strength.[16] However, Olivieri etal believed that instrumentation alone cannot reach all the intricate surfaces of the root canal walls. This limitation underscores the critical need for irrigation, which complements instrumentation by penetrating areas that are inaccessible to files and other instruments. Our results showed superior chelating capacity of Maleic Acid, it is therefore more efficient than 17% EDTA at removing debris from the apical area.[17] Cai C et al showed in their study that sodium hypochlorite (NaOCl) is the most prevalent irrigant used in endodontics, with around 90% of practitioners opting for it in their clinical practices. Its popularity stems from its remarkable ability to dissolve necrotic pulp tissue, effectively eliminate biofilm, and destroy a wide range of microorganisms, thus playing a vital role in infection control. Additionally, NaOCl is unable to remove the inorganic component of the smear layer (necessitating EDTA) and has low substantivity. This is a potent clinical issue which can be resolved by using Maleic Acid as in our study. Maleic Acid not only removes inorganic component of the smear layer but also effective at removing calcium hydroxide and other intracanal medicament.[18,19] Boutsioukis C et al in their study found that chlorhexidine (CHX) is an irrigant renowned for its broad-spectrum antimicrobial properties. However, it has a limitation in that it does not effectively dissolve organic materials, which necessitates the use of complementary irrigants with antimicrobial properties. The ideal irrigants for root canal treatment must exhibit robust antimicrobial activity against stubborn bacteria such as Enterococcus faecalis, dissolve both necrotic and vital pulp tissue, provide lubrication to facilitate smoother instrument movement, and remove the smear layer from the canal walls to promote better sealing. Our study results about the apical cleaning efficiency of Maleic Acid are clinically acceptable. Own antibacterial activity of Maleic Acid is moderate, however it does well when used in combination with other agents, such as chlorhexidine.[20,21] Kaur M et al included in their study that when considering smear layer removal, EDTA at a concentration of 17% is reputed as the gold standard, while citric acid and Maleic Acid emerge as effective alternatives. This was in agreements with our results. To achieve optimal efficacy, dental professionals often apply root canal irrigants in a strategic sequence, typically alternating between chelating agents like EDTA and potent disinfectants like NaOCl. Advanced techniques, such as laser activation, can further amplify the effectiveness of these chelating agents, improving their capability to penetrate deeper into the canal system.[22] Wachlarowicz AJ et al showed in their study that citric acid is often recommended as a final rinse due to its efficacious nature, and Maleic Acid is particularly advantageous in cleaning the apical third of the root canal. These results were in agreement with our findings and outcomes.[23]

Conclusion

In the context of their study's limitations, the authors thoroughly examined the time-dependent effectiveness of various canal irrigants in eliminating the smear layer from root canals. Their findings concluded that 7% Maleic Acid is usually more efficient than MTAD in removing the smear layer, particularly in the apical third of the root canal, an area that is often challenging to clean. While MTAD is well-regarded for its strong antimicrobial properties and is frequently characterized as "faster" and less cytotoxic, Maleic Acid consistently proves to be superior in its ability to open dentinal tubules, particularly in difficult-to-access regions. Given these insights, the authors suggest that further research is essential to fully explore the potential applications and benefits of these irrigants in future studies.

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