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ASSESSING CONVENTIONAL AND ULTRASONIC IRRIGATION FOR DEBRIS AND SMEAR LAYER REMOVAL IN PRIMARY TEETH: AN IN VITRO SCANNING ELECTRON MICROSCOPY STUDY

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ABSTRACT

This in vitro study compared the efficacy of conventional irrigation with a lateral vent needle using 2.5% sodium hypochlorite (NaOCl) versus ultrasonic irrigation with 2.5% NaOCl in removing debris and smear layer from primary molars. Twenty-eight primary molars were randomly assigned to two groups (n=14 each). After standardized root canal preparation, Group I underwent conventional irrigation, and Group II received ultrasonic irrigation. Debris and smear layer were evaluated using a Scanning Electron Microscope (SEM) at 200× and 1000× magnifications, respectively, across coronal, middle, and apical thirds, with scores ranging from 1 (clean) to 5 (dirty). Statistical analysis using ANOVA and Mann-Whitney U tests revealed that ultrasonic irrigation significantly outperformed conventional irrigation in debris and smear layer removal across all root canal thirds ($p < 0.001$). The apical third showed the highest debris and smear layer scores in both groups, but ultrasonic irrigation consistently achieved lower scores. These findings suggest that ultrasonic irrigation with 2.5% NaOCl is more effective for enhancing root canal cleanliness in primary teeth, potentially improving pulpectomy outcomes. Further clinical studies are needed to validate these results.

KEYWORDS: Primary teeth, pulpectomy, ultrasonic irrigation, smear layer, debris removal

INTRODUCTION

Dental caries is the most common chronic disease in children, largely avoidable yet with serious consequences if untreated. If not treated, it may worsen, potentially causing the pulp to remain vital or become necrotic. If a non-vital pulp diagnosis is made, the best course of action may be to preserve the tooth to maintain overall oral health, space, and arch integrity (Dentistry AAoP, 2021).

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Trauma to the teeth is the second most frequent cause of non-vital teeth in young children. The primary causes of Traumatic Dental Injuries (TDI) in primary teeth are children's varying levels of locomotor development, such as falls during early walking, which can be linked to TDI (Adolph et al., 2012).

For primary teeth with irreversibly inflamed or necrotic pulp due to caries or trauma, pulpectomy is a root canal procedure (Coll et al., 2020). The process of non-vital treatment (NVT) begins with case selection. It includes local anesthetic administration, tooth isolation, access opening, pulp removal, root length measurement, mechanical preparation, and debridement of the root canal (Coll et al., 2020). Disinfection with irrigants, drying, and obturation with a biocompatible, resorbable material follow. The process culminates in a final restoration to prevent microleakage (Coll et al., 2020). The complex root morphology of primary teeth, patient age, parent or patient preferences, behavior, medical history, pathologic and physiologic root resorption, and proximity to succedaneous teeth can influence non-vital pulp therapy outcomes (Coll et al., 2020).

Effective root canal treatment requires irrigation for reasons such as reduced friction, enhanced cutting efficiency, tissue dissolution, cooling the tooth and files, canal cleaning, and antimicrobial/antibiofilm action (Haapasalo et al., 2014). A thin layer of dentin debris produced during root canal instrumentation is known as the smear layer. The thickness of the material varies based on multiple parameters and can reach up to 110 µm. Root canal failure may result from sealers being unable to penetrate dentinal tubules due to the smear layer (Czonstkowsky et al., 1990). Studies show that removing the smear layer from the dentin surface enhances the ability of all sealers to eliminate bacteria from dentinal tubules (Zancan et al., 2021).

Various irrigation strategies can be applied during root canal therapy. Among the most popular methods is conventional irrigation (Alakshar et al., 2020). For successful chelation, irrigation fluids must be in direct contact with the root canal wall. However, conventional needle irrigation has been shown to be ineffective at cleaning the most apical areas of the root canal system and removing tissue remnants. Consequently, several irrigant agitation and activation techniques have been developed to enhance the removal of debris and the intracanal smear layer, particularly in the apical third (Andreani et al., 2021).

In an experimental study, Andreani et al. (2021) compared the effects of irrigant activation devices and traditional needle irrigation on debris and smear layer removal in curved canals. Both methods remove the smear layer, making dentinal tubules visible (Andreani et al., 2021). Overall, the effectiveness of different irrigation techniques on debris and smear layer removal in primary teeth has been the subject of a few studies, but most studies have shown that activated irrigation techniques, such as ultrasonic irrigation, are effective at removing debris and smear layers. We stated the null hypothesis as follows: Conventional irrigation using a lateral vent needle with 2.5% sodium hypochlorite is as effective as ultrasonic irrigation with 2.5% sodium hypochlorite in removing debris and smear layer in primary teeth.

After a thorough literature review and analyzing the gaps in the existing literature, the current study aimed to evaluate the efficacy of two irrigation techniques—conventional irrigation with 2.5% sodium hypochlorite and ultrasonic irrigation with 2.5% sodium hypochlorite—on debris and smear layer removal from primary molars using a Scanning Electron Microscope.

Review of Literature

Importance of Debris and Smear Layer Removal in Primary Teeth

Toxins, necrotic materials, endodontic bacteria, and their byproducts are the primary causes of root canal infections. The main objective of root canal therapy is the removal of necrotic and diseased materials, as well as any remaining metallic or chemical components in the event of a re-root canal (Zeng et al., 2018). Facilitating the flow of irrigating solution into the canal space is a crucial part of root canal preparation as it is a necessary step in the removal of infection. The most important step in eliminating germs is to prepare the canal space, thoroughly cleanse it with irrigation, and apply medication (Neuhaus et al., 2016).

The inflammatory disease known as apical periodontitis is typified by a complicated interaction between the host's defensive mechanism and microbial tissue invasion. The defense mechanism stops the microbial infection from spreading past the apical foramen by keeping it inside the root canal system; nevertheless, because the bacteria remain in the pulpal tissues, pulpal disease and periapical inflammation result (Hahn et al., 2007).

