Dentistry 3000

Vol 13, No 1 (2025)
ISSN 2167-8677 (online)
DOI 10.5195/d3000/2025.921

Evaluation of Irrigation Solutions and Activation Techniques in Endodontic Therapy

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Abstract

The study examined the current practices of irrigation and activation techniques used by dental professionals in Iraq, focusing on the selection and application of chemical irrigants and adjunct techniques during endodontic therapy. A cross-sectional survey was conducted among 108 participants, including general dental practitioners (GDPs) and endodontic specialists. The survey aimed to capture detailed information about the choice of irrigation solutions, the duration, depth, and pressure of irrigation, and the adjunctive techniques employed, such as ultrasonic and sonic activation. The findings reveal that while sodium hypochlorite remains the most used irrigant, advanced activation methods like passive ultrasonic irrigation (PUI) are underutilized despite their proven benefits. Additionally, most respondents adjust their irrigation protocols depending on canal anatomy, with an emphasis on tailored approaches to achieve optimal disinfection. The study highlights the need for better training and access to modern irrigation tools to improve treatment outcomes.

Open Access

Citation: Nema TG, et al. (2025) Evaluation of Irrigation Solutions and Activation Techniques in Endodontic Therapy. Dentistry 3000. 1:a001 doi:10.5195/d3000.2025.921
Received: May 1, 2025
Accepted: May 26, 2025
Published: June 27, 2025

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Introduction

The evolution of irrigation in endodontics has greatly impacted the success of root canal treatments, with advancements in irrigant solutions and activation methods playing crucial roles. Initially, endodontic irrigation relied heavily on sodium hypochlorite, a powerful tissue solvent with broad antibacterial properties, though its limitations in biofilm removal were soon recognized [1]. Over time, additional solutions like EDTA were introduced to address issues such as smear layer formation [2]. As root canal systems are complex, irrigants alone could not achieve complete disinfection, prompting the development of mechanical activation techniques like ultrasonic and sonic irrigation to enhance the penetration of solutions into the apical regions [3].

Recent innovations have focused on improving the efficiency of these activation methods. For example, photon-induced photoacoustic streaming (PIPS) using lasers has shown promise in improving canal cleaning [4], and passive ultrasonic irrigation (PUI) has been recognized for its ability to reach difficult canal areas [5]. Newer solutions like QMix and MTAD also contribute to effective antimicrobial properties and smear layer removal [6]. Studies have shown that these newer techniques, in conjunction with appropriate irrigants, significantly enhance the disinfection process and reduce post-operative complications [7]. Furthermore, the combination of multiple irrigation systems has proven beneficial, as no single solution can fully achieve optimal results on its own [8].

This ongoing evolution highlights the importance of refining both irrigation protocols and activation devices to improve the outcomes of endodontic treatments. As endodontic science continues to progress, the need for effective, biocompatible, and efficient irrigation solutions will remain central to achieving long-term success in root canal therapy [9].

Challenges in effective root canal irrigation limitations of current irrigation methods and the need for activation systems root canal irrigation remains a significant challenge due to the intricate anatomy of the canal system, including narrow spaces and lateral canals

that make it difficult to achieve thorough disinfection [10]. Traditional syringe irrigation methods, though widely used, often fail to adequately reach the apical third of the canal, which is crucial for effective treatment [11]. This limitation has prompted the development of advanced activation systems like passive ultrasonic irrigation (PUI) and laser-assisted techniques, which have shown promise in improving the effectiveness of irrigant delivery [12]. These systems are particularly useful in cleaning complex canal systems and ensuring that the irrigant reaches areas that syringe irrigation may miss [13]. While these newer systems improve bacterial reduction and debris removal, no method has proven completely effective, especially in areas such as the isthmus and the apical third of the root canal [14]. Furthermore, studies have indicated that combining multiple techniques, such as PUI with laser activation, may offer superior results compared to single-method activation [15]. These innovations highlight the ongoing need for improved irrigation systems and activation protocols to ensure optimal disinfection of the entire root canal system [16]. Despite advancements, achieving complete eradication of microbial life, particularly in the apical and isthmus regions, remains a formidable challenge [17]. The integration of advanced technologies such as photodynamic therapy and next-generation irrigation devices could offer more promising solutions for these challenges in the future [18].