The goals of endodontic therapy are to clear the root canal system of bacteria, microbial biofilms, and byproducts and to stop further infection of the intracanal areas. Combining root canal preparation and disinfection allows for the reduction of the bacterial load to a level below that which is necessary to ensure healing, while appropriate sealing encapsulates the small amount of remaining bacteria. Enlarging and shaping channels and removing germs and byproducts from even inaccessible and non-instrumented surface areas are the first two phases, or root canal preparation and disinfection. The entombment of surviving bacteria, or the second stage, is essential for lowering the likelihood of chronic AP. In order to accomplish significant bacterial eradication, three interrelated procedures are available: (1) mechanical instrumentation, (2) irrigation with disinfection solutions, and (3) active irrigation. While mechanical instrumentation is required for the preparation of root canals, it does not guarantee total disinfection. Smear layers form and are unreachable, biofilm persists in the root canal walls, and non-instrumented surface areas are not cleaned. Approximately 35–53% of the root canal walls remain undisturbed. In actuality, endodontic disease is a biofilm-mediated infection, and the persistence of biofilms and smear layers weakens the system's fluid-tight seal, hinders root canal cleaning, reduces filling material adherence, and worsens the course of long-term treatment outcomes (Tonini et al., 2022).

Combining mechanical debridement with antibacterial irrigants increases the efficacy of the root canal disinfection processes. Because it immediately affects the root canal walls and makes it possible for the antibacterial agents to enter the dentinal tubules, the chemo-mechanical preparation greatly lowers the bacterial load. Microorganisms can, however, still exist in the main canal and throughout the root canal system even after chemo-mechanical preparation. The efficiency of irrigation can be improved with irrigation activation systems. The antimicrobial effects of chemo-mechanical preparation in infected root canals are augmented by activation systems, which distribute and move the irrigant throughout the canal system, improving chemical surface cleaning and erosion (Hargreaves & Cohen, 2010).

The microorganism is the primary etiological cause in the development of the periapical lesion. Pertinacious infection can be the cause of endodontic procedure failure. Microbes within the dentinal tubules and canal space cause persistent infection or inflammation of the periradicular tissue. The removal of the microorganisms from the root canal space determines how endodontic therapy turns out. Within the infected root canal, the overall bacterial burden varies from 10^2 to $>10^8$. Gram-positive anaerobic facultative cocci called Enterococcus faecalis are normal oral cavity residents that are seen in the root canal microbiota of endodontic infections that are persistent. In between 24% and 74% of asymptomatic and reinfection cases, these organisms are frequently detected. Using irrigants and irrigating equipment, the root canal can be thoroughly cleaned, which is essential to lowering the bacterial load inside the canal. The flushing, antibacterial action, solution type, and distribution methods of the irrigant are its most crucial features that need to be taken into account (Attavar et al., 2023).

Microorganisms may also be present in the smear layer and any debris that remains in the canal. Eliminating microorganisms that have infiltrated dentinal tubules is essential since they can negatively impact the results of endodontic treatments. In order to determine the outcome of primary teeth root canal therapy, thorough cleaning is essential. The intricate structure of the primary roots, which include lateral canals and isthmuses that harbor dental germs, combined with physiologic resorption that starts shortly after the primary tooth is fully formed, causes changes to the size, location, and form of the apical foramen. This makes the cleaning and shaping procedure, even with the most advanced instrumentation, less predictable and probably insufficient. Irrigation solutions, medicines, and sealants cannot enter dentinal tubules due to the persistence of debris and smear layer created by root canal instrumentations on root canal walls. It has been shown that the long-term result of primary teeth pulpectomy was improved after the smear layer was removed. This is especially important in primary teeth with early signs of pulpal necrosis and peri-radicular lesions (Hachem et al., 2022).

Overview of Different Irrigants

Sodium hypochlorite (NaOCl) is the most often used irrigant. It dissociates into Nal and OCl" ions when put in water. The main form, HOCl, exhibits antibacterial action at pH values of neutral or acid. NaOCl is applied in a range of concentrations from 0.5% to 5.25%. According to the literature, NaOCl is the only irrigant that can dissolve dentinal collagen and necrotic and less vital pulp remnants but not the smear layer (Tošić et al., 2016). NaOCl has an antibacterial minimum in vitro concentration of 0.5%. On the other hand, in vivo NaOCl effectiveness is decreased by organic matter and biofilm. As a result, higher concentrations and constant changes in NaOCl seem to have a greater impact on the biofilm, but they may also put the patient at risk for more adverse consequences (Haapasalo et al., 2014).

In this study, 2.5% NaOCl was chosen as the irrigant due to its well-established efficacy in dissolving organic tissue, destroying the biofilm, and eliminating the pathogenic microbiome within the root canal system, while balancing efficacy and safety, especially in pediatric patients (Dioguardi et al., 2018).

Debris and Smear Layer in Primary Teeth

Definition and Composition

An amorphous film or a distorted layer of organic and inorganic particles created by dentin, enamel, or cementum reduction or instrumentation is known as the smear layer. Using manual or rotary devices to cut tooth structure does not tear the mineralized matrix. Rather, it fractures, producing a sizable amount of debris consisting of a mineralized collagen matrix. This is present where the dentin matrix and restorative material converge to produce the smear layer (Patel & Barnes, 2019).

Dentin chips and necrotic or viable pulpal tissue that adhered to the canal walls make up the debris. The crystalline structure of the smear layer, which is the end result of the canal shaping process, is made up of inorganic and organic leftovers as well as microorganisms and their byproducts. It is 1-2 microns thick and covers the canal walls unevenly (Rasheed & Jawad, 2021).

Effects on Dental Treatment Outcomes

Barcelos et al. conducted a double-blind, randomized, controlled clinical trial to examine the effects of pulpectomy on primary teeth after the smear layer was removed. Teeth were irrigated with either 0.9% physiologic solution (G2) or 6% citric acid and 0.9% physiologic solution (G1) after chemomechanical preparation using K-files and 2.5% sodium hypochlorite (NaOCl). Intracanal administration of camphorated paramonochlorophenol was employed. One week later, at the follow-up consultation, root canals were filled with a paste made of zinc oxide and ethanol. The results of the study showed that removing the smear layer from the affected tooth not only improved the outcome of pulpectomy procedures, but it also significantly improved the outcomes for teeth with pulpal necrosis, pre-operative symptoms, or periapical/inter-radicular radiolucency (Barcelos et al., 2012).

Challenges in Removal from Primary Teeth

Children's primary teeth root canal therapy can be difficult and time-consuming, particularly when it comes to canal preparation. Rotating files can make root canal therapy easier and more convenient; therefore, using them on younger patients might be a better idea. One of the most crucial stages of primary root canal therapy is canal preparation, which primarily focuses on the debridement of the canals. For both permanent and primary teeth, the mechanical cleaning and contouring of root canals follow the same principles. Similar to manual filing, NiTi devices can effectively clean the curvatures and irregularities of the root canal walls of primary teeth by rotating them in a clockwise direction, which removes pulp tissue, dentin, and necrotic leftovers from the canals. On the other hand, primary teeth's tiny, narrow canals require caution. Primary molar canals are tortuous and ribbon-shaped, so more of the softer dentin may be removed without always needing a crown-down approach (Cohen & Hargreaves, 2006).