The study aims to assess the effectiveness of commonly utilized irrigation solutions, including sodium hypochlorite and ethylenediaminetetraacetic acid (EDTA), in achieving significant bacterial reduction, smear layer removal, and the ability to penetrate complex root canal systems. Additionally, the study seeks to investigate the impact of various activation systems, such as ultrasonic, sonic, and laser-based devices, on the distribution and efficacy of irrigants within the root canal, particularly in areas like the apical third, where traditional irrigation often proves less effective. The research further aims to compare the efficacy of manual dynamic activation methods with machine-assisted activation systems, such as passive ultrasonic irrigation and photoactivated disinfection, in enhancing root canal cleanliness and disinfection. Ultimately, this study will explore the role of endodontic irrigants and activation methods in preventing reinfection of the root canal system and promoting long-term treatment success. By examining these factors, the study seeks to contribute to the understanding of how modern irrigation protocols can minimize post-treatment complications and improve the overall success rates of root canal therapy.

Materials and Methods

Study Design and Setting

This cross-sectional questionnaire-based survey was conducted between February 10th and March 10th, 2023. The study targeted dental practitioners and endodontic specialists across Iraq, following approval from the Research Ethics Committee of the College of Dentistry. The survey was distributed electronically to reach dental professionals practicing in both government and private sectors. Government sector dentists were recruited from dental hospitals and primary healthcare centers, while private sector practitioners were randomly selected from private hospitals and polyclinics across Iraq.

Study Population and Sampling

The study population comprised general dental practitioners (GDPs) and endodontic specialists actively practicing in Iraq. The final sample included 108 respondents, with 92 GDPs representing 85.2% of participants and 16 endodontic specialists accounting for 14.8%. The participants represented a broad spectrum of clinical experience ranging from one month to 30 years across both government and private dental sectors. Twenty-six respondents (24%) were public sector workers, while the remainder practiced in private settings.

Questionnaire Development and Structure

The questionnaire was meticulously designed to capture comprehensive information about irrigation practices during endodontic treatment. The instrument was structured into three main domains with a total of 16 questions, incorporating both open-ended and close-ended formats. The demographic domain gathered information about practice settings and professional rankings. The chemical irrigant utilization domain explored aspects such as primary irrigation solution selection, concentrations used, reasons for selection, and technical parameters of irrigation procedures. The irrigation adjunct utilization domain investigated the use of various irrigation enhancement techniques and devices. The questionnaire utilized multiple response formats including numerical rankings, multiple choice questions, and multiple selections with options for free text answers where appropriate. The diverse question structure that was developed collected both the quantitative and qualitative data on irrigation practices. Data Collection Process Professional networks, dental associations and other sources were used to disseminate the electronic questionnaire. Responses were collected over a one-month period and participants were given clear instructions on how to complete it. The survey was meant to be comprehensive in scope but concise enough that response would be encouraged. Data accuracy and completeness were assured using electronic format as it offered easy access and submittance of responses.

Variables and Measurements

Some of the key variables associated with the practice of irrigation were measured in the study. The study focused on the outcome variables comprised of the irrigation solutions chosen by the practitioners, the concentrations used, delivery methods chosen, and the use of activation techniques. The questionnaire was able to collect detailed information about the types of solutions utilized, hence, sodium hypochlorite, chlorhexidine, EDTA, saline and various combinations of the same. The specific measurement included the solution concentrations for NaOCl (≥5.25, 2.5–5, 0.5%), the volume used per canal, the selection of needle gauge (27, 30, and other), measured irrigation depth (measured from apex) and duration of irrigation per canal.