Review of Irrigation Techniques

Traditional Irrigation Methods (e.g., Syringe Irrigation, Manual Agitation)

Syringe irrigation is regarded as a significant technology due to its accessibility and effectiveness. It is the accepted clinical standard as of right now. Because it takes advantage of the force created inside the barrel by the pressure on the plunger, it is often referred to as a positive pressure irrigation technique. There are numerous kinds of needles with varying flexibility, tip apertures, and diameter sizes. Certain types of needles—made of plastic, nickel-titanium, and stainless steel—improve flexibility, particularly in curved canals. Additionally, there are two types of tip-opening designs that are accessible. The first is a set of open-ended needles that allow the irrigant to flow directly through the tip. Closed-ended needles are used in the second one to help the irrigant flow through one or more sides. When the apical size of open-ended needles is prepared to size 30, the irrigant can only extend 1 mm past the needle tip. To prevent irrigant extrusion, the apical size should be set flexibly, 2-3 mm shorter than the working length. However, in terms of irrigant extension, closed-ended needles are thought to be less effective than open-ended needles, and they also pose a lower chance of sodium hypochlorite accidents. Grossman realized that in order to improve irrigation efficiency using traditional syringes, sufficient apical preparation was required. Small diameter needles between 27 and 31 gauge are advised to be used. The standard is primarily 30-gauge needles, which match instrument size 35. The primary issue arises when using needles with a diameter of less than 30 gauge, since additional force must be supplied to the plunger to guarantee the irrigants flow (Brunson et al., 2010).

Below are some factors that improve the efficacy of conventional syringe irrigation: Proximity of the needle to the apex, large volume of irrigant, small gauge of irrigation needle (30 gauge or less), slow irrigant delivery, and agitation (Tashkandi & Alghamdi, 2022). However, following traditional syringe irrigation, inaccessible regions harboring germs and debris were discovered. It happens as a result of the irrigating solution's penetration depth and needle tip position. A technique that offers more canal debridement and deeper penetration with less apical extrusion would be preferable (Tashkandi & Alghamdi, 2022).

The irrigation technique that is used the most frequently worldwide is conventional needle irrigation (CNI). This approach appears to be unable to clear the apical third of the root canal and flush out residues of both organic and inorganic tissue, despite having good control over the irrigant delivery. Numerous supplementary methods have been devised to surmount the constraints associated with CNI. It has been proposed that passive ultrasonic activation improves root canal disinfection. By employing ultrasonic activation of the irrigant to enhance the cleanliness of both instrumented and uninstrumented areas, this technology is anticipated to facilitate the delivery of irrigants into challenging-to-reach places (Boutsioukis et al., 2010).

Ultrasonic Irrigation

In the root canal, this is the process of activating the irrigant solution utilizing ultrasonic radiation between 25 and 32 kHz. This ultrasonic activation method is regarded as a clinical standard and is frequently employed. By producing acoustic microstreaming—the irrigant moving quickly and in a circular motion around the vibrating file—and acoustic cavitation—the formation and deformation of bubbles—this method improves chemical debridement. This tremendous energy makes sure that the irrigant reaches the far-flung parts of the intricate root canal structure. When the file moves freely within the root canals, ultrasonic stimulation produces the optimum results. Additionally, the thinner files displayed improved streaming velocity, acoustic microstreaming, and higher frequency. According to certain research, there may be no advantage at all from acoustic cavitation in ultrasonic irrigation. Researchers described and examined two kinds of ultrasonics. The first is called ultrasonic instrumentation (UI), which is a hybrid technology of instrumentation and irrigation. According to certain research, the canals made using this method are cleaner than those prepared with traditional equipment. Other research, however, revealed that passive ultrasonic irrigation was more effective in removing pulp tissue. The reason for this was found to be the uncontrolled dentin cutting, which could result in strip perforation and severely irregularly shaped canals. It is, therefore, not advised to utilize ultrasonic instrumentation anymore. The second method is called passive ultrasonic irrigation (PUI), and it involves activating the irrigation system without concurrently instrumenting it. This method creates acoustic streaming and cavitation of the irrigant by sending energy from the oscillating file to the irrigant inside the root canal. During PUI, two flushing techniques—continuous and intermittent ultrasonic irrigation—can be applied. An irrigation syringe is used to inject the irrigant into the root canal during intermittent ultrasonic irrigation. With continuous ultrasonic irrigation, this is uncontrollable because the irrigant flows continuously through the ultrasonic device itself. In contrast, this technique gives you control over the amount of irrigant utilized and the penetration depth inside the root canal. The two methods demonstrated similar efficacy in removing dental debris. When the irrigation time was three minutes, both methods removed dentin debris from the root canal in the ex vivo model equally well (Retsas & Boutsioukis, 2019).

Comparison of Different Techniques and Effectiveness in Debris and Smear Layer Removal

The multisonic ultracleaning system (MUS) was found to be significantly more effective at tissue dissolution using 3% NaOCl compared to all other irrigation methods. Conventional irrigation methods, such as CNI, were found to be the least effective. These results are consistent with a previous study in which the tissue dissolution by the MUS was found to be 8-15 times greater than that of conventional irrigation methods (Liu et al., 2023). Ultrasonic irrigation has been shown to outperform conventional irrigation in debris and smear layer removal, particularly in the apical third, due to acoustic streaming and cavitation effects (Andreani et al., 2021).

Results from Previous Studies

Summary of Findings from In Vitro Studies Comparing Irrigation Techniques

In nearly all three root thirds (cervical, middle, and apical), conjugation of dentinal tubules, erosion of peritubular dentin, and breakdown in the intertubular dentin were observed in an SEM examination on primary teeth irrigated with 10% EDTA + 5.25% sodium hypochlorite. In the root canals of the primary maxillary anterior teeth, EDTA and citric acid made it easier to remove the smear layer, while sodium hypochlorite encouraged the creation of a smear layer during shaping (Hariharan et al., 2010).

Using data from bacteriologic sampling of root canals treated by endodontic residents, Kirk Huffaker et al. studied the use of a passive sonic irrigation device to eradicate cultivable bacteria from root canals in vivo and compared it with that of normal syringe irrigation. The ability of the sonic group and the control group to remove cultivable bacteria from root canals was not found to differ significantly, but they did find that a second session and between-visit calcium hydroxide disinfection were able to remove cultivable bacteria from a significantly greater number of teeth than a single treatment session (Huffaker et al., 2010).

In 2020, Ballal and colleagues assessed the impact of NaOCl irrigant activation on the decrease of intracanal bacteria from root canals in teeth undergoing root canal therapy among eighty patients with asymptomatic apical periodontitis. They did this by using passive ultrasonic activation and needle irrigation alone. The biggest decrease in the colony-forming units was linked to passive ultrasonic activation, with noticeably reduced CFUs when needle irrigation was taken into account. The study demonstrated how passive ultrasonic activation can lower the bacterial burden in the root canal system, which is crucial for the effectiveness of root canal therapy (Ballal et al., 2020).

Identification of Knowledge Gaps or Conflicting Results

The dearth of randomized clinical trials, particularly those that concentrate on the long-term treatment outcome, is a well-known issue with root canal irrigation. The majority of methods and solutions fall under the category of “mechanism-based” reasoning since they are mostly based on laboratory study results, which are viewed as the lowest level of evidence. Frequently, there is a gap in the inferential chain from an irrigant or irrigation technique to a clinical result. Furthermore, the laboratory models used are frequently not verified, and in certain instances, they could be glaringly unrealistic and simplistic. Therefore, extreme caution must be exercised when extrapolating laboratory study results to the clinical context. The outcomes of the studies are inextricably linked to the absence of clinical trials. The main outcome of interest in clinical endodontics is the prevention or repair of apical periodontitis; however, in experimental investigations, easier-to-measure surrogate end-points are typically used in order to reduce the length of the post-operative monitoring period or to conduct the tests in a laboratory. The most pertinent surrogate endpoint is the decrease in the intracanal microbial burden, which is at least somewhat associated with the healing of apical periodontitis. There is no clear correlation between the primary outcome and other frequently utilized endpoints, like the elimination of hard-tissue debris, pulp tissue remnants, or the smear layer. Rather, their application is predicated on several suppositions and theories connecting them to the decrease in the microbial burden. The remaining pulp tissue may provide nourishment for bacteria that are still alive and may also interact with the irrigants to reduce their effectiveness. Hard-tissue detritus buildup may make it more difficult for irrigants to reach intact biofilm that is found in isthmuses and other uninstrumented locations. The smear layer in instrumented locations may also harbor bacteria or prevent irrigants from reaching them. However, as was recently shown for the apical extrusion of debris, a frequently employed endpoint in root canal preparation research, a credible hypothesis is insufficient to validate a surrogate end-point. The inferential chain needs to make sense and be supported by evidence, not just theory. Conflicting results in the comparison of irrigation techniques employing distinct outcome measures are not unusual, and they have cast doubt on the usefulness of removing hard-tissue debris or pulp tissue remains as indicators of an irrigation method's antimicrobial impact. Furthermore, the conclusions of SEM investigations on the removal of the smear layer are not regarded as valid due to their persistent criticism for basic methodological flaws (Boutsioukis et al., 2022).

The morphological characterisation of the biofilm on a material is made possible by the high-resolution and high-magnification pictures of surface features that are obtained using scanning electron microscopy (SEM). When compared to light microscopy, its greater depth of field makes it easier to examine irregular surfaces (Du et al., 2013).

It is essential to create safer and more effective irrigants, more realistic and workable operating techniques and procedures, and smaller, more reasonably priced equipment for root canal irrigation due to the complex anatomy of root canals and the wide variety of infections that can arise. Intracanal medications are receiving less attention due to improvements in root canal cleaning methods. The development of next-generation antimicrobial peptides, nanoparticles, and other medications or formulations has the potential to completely transform the principles and practices of root canal therapy as well as introduce significant modifications to intracanal medication. However, the ultimate goal of root canal therapy does not change: infection control to maximize the preservation of the damaged tooth (Zou et al., 2024).

MATERIALS AND METHODS

This study was carried out in the laboratory, which involved two steps:

1. Irrigating the canals with different irrigants as per group allocation.
2. Assessment of debris and smear layers using a Scanning Electron Microscope.

Materials Used in the Study

The following instruments and materials were used in this study.

METHOD

Ethical Approval

Prior to the commencement of the study, ethical clearance was sought from the Research Ethics Committee of the Faculty of Dentistry at Mansoura University, Egypt.

Sample Size Calculation

The sample size was estimated using the G power program version 3.1.9.7. Based on the results of an in-vitro study by Mathew et al. (2023), where the effectiveness of different irrigation techniques on debris and smear layer removal in primary teeth was studied using a scanning electron microscope, the effect size (f) was 1.05, alpha error (α) at 0.05, and power of 90.0% while performing a two-tailed test, the total sample size was estimated to be 28 with 14 teeth per group.

Study Design

This study is an in vitro experimental study that compares the effectiveness of two different irrigation techniques on debris and smear layer removal in primary teeth.

Selection of Teeth

The teeth were collected from the outpatient clinic of Pediatric Dentistry, Faculty of Dentistry at Mansoura University.

TABLE (1) List of Instruments and Materials

Category	Item	Brand/Origin
Imaging Tools	Periapical X-ray	Dentsply Sirona (Germany)
Handpieces and Burs	High-speed handpiece	Dentsply Sirona (Germany)
	Round diamond bur	Dentsply Sirona (Germany)
Endodontic Files and Motors	Endodontic files (K-hand file)	Dentsply Sirona (Germany)
	EndoMotor	Wismy EndoMotor (China)
	Rotary files	FKG SWISS ENDO (Switzerland)
Irrigation Devices	Ultrasonic device	WOODPECKER (China)
	Dental Endodontic Irrigation Needle (single)	Dentsply Sirona (Germany)
	Dental Endodontic Irrigation Needle Tips (end-closed, side-vented, 30-gauge)	Dentsply Sirona (Germany)
	Disposable syringes	Becton Dickinson BD (USA)
Irrigation Solutions	Sodium hypochlorite (2.5% concentration)	Moka Dant (Egypt)
Other Materials	Paper points	Dentsply Sirona (Germany)
	Dental diamond disc	Komet (Germany)
	Silica gel	Sorb-Tech (USA)
	Sputter Coater	Structure Probe, Inc. (USA)
Analytical Tools	Scanning Electron Microscope (SEM)	Japan Electron Optics Laboratory (Japan)

Fig. (1). EndoMotor (Wismy EndoMotor)

Fig. (2). Rotary files (FKG SWISS ENDO)

Fig. (3). Ultrasonic device (WOODPECKER)

Fig. (4) Sonic device (EQ-S EunSung Global)

Fig. (5). Sodium hypochlorite (2.5% and 5.25% concentration)

Exclusion Criteria

The following were the exclusion criteria in the study:

- Tooth with any signs of internal or external root resorption.
- Previously root canal-treated teeth.
- Tooth with incomplete root formation.
- Tooth with excessive wear or attrition.
- Tooth with pulp stones or calcifications.