Statistical Analysis

Data analysis was conducted using Statistical Package for the Social Sciences (SPSS) version 26.0 for Windows. The analysis focused on descriptive statistics to characterize current irrigation practices among dental professionals. Results were presented as frequencies and percentages, with visual representations through pie charts and bar graphs to illustrate distribution patterns of various practices. This approach allowed for clear presentation of trends in irrigation solution selection, concentration preferences, and technical aspects of delivery.

Quality Control Measures

The study implemented several quality control measures to ensure data reliability. The questionnaire underwent expert review to establish content validity and ensure comprehensive coverage of irrigation practices. Electronic data collection minimized entry errors and facilitated standardized response formats. Regular data verification processes

were implemented to maintain data integrity throughout the collection period.

Ethical Considerations
The study protocol received approval from the Research Ethics Committee of the College of Dentistry. Participant confidentiality was maintained through anonymous data collection, and all responses were handled with strict confidentiality. Participation was voluntary, and respondents had the right to withdraw at any time. Data storage adhered to institutional security protocols to protect participant information.

Study Limitations
The study acknowledged certain limitations inherent in its design. The self-reported nature of the data may have introduced recall bias. The electronic distribution method, while efficient, might have limited reach to some practitioners without reliable internet access. The voluntary participation aspect could have introduced selection bias. These limitations were addressed through standardized questionnaire format and clear instructions for completion.

Timeline and Resources
Data collection occurred over a one-month period from February 10th to March 10th, 2023. The study utilized electronic survey platforms for data collection and SPSS software for analysis. Professional networks and dental associations facilitated questionnaire distribution. The research team managed data collection, entry, and analysis throughout the study period.

Results

The analysis of 108 completed self-reported questionnaires revealed a clear distribution pattern among dental practitioners. Most respondents were general dental practitioners (GDPs), comprising 92 participants and representing 85.2% of the total sample. In contrast, endodontic specialists made up a notably smaller proportion, with only 16 participants accounting for 14.8% of the total respondents. This distribution pattern demonstrates the predominance of general practitioners compared to specialists among the study participants. The data reflects the composition of dental practitioners who participated in the survey during the study period between February and March 2023, providing a snapshot of the professional distribution among respondents involved in endodontic procedures in Iraq.
The analysis of practice settings among the study participants revealed that most dental practitioners worked in the private sector, representing 76% of the total respondents. In contrast, public sector workers constituted a smaller proportion of the sample, with twenty-six participants accounting for 24% of the total respondents. This distribution pattern shows the predominance of private practice among the surveyed dental professionals during the study period between February and March 2023, providing a clear representation of the practice setting distribution among dental practitioners performing endodontic procedures in Iraq.
The analysis of chemical solutions usage revealed that sodium hypochlorite (NaOCl) alone was used by twenty-nine respondents representing 26.9% of participants. The combination of NaOCl with EDTA and saline was reported by twenty-one participants accounting for 19.4%, while fifteen practitioners (13.9%) used NaOCl combined with EDTA, chlorhexidine, and saline. The use of NaOCl with EDTA only was documented by seven respondents (6.5%), and NaOCl with saline was utilized by six participants (5.6%). A smaller proportion of practitioners, representing 4.6%, used NaOCl with chlorhexidine and EDTA. The combination of NaOCl with chlorhexidine was employed by two respondents (1.9%), while NaOCl with chlorhexidine and saline was used by three practitioners (2.8%). Other combinations of irrigants, including various permutations of NaOCl, EDTA, chlorhexidine, and saline, were each used by one to two respondents, collectively accounting for the remaining percentage of chemical solution usage among the study participants during the survey period.
The analysis of NaOCl concentration usage revealed that most respondents (55.6%) used full-strength NaOCl with concentrations ≥5.25%. A smaller proportion of practitioners (19.4%) utilized NaOCl concentrations between 2.5-5%, while 22.2% of respondents used 0.5% concentration. A minimal number of participants (2.8%) reported not knowing the concentration of NaOCl they used in their practice. Regarding distribution of chlorhexidine (CHX) concentration usage among participants, 46.3% reported not using CHX at all in their endodontic treatments, while 38% used 2% CHX concentration, and 15.7% utilized 0.2% concentration. When participants were asked about their reasons for selecting irrigation solutions, antibacterial capability emerged as the primary factor, cited by 55.6% of respondents. Tissue dissolution ability was the second most important reason, reported by 33.3% of participants. Biocompatibility was considered the main factor by 7.4% of respondents, while substantivity was cited as the primary reason by only 3.7% of the participants.
The analysis of smear layer removal practices revealed that most respondents, comprising 87 participants (80.6%), aimed to remove the smear layer during endodontic therapy, while 21 participants (19.4%) did not attempt smear layer removal in their practice. 76 respondents, representing 70.4% of the participants, reported that their selection of irrigant would change depending on whether the apex is open or closed, whereas 32 participants (29.6%) maintained the same irrigation protocol regardless of the apical status. These findings provide a clear representation of the practitioners' approaches to smear layer management and their consideration of apical anatomy when selecting irrigation solutions during the study period between February and March 2023.

Regarding needle gauge selection, fifty respondents (46.3%) used 27-gauge needles, while thirty-two participants (29.6%) preferred 30-gauge needles. Twenty-four practitioners (22.2%) utilized 25-gauge needles, and only two respondents (1.9%) used other needle sizes. Concerning the depth of needle penetration during irrigation, forty-three participants (39.8%) irrigated to 3 mm from the apex, while twenty-six respondents (24.1%) irrigated to 4 mm from the apex. Twenty-three practitioners (21.3%) irrigated to 2 mm, and sixteen participants (14.8%) irrigated to 1 mm from the apex. Regarding irrigation duration, forty-four respondents (40.7%) applied irrigant for 30 seconds to 1 minute per canal, while twenty-five participants (23.1%) irrigated for over 2 minutes. Twenty-five practitioners (23.1%) irrigated for less than 30 seconds, and fourteen respondents (13%) applied irrigant for 1-2 minutes per canal. In terms of irrigation volume, fifty-two participants (48.1%) used 5 mL of irrigating solution, while twenty-eight respondents (25.9%) used 2 mL. Sixteen practitioners (14.8%) utilized 10 mL, and twelve participants (11.1%) used other volumes of irrigating solution during their endodontic procedures.
The analysis of adjunct usage during irrigation revealed that sixty-one respondents (56.5%) reported using adjuncts to irrigation, while forty-seven participants (43.5%) did not utilize any adjuncts during their endodontic procedures. The distribution of different techniques used for irrigation adjuncts, where manual agitation was the most employed method reported by forty-nine participants (45.4%), followed by ultrasonic activation used by twenty-six respondents (24.1%). Sonic activation and subsonic activation were utilized by smaller proportions of practitioners, with seven participants (6.5%) using each method. The combination of ultrasonic activation with manual agitation was reported by seven respondents (6.5%), while negative pressure irrigation systems such as EndoVac were used by three

participants (2.8%). Various other combinations of activation techniques were each employed by one to two practitioners, representing smaller percentages of the total respondents during the study period.

The analysis of adjuncts to irrigation usage revealed that manual agitation was the most frequently used technique, employed by 45.4% of respondents, followed by ultrasonic activation which was utilized by 24.1% of participants. Sonic activation and the combination of ultrasonic activation with manual agitation were each used by 6.5% of practitioners. Negative pressure irrigation systems such as EndoVac and subsonic activation combined with manual agitation were each employed by 2.8% of respondents. Several combinations of techniques were used by smaller proportions of participants, with negative pressure combined with manual agitation, sonic activation with manual agitation, sonic activation with subsonic activation, and ultrasonic activation with sonic activation each being utilized by 1.9% of respondents. The remaining combinations, including subsonic activation alone, ultrasonic activation with sonic activation and negative pressure with manual agitation, ultrasonic activation with subsonic activation, and ultrasonic activation with subsonic activation and manual agitation were each used by 0.9% of practitioners. Other unspecified techniques accounted for 0.9% of responses, bringing the total to 100% of surveyed participants.