Experimental Procedure

Group Assignment and Randomization

Each tooth was assigned a particular number from 1 to 28. An online randomizing program (www.randomizer.com) was used to generate random numbers, and selected teeth were randomly allocated into two groups equally with 14 teeth per group using the below-mentioned:

- **Group I**: Conventional irrigation employing a lateral vent irrigation needle with 2.5% sodium hypochlorite (NaOCl) (14 teeth).
- **Group II**: Ultrasonic irrigation technique using 2.5% sodium hypochlorite (NaOCl) (14 teeth).

Fig. (6). Silica gel (Sorb-Tech)

Fig. (7). Sputter Coater (Structure Probe, Inc)

Fig. (8). Scanning Electron Microscope

Irrigation Techniques

Access Opening and Standardization of Working Length

The teeth were cleaned using an ultrasonic tip and kept in distilled water until the start of the study. Following access cavity preparation using a high-speed Sirona and round bur, patency was verified with a size 10 K-file that was introduced into the root canal until the tip was seen at the apical foramen. A rubber stopper was adjusted to the reference point (occlusal edge of the access cavity). The crowns of the teeth were sectioned with a diamond disc to standardize the root length at 12 mm, and the working length (WL) was determined to be 1 mm short of the apical foramen with a size 15 K-file. The true length of the tooth was established, from which 1 mm was subtracted to establish the working length (WL). We completed cleaning and shaping till size 25 K-file. After that, we used a rotary system (Wismy EndoMotor) with a speed of 1000 rpm and torque 1 Ncm with FKG XP Endo Shaper and Finisher size 25.

Irrigation

The following protocol was followed to perform irrigation for each of the teeth groups:

- **Group I**: Conventional irrigation employing a lateral vent irrigation needle with 2.5% sodium hypochlorite (NaOCl): After filing, root canals were prepared with EndoMotor to the working length. Irrigation was performed with 3 mL of 2.5% sodium hypochlorite (NaOCl) using a 30-gauge side-vented needle, and the canal was dried with paper points.
- **Group II**: Ultrasonic irrigation technique using 2.5% sodium hypochlorite (NaOCl): After patency verification with a size 10 K-file, root canals were prepared with EndoMotor to the working length. Irrigation was done with 3 mL of 2.5% sodium hypochlorite (NaOCl) using a 30-gauge single needle, followed by activation of the irrigant using an ultrasonic device operating at a frequency of 45 kHz for 30 seconds and drying the canals with paper points.

After we finished root canal shaping and irrigation, we washed all the samples with distilled water and saved them in normal saline. First, we removed the crown by using a fine diamond disc. After that, the canals were divided into two halves with a fine diamond disc and a chisel and mallet by entering approximately 0.5 ml in the etch side. A chisel and mallet were used to split each sample. We immersed it again in normal saline until it was time to examine the samples under SEM, and 48 hours before examining the samples, we put them inside the airtight container with silica.

Scanning Electron Microscope (SEM) Examination

The SPI-module line of modular sputter coaters and carbon coaters are optimized for gold coating and carbon coating for all SEM/EDS applications.

After that, the samples were examined by SEM 3 times on 200X and 3 times on 1000X (coronal, middle, and apical), and the greatest amount of debris and smear layer was selected.

The absence and presence of the debris at 200× magnification were assessed using the following scores:

- **Score 1**: The canal wall is clean, with a few debris particles.
- **Score 2**: Few small agglomerations.
- **Score 3**: Many agglomerations, less than 50% of the canal wall covered.
- **Score 4**: More than 50% of the canal wall is covered with debris.
- **Score 5**: Complete coverage of the canal wall by debris.

The absence and appearance of the smear layer at 1000× magnification will be assessed using the following scores:

- **Score 1**: No smear layer, orifices of the dentinal tubules patent.
- **Score 2**: There is a small amount of smear layer and some open dentinal tubules.
- **Score 3**: Homogeneous smear layer along almost the entire canal wall, with only very few open dentinal tubules.
- **Score 4**: The entire root canal wall was covered with a homogeneous smear layer, with no open dentinal tubules.
- **Score 5**: A thick homogeneous smear layer covering the entire canal wall.

Statistical Analysis

All the statistical analyses were performed using the Statistical Package for Social Science (SPSS), version 20 (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, USA). Shapiro-Wilks test showed normal distribution of the data (p>0.05). Hence, the parametric test of statistical significance was used. Continuous variables were presented as Mean and Standard Deviation. The groups were compared using a one-way analysis of variance (ANOVA). A p-value of ≤ 0.05 was considered statistically significant.

RESULTS

Table (1). Intra-observer Agreement

Metric	Conventional Irrigation 2.5% NaOCl	Ultrasonic Irrigation 2.5% NaOCl
Debris	.919	.741
Smear Layer	.781	.895

Table (2). Inter-observer Agreement

Metric	Conventional rrigation 2.5% NaOCl	Ultrasonic Irrigation 2.5% NaOCl
Debris	.844	.691
Smear Layer	.767	.417

Based on the guidelines from Altman (1999), and adapted from Landis & Koch (1977), a kappa (ϰ) ranging from .417 to .928 represents moderate to very good agreement.

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Debris Layer Evaluation

The Mean ± SD score for debris was highest in the apical, followed by the middle, and least in coronal in all study groups (Figure 1a).