Regarding the preference for using adjuncts to irrigation in different endodontic treatments, most respondents comprising fifty-nine participants (54.6%) reported using adjuncts in all cases of endodontic treatment. Thirteen practitioners (12%) used adjuncts specifically for non-surgical root canal treatment, while twelve respondents (11.1%) employed adjuncts only during non-surgical root canal re-treatment procedures. Twenty-four participants (22.2%) indicated that they did not use any adjuncts to irrigation during their endodontic procedures. These findings represent the distribution of adjunct usage preferences among the surveyed dental practitioners during the study period between February and March 2023.

Discussion

The scientific rationale behind this study lies in the critical role of irrigation solutions and activation techniques in the success of endodontic therapy, particularly in root canal treatments. Effective irrigation is essential for thorough disinfection and the removal of debris and biofilm from complex root canal systems. With the development of new irrigation technologies, full completion of disinfection is not achieved hard to reach areas such as the apical third and lateral canals. The current methods, notably syringe irrigation, have been well described as being limited in delivering cleaning to these areas resulting in incomplete cleaning as well as possible post treatment complications. To overcome these limitations, over the years, a variety of innovation was developed, for instance different irrigants as well as mechanical activation, such as passive ultrasonic irrigation (PUI) and laser-based systems. Currently, these newer techniques are adopted and integrated with varying levels of differences between dental professionals because of factors like familiarity, cost and training. The aim of this study is therefore to determine and evaluate the present knowledge, attitudes and practices of existing Iraqi dental professionals concerning the endodontic irrigation methods.

The scientific problem considered in this study is the lack of implementation of advanced irrigation techniques and solutions once it is known that these techniques and solutions can improve the cleaning and disinfection of root canals. Although literature supports use of newer techniques, a significant gap exists between them and their widespread use. This point of discrepancy emphasizes the difference between theoretical advantages of an advanced irrigation system and achievable practicality of an advanced irrigation system in a daily practice. On top of the complexity of root canal anatomy, these solutions must be highly effective and targeted, not provided by traditional methods. Central to this is why dental professionals still use older techniques despite being able to choose a superior solution.

The main objective of this study involves the identification of current practices, preferences and hurdles observed by dental professionals in Iraq in gutta percha and activation techniques for endodontic irrigation. Secondly, the study desires to investigate into the factors which are responsible for selection of irrigating terminals, the amount of the awareness of other, more efficient techniques of activation in consumers and the hurdles its application into the hands of professionals. A second goal involves assessing the connection between professional background, time on the job and choice of methods of irrigation and exploring the perceived effectiveness of these different systems.

This study uses methodology of distributing a structured questionnaire among the detached sample of dental professionals in Iraq. The questionnaire seeks to gather information on the various irrigation systems utilized, the technique of activation employed, the training received and the barriers to the integration of newer systems into professional practice. The advantage of this approach lies in its ability to have a complete knowledge of the current state of endodontic irrigation practices in the region and getting a precise picture of the contributing reasons why advanced techniques are not being adopted. This study is seeking to provide the findings to amplify whatever changes may be found necessary to improve irrigation protocols, training protocols, and overall outcomes of root canal therapy in Iraq and possibly other areas facing this dilemma.

Results from the present study on the distribution of chemical irrigation solutions show high reliance on sodium hypochlorite (NaOCl), usually used primarily because of its effectiveness in tissue dissolution and broad-spectrum antibacterial properties. Along with this, the study also shows a trend with many practitioners using NaOCl along with chelating agents such as ethylenediaminetetraacetic acid (EDTA) for the best effect of smear layer removal. This finding supports previous studies that show the need for combination therapies to gain control over the different aspects of the disinfection and cleaning in the root canal system discharge. For example, in [19] on the trends of irrigation practices among Saudi Arabian dental professionals, they also found that dental professionals favor some types of NaOCl, including full strength, which is in line with the present study findings about the dominance of NaOCl in clinical settings. Nevertheless, little to no (47%) of respondents in this study used adjuncts such as ultrasonic activation as has been among adjuncts only used by a minority of participants though adjuncts are known to increase irrigant penetration and overall cleaning [19].

Additionally, the findings of the present study regarding the use of NaOCl in valence with EDTA or saline are consistent with the previous work [6,20] on combination of sodium hypochlorite with chelators as EDTA or newer solutions such as MTAD, showing that the combination with chelators such as EDTA or newer solutions, like MTAD could enhance the antimicrobial activity of sodium hypochlorite as well as maximize the smear layer removal. The present findings indicate that though NaOCl still is the most preferred irrigant, newer irrigation like MTAD and QMix are being availed to equip these traditional solutions in overcoming some of these limitations, viz., the antimicrobial efficacy and biocompatibility of the treatment [6,20].

The present study also emphasizes another critical aspect, namely the variation of irrigation protocols on clinical factors such as root canal anatomy with 71% of the participants are dependent upon condition of the apex

either (open)or (closed). However, this variation is of particular importance since root canal complexity usually necessitates a more thorough disinfection protocol. This is in line with the results of the several past studies and recently a systematic review [21] highlighted the demand of anatomical specialization of the root canal system and specified the irrigation strategies accordingly. Additionally, 47 per cent of respondents utilized adjunctive activation techniques as found in other literature; these adjunctive activation techniques can significantly enhance the penetration of irrigants into complex canal system, particularly in the apical third of a canal which are difficult to reach.

Results of the current study showed a global trend in use of NaOCl as a primary irrigant, which is increasing in the interest for newer solutions as well as adjunctive techniques, as compared to other studies. Yet, as pointed out previously [20,21], although activation techniques are to more advanced, there is a gap between the adoption of such techniques and adjuncts because knowledge, training, and cost are still important barriers to their widespread use. The results of the study also suggest that dental professionals may be using these adjuncts below their potential to improve treatment outcomes and thus suggest that further education and evidence for such integration into routine practice may be required.

Finally, while the present study reaffirms the continued reliance on NaOCl as the basis of chemical irrigation in endodontics, it also highlights the need to use newer adjunctive solutions, as well as activation techniques, in combination with NaOCl for maximum effectiveness. It then compares to recent studies to illustrate both the consistency and the differences in clinical practices, especially as it pertains to the how recent studies adopted advanced irrigation protocols and new activation methods.

The present study examined the analysis of smear layer removal practices which revealed that eighty percent (80.6%) of the respondents performed to remove the smear layer during the endodontic therapy. This is a usual way in endodontics, as smear layer cleaning is necessary to ensure sealing root canal for proper antiseptics action of irrigants. Nevertheless, only a small percentage (19.4%) did not attempt to remove the smear layer, which could indicate either a lack of knowledge as how leaving the smear layer behind may cause unfavorable consequences or difficulties associated with the adoption of methods for its removal. Some previous studies have indeed found that so many practitioners have iteratively and somewhat idiosyncratically come to balance about how much they want to remove the smear layer, but to do so with widely discrepant methods. For instance, [22] showed that lasers activated irrigation (LAI) comprising 17% EDTA was very effective at removing the smear layer, which agrees with findings in the current study that the practitioners are becoming more and more conscious of the importance of more extensive cleaning procedures. Yet, these advanced methods are not applied universally, and this may explain the variability in practitioner practice observed in the present study.