- The Mean ± SD score for debris was highest in conventional irrigation 2.5% NaOCl and least in ultrasonic irrigation 2.5% NaOCl in all thirds (Figure 1b).
- In coronal, the Mean ± SD score of debris was statistically significantly ($p < .001$) higher in conventional irrigation 2.5% NaOCl (3.14 ± .90) and least in ultrasonic irrigation 2.5% NaOCl (1.00 ± .00).
- In middle, the Mean ± SD score of debris was statistically significantly ($p < .001$) higher in conventional irrigation 2.5% NaOCl (3.29 ± .76) and least in ultrasonic irrigation 2.5% NaOCl (1.14 ± .38).
- In apical, the Mean ± SD score of debris was statistically significantly ($p < .001$) higher in conventional irrigation 2.5% NaOCl (3.71 ± .49) and least in ultrasonic irrigation 2.5% NaOCl (1.43 ± .54).
- In conventional irrigation 2.5% NaOCl, the Mean ± SD score of debris was higher in apical (3.71 ± .49), followed by middle (3.29 ± .76), and least in coronal (3.14 ± .90). However, the difference was statistically not significant ($p > .05$).
- In ultrasonic irrigation 2.5% NaOCl, the Mean ± SD score of debris was higher in apical (1.43 ± .54), followed by middle (1.14 ± .38), and least in coronal (1.00 ± .00). However, the difference was statistically not significant ($p > .05$).

Figure 2. Representative images of debris in the apical, middle, and coronal thirds in the study groups

Smear Layer Evaluation

The Mean ± SD score for the smear layer was highest in the apical, followed by the middle, and least in coronal in all study groups (Figure 3a).

The Mean ± SD score for the smear layer was highest in conventional irrigation 2.5% NaOCl and least in ultrasonic irrigation 2.5% NaOCl in all thirds (Figure 3b).

- In coronal, the Mean ± SD score for smear layer was statistically significantly ($p = .001$) higher in conventional irrigation 2.5% NaOCl (2.43 ± .54) and least in ultrasonic irrigation 2.5% NaOCl (1.00 ± .00).
- In middle, the Mean ± SD score for smear layer was statistically significantly ($p = .001$) higher in conventional irrigation 2.5% NaOCl (2.86±.38) and least in ultrasonic irrigation 2.5% NaOCl (1.29±.49).
- In apical, the Mean ± SD score for smear layer was statistically significantly ($p = .001$) higher in conventional irrigation 2.5% NaOCl (3.00± .00) and least in ultrasonic irrigation 2.5% NaOCl (1.71±.76).

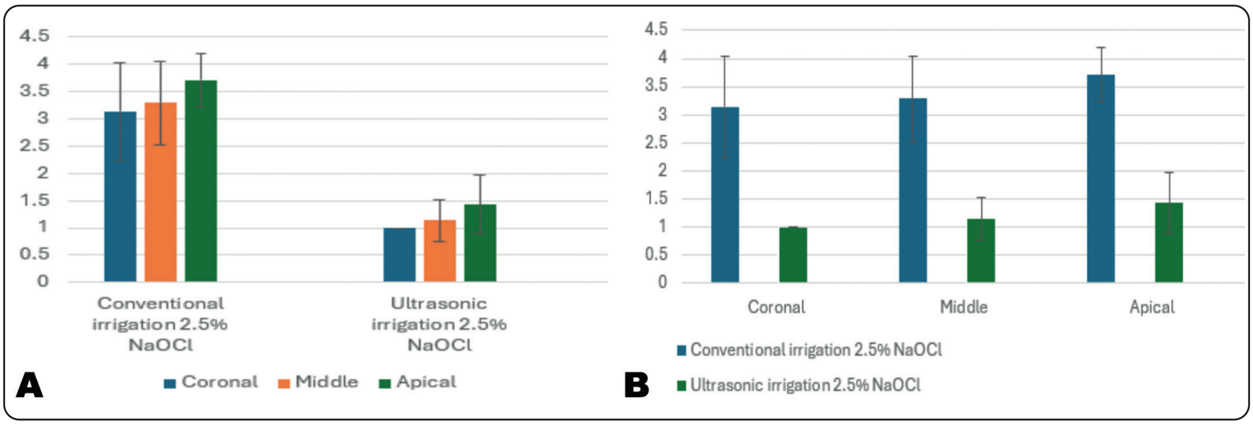

Figure la. Mean ± SD scores for debris evaluations

Figure lb. Mean ± SD scores for debris evaluations

- In conventional irrigation 2.5% NaOCl, the Mean ± SD score for smear layer was statistically significantly ($p < .05$) higher in apical (3.00 ± .00), followed by middle (2.86 ± .38), and least in coronal (2.43 ± .54).

- In ultrasonic irrigation 2.5% NaOCl, the Mean ± SD score for smear layer was higher in apical (1.71 ± .76) followed by middle (1.29 ± .49) and least in coronal (1.00 ± .00). However, the difference was statistically not significant ($p > .05$).

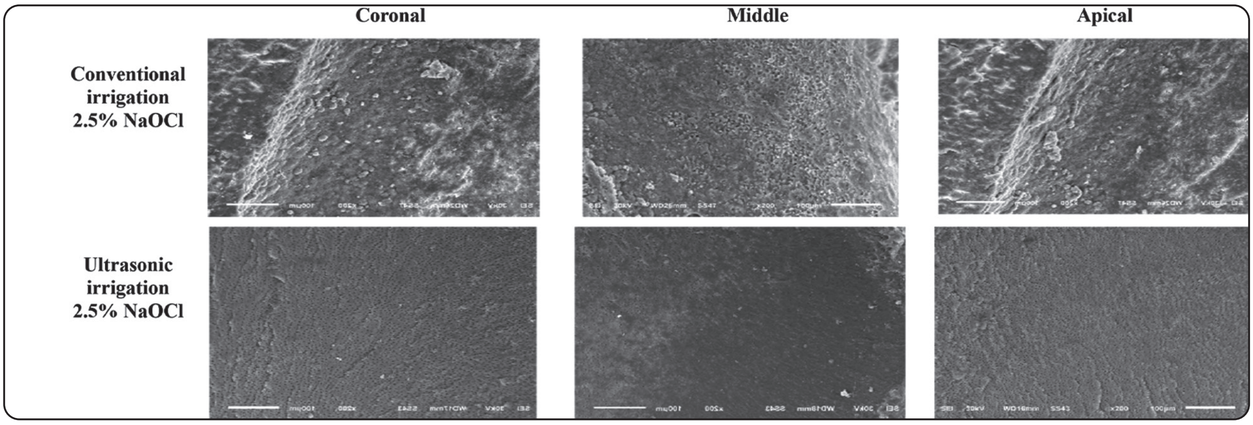

Fig. (2). Representative images of debris in the apical, middle, and coronal thirds in the study groups

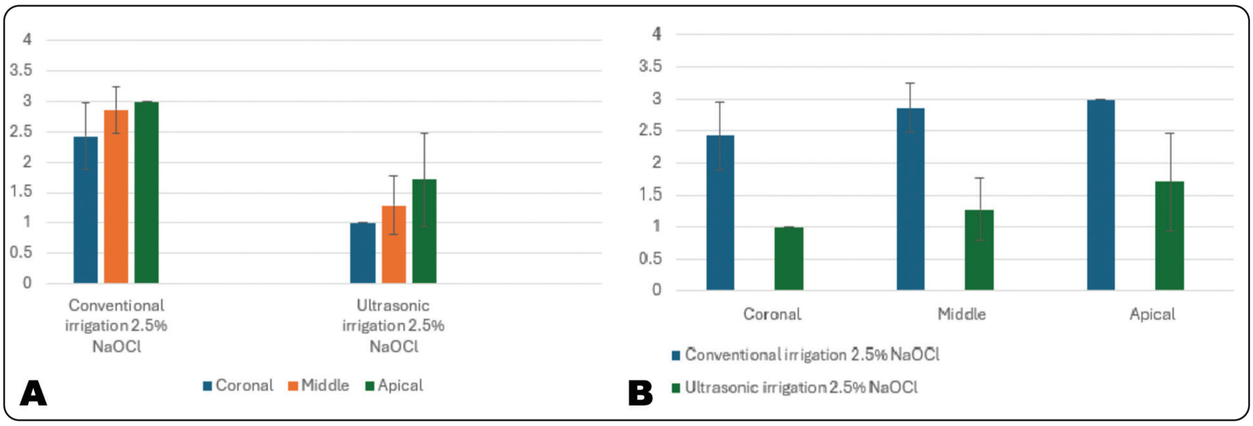

Fig. (3a). Mean ± SD scores for smear layer evaluations

Fig. (3b). 1\1:ean ± SD scores for smear layer evaluations

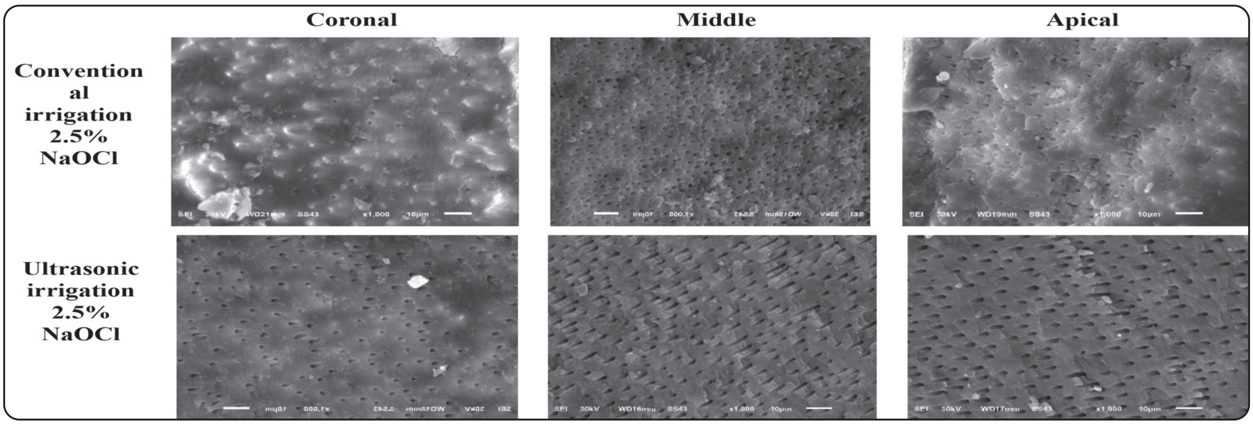

Fig. (4). Representative images of smear layer in the apical, middle, and coronal thirds in the study groups

DISCUSSION

This in-vitro study was designed to assess the efficacy of two irrigation techniques—conventional irrigation using a lateral vent irrigation needle with 2.5% sodium hypochlorite (NaOCl) and ultrasonic irrigation with 2.5% sodium hypochlorite (NaOCl)—on the removal of debris and smear layer in deciduous molars as evaluated on a Scanning Electron Microscope.

Pioneer researchers of instrumentation in root canals stated that there existed a smear layer that comprised dentin, some remnants of odontoblastic processes, pulpal tissue, and bacteria (McComb & Smith, 1975). Due to limited studies in the primary teeth as compared to the permanent dentition, it is quite common to generalize the findings of the permanent dentition to the primary teeth and likewise in the case of root canal instrumentation as well, the gold standard treatment that is often employed in permanent dentition is simulated in the primary dentition which closely reproduces the procedure of pulpectomy.

Sodium hypochlorite has been in use for decades. Irrigating root canals during root canal procedures with sodium hypochlorite is well known to cause necrosis of surrounding tissues and may also elicit the sensation of pain among patients undergoing treatment (Hülsmann & Hahn, 2000). The bacteria present in the smear layer may also add to limiting the efficacy of the root canal irrigant used, and thus, removal of the smear layer becomes a mandatory norm. Several theories proposed in the literature support the removal of this layer. To state some of them, the smear layer widely varies in thickness and volume, contains bacteria and by-products, necrotic tissue along with the dentin and pulp, and there could be deeper penetration of the microorganisms if this layer is left as is. The removal of the smear layer aids in enhancing the effectiveness of the irrigants and other methods of disinfection that may be implemented during the procedure. The smear layer may interfere with the bond that may otherwise exist between the root canal wall and the obturating materials, and a compromise in this bond may lead to areas where leakage and bacterial contamination occur (Weller et al., 1980).

In our study, the intra- and inter-observer agreement for the debris layer and smear layer removal ranged from moderate to very good, which is a positive feature of the study. In relation to the area of the tooth, i.e., cervical, middle, and apical, our study showed that irrespective of the irrigation technique employed, both debris and smear layer scores significantly remained at a maximal level at the apical third region of the tooth and there were significantly least remnants of debris and smear layer in the cervical third region of the tooth. When the presence of debris was assessed based on the technique employed, conventional irrigation with 2.5% sodium hypochlorite was the least efficient, whereas ultrasonic irrigation with 2.5% sodium hypochlorite proved to be the most efficient technique in removing debris. Similar to our study findings in relation to the debris removal, in the case of smear layer removal as well, conventional irrigation with 2.5% sodium hypochlorite was the least efficient, whereas the smear layer scores were the least in the group of teeth where ultrasonic irrigation was used as canal irrigants with 2.5% sodium hypochlorite.