The results of the present study also showed that many respondents (70.4%) modified their irrigation protocol based on the apical anatomy (open or closed apex). It is in accordance with current literature which acknowledges that the techniques of irrigation should be devised for the anatomical conditions of root canal. For example, these techniques have shown it more effective to reach areas near the apex with complex anatomy, such as cases commonly encountered when PUI and laser-activated irrigation are used. Studies such as those by Faus-Llácer et al. (2020) [23] demonstrated that paradigms of irrigant activation are most likely advantageous in the apical canal third, which tends to be inaccessible with conventional syringe irrigation alone. Thus, the present study's findings support those observations that practitioners are becoming very aware of the necessity to adjust to the bioform characteristics to achieve satisfactory results in root canal treatment. Nevertheless, just as in the work of Sahar-Helft et al. (2015) [22], the study also pointed out that not all practitioners adjust as much as they should, which may stem from, among others, limited access to high level tools or unfamiliarity with such methods.

To ensure that the full root canal length is properly disinfected, it is crucial that the variation in the use of irrigant based on the apical anatomy is utilized. Iandolo et al.'s (2023) study [24] established the point again that modern irrigation techniques such as PUI are useful in improving cleaning of the apical third, which is difficult to treat using traditional methods. Further, the findings from the current study regarding the variability of irrigation protocols also indicate that practitioners understand the need for more personalized approach, although practical barriers such as training and availability of new technologies could restrict more widespread implementation of these methods.

Finally, it is also concluded that most practitioners believe that canal cleaning and disinfection, including smear layer removal, is a critical component of root canal therapy, but that adoption of more advanced techniques such as ultrasonic and laser activated irrigation is inconsistent. The findings support existing research indicating the usefulness of such methods, but also impediments for their widespread use. Practitioners need to continue to educate themselves and have access to modern tools, now that the role of customized irrigation protocols in improving the outcome of endodontic treatments is understood.

The present study showed that of participants, 46.3% preferred 27-gauge needles, 29.6% 30-gauge needles and just 24% the market standard needles. This is a consensus in endodontics that favors the use of such smaller gauge needles (27 and 30), as they can pass through the intricate anatomy of root canal, especially in narrower canals. Although the studies may differ slightly on exact needle size and needle types, they have shown that smaller needles are better able to penetrate and have a better ability to put the irrigant down in those hard-to-reach areas, with possibly higher-pressure requirements. For instance, Boutsioukis et al (2007) [25], reported that smaller needles (30-gage) caused higher intra-barrel pressure while irrigating, that would then affect flow rate and delivery of the irrigant deeper into the canal, indicating that needle selection significantly affects the efficiency of irrigation.

The results of the current study regarding the depth of needle penetration show that 39.8% of the respondents irrigated to 3 mm from the apex, 24.1% to 4 mm, and 14.8% to just 1 mm. The concepts agree with a more general understanding that root canal disinfection requires deeper penetration of the irrigation, and in the apical third where cleaning has been shown to be most difficult. According to previous work [26], needle of penetration depth to the apical third alters apical preparation and is dependent on the employed gauges. The findings of their study demonstrate the clinical significance of taking the depth of placement into account when disinfecting, especially in the presence of complex canal anatomy [26].

Regarding irrigation duration, the current study identified various practices with 40.7% of the respondents irrigating 30 seconds - 1 minute per canal. As previously published [27], irrigation volume and duration were studied to understand the impacts on cleaning of the two parameters and the results indicated that the cleaner of choice is dependent on the volume used with the total time of irrigation adding to the volume used in the optimization. The results of the present study, almost a quarter of respondents took more than 2 minutes using irrigation, agree with recommendations that a longer duration may lead to better efficacy, especially, in complex canals for full antimicrobial action [27].