Since our study focus was on primary teeth, the teeth in the deciduous dentition with such an advantage would be the primary molars, which were included in this study. A scanning electron microscope was employed to view and assess the sections of the tooth since employing an SEM enhances the vision of the researcher to observe the movement of the irrigant, the efficacy of the irrigant, and the effectiveness of the techniques in obtaining a clean, sterile root canal. Irrigation of the root canal is usually done using sodium hypochlorite using a 2 ml syringe of concentrations between 2.5% to 5.25%, ensuring that it is filled in the canal. Sodium hypochlorite irrigation is recommended from as early as access opening and continues during biomechanical preparation, even before the canals are negotiated. The locations of the orifices are tracked down and in between each file during the instrumentation procedure for the canal is carried out.

In this study, 2.5% sodium hypochlorite (NaOCl) was chosen over normal saline as the primary irrigant due to its well-established efficacy in dissolving organic tissue, destroying the biofilm, and eliminating the pathogenic microbiome within the root canal system. Sodium hypochlorite is an effective antimicrobial agent with potent tissue-dissolving properties, a property that is not inherent in normal saline. Studies have shown that while saline can act as a good irrigating agent, it is incapable of providing adequate bactericidal or smear layer removal capabilities required for optimal disinfection in endodontic procedures (Boutsioukis & Arias-Moliz, 2022). Furthermore, saline irrigation fails to degrade necrotic pulp remnants and organic debris, making it unsuitable as a primary irrigant (Haapasalo et al., 2014). Hence, using 2.5% NaOCl was a deliberate choice to balance efficacy and safety, especially in pediatric patients.

Rotary files also improve the effectiveness of sodium hypochlorite irrigation by facilitating better irrigant penetration into the apical third. Studies have shown that the mechanical agitation created by rotary instrumentation significantly enhances the flow and penetration of the irrigant, aiding in improved debridement and smear layer removal (Gu et al., 2009). Furthermore, rotary files reduce operator fatigue and enhance procedural efficiency, which is particularly beneficial in pediatric dentistry where patient cooperation may be limited.

The choice of FKG SWISS ENDO rotary files was made in this study due to their advanced design, which enhances debris removal and improves shaping efficiency. Rotary file systems offer consistent and controlled canal preparation, minimizing procedural errors such as ledging, perforation, or apical transportation. The unique alloy composition and flexibility of the FKG SWISS ENDO files allow them to efficiently negotiate curved canals, which are commonly found in primary molars (Peters et al., 2003).

The reason for ultrasonic irrigation with sodium hypochlorite being most effective in debris removal as well as smear layer removal is that when performing ultrasonic irrigation, the tip of the equipment does not come in contact with the root canal surface at any point during the procedure, and hence any damage to the dentin will be prevented. Passive Ultrasonic Irrigation is the concept applied where the energy is transferred through vibrations only and the acoustic streaming leads to debridement of debris and the smear layers (Gu et al., 2009).

The poor results obtained for both debris and smear layer removal from conventional irrigation could be due to the depth in the root canal up to which the needle can be inserted is limited based on the diameter of the needle, shape of the needle used, the root canal width if narrower restricts the path of entry of the needle. Any curvature or taper in the natural root canal anatomy will also restrict the accessibility for conventional irrigation. There is also a chance of the occurrence of the vapor lock phenomenon, which usually is encountered in the conventional irrigation technique where the air bubbles formed in the apical third of the root canals when the irrigant is introduced, preventing the reach of the irrigant to the apical area. Root canal being a close-ended cavity, these air bubbles remain entrapped and make debridement in the apical third of the tooth close to impossible (Boutsioukis et al., 2010).

Strengths and Limitations

As per the best knowledge of the authors, a study determining the various irrigation techniques in order to effectively clear the organic debris and smear layer was needed to assess and adopt the most practical and clinically sound irrigation technique while performing pulpectomy in primary teeth. This study provided significant results within certain limitations. The limitation of this study is that the tooth specimens were sectioned, which would have led to the destruction of the hard tissues observed under the SEM. The in-vitro design of the study may also pose a limitation of this study. A scanning electron microscope is a good tool for the assessment of the efficacy of irrigants and irrigation methods. However, the assessment using this type of microscope is not ideal since the teeth specimen have to be sectioned in order to carry out the analysis. The results using this method of analysis are interpreted in the form of scores, which is quite subjective. Hence, the interpretation may vary based on the observations of different investigators. Despite training the investigators prior to the conduct of the study, a more objective type of interpretation seems to be more precise and devoid of observation bias. It is also noteworthy to mention that the root canal system in which the irrigation methods are tested is a complex environment, and it greatly varies in anatomy, which makes cleaning of the root canal a difficult task. Further investigations can be carried out to validate the findings of our study.

CONCLUSIONS

Within the limitations of our study, the following results can be inferred. They are:

- With a good intra- and inter-observer agreement that was confirmed in the study, the validity of the study findings is acceptable. Both debris and smear layer removal was poorly done at the apical third of the root canal.
- An ultrasonic irrigation system with sodium hypochlorite solution was deemed to be the best irrigation technique, and conventional irrigation with 2.5% sodium hypochlorite was the least effective among the irrigation techniques studied.
- In terms of debris debridement, there was a statistically significant difference in debris scores between the two irrigation techniques in all the thirds of the root canal.
- In terms of smear layer removal, there existed a statistically significant difference in the smear layer scores between the two techniques used in all the thirds of the root canal.

RECOMMENDATIONS

The recommendations given from this study are:

- With several irrigation methods known in the literature apart from the widely known conventional irrigation system, it is important for clinicians to know the indications for each of the methods of irrigation so that it lies in the hands of the clinician to decide the best irrigation method depending on the case being handled. Hence, a customized irrigation method can be provided to each patient, which is individually tailored for their needs. Future research can emphasize strengthening the data available in the literature to enable the clinicians to make the best decisions for their patients easily.
- With the ever-evolving nature of the microbiota in the oral cavity and the root canal system, it is important to continuously study the changes and the newer strains that may be identified. Thereby, identifying innovative methods to eradicate microorganisms through irrigation is important, and studies in this end have to be conducted unceasingly to better understand the microbiome and obtain a sterile canal during the procedure.
- Owing to the complexity of the anatomy of the root canal system, there are definitely chances of encountering unique root canal anatomy during clinical practice, and studies highlighting the methods adopted during such scenarios can help other clinicians be aware of and learn about the diversity in the anatomy.
- With increasing technology, the visualization along with magnification of these structures have always improved and will continue to trajectorially enhance with the developing technology. Further studies can be done to employ equipment with higher resolution and advanced technology, which will, in turn, aid in studying the topic in greater depth, and unknown facts about the root canal system may be learnt.

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