For irrigant used volume 48.1% of the respondents used 5 mL, 25.9% used 2 mL, 14.8% used 10 mL. Therefore, proper canal disinfection depends on the volume of irrigant. In wider or more curved canals, smaller volumes may not sufficiently irrigate the entire length of the canal. Although studies have demonstrated that greater irrigation volumes will enhance the flushing capacity of irrigants, and ability to remove debris and bacteria, the application of large volumes of irrigants without proper technique carries the risk of irrigant extrusion beyond the apex and subsequent post treatment complications. Consequently, the current study's findings that higher volumes help in the removal of the smear layer and that biofilm are also supported by previous research [28] that showed that the volume used directly affects the removal effect of the smear layer and biofilm.

Finally, the results of the present study agree with the current literature as far as the implications of the needle gauge, penetration depth, irrigation duration and volume in root canal disinfection. They are tightly interlinked to such an extent that optimizing them all can greatly improve treatment outcome. It is proposed such a comparison with other studies [25,27] served to further drive the importance of selection of appropriate irrigation parameters with respect to individual case, such as canal anatomy and the clinical objectives. More research is needed to further refine guidelines regarding the irrigation techniques that maximize clinical efficiency and minimize complications.

Regarding the adjunct techniques used for irrigation, the results of this study on how the participants used them show that 45.4 percent used manual agitation. This matches the conventional manner of increasing the efficiency of the irrigation solution. Manual agitation by gutta-percha cone is considered a simple, easy and reliable method to distribute irrigants throughout the root canal system. It is known to aid in debris removal and augment the chemical effects of the irrigant upon disinfection when used with sodium hypochlorite (NaOCl). Nevertheless, the present study also demonstrated that a relatively small percentage of practitioners (24.1%) used ultrasonic activation, even though this has been proven to increase irrigant flow and reach apical and lateral canal difficult medication. Ultrasonic activation is effective in improving post-operative outcomes and root canal cleanliness through facilitated deeper penetration of irrigants into the intricate canal anatomy [29].

Combinations of techniques including sonic activation with manual agitation (6.5%) and ultrasonic activation with manual agitation (6.5%), also were reported; however, these combinations were less used. These findings indicate the use of multi-modal irrigation techniques with the combination of mechanical activation and other methods to increase the canal disinfection efficiency. Hybrid approaches are proven to improve on the effectiveness of single methods of cleaning and disinfection, paying special attention to combined manual agitation with other activation techniques [30].

In addition, the study noted the use of negative pressure systems such as EndoVac and subsonic switch with manual agitation as at 2.8% of respondents. Negative pressure irrigation systems have become accepted as good at clearing debris into the apical region, notably decreasing the risk of extruded irrigants. Nevertheless, the costs associated with these systems and limited availability make these systems underused in the current study. Later, Plotino et al. (2016) [31] reported on the advantages of using negative pressure systems in removal of debris while minimizing the risk of extrusion.

The finding of the present study is in line with global trend in which manual agitation is a staple and newer and more sophisticated systems such as ultrasonic and negative pressure irrigation are slowly supplanting it. The present study`s finding echoed Sinusila and Minu (2019) [32] that mechanical activation systems improve debridement and cleaning efficiency; while manual techniques still dominate, the interest in integrating them to improve the endodontic treatment outcomes increases. Finally, we conclude that although the technology of manual irrigation agitation extends its use, more advanced devices, such as ultrasonic and negative pressure systems, are introduced. Manual agitation is a practical and reliable approach that can still be used but advancements in new technologies have a great potential for improving root canal disinfection, especially for complex canal anatomies. Future research and improved techniques in this area may improve the irrigation protocols and clinical outcome.

Conclusion

Based on the results, we conclude that sodium hypochlorite irrigation is still relied upon, but that the use of adjunctive activation methods is understood. Although these advances have made stride, the widespread adoption of these technologies continues to be hindered by a lack of familiarity with new technologies, cost and device availability. This shows the importance of continuing education for dental professionals and increases the need for more integration of higher infrastructure endodontic systems.

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