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Efficacy of smear layer removal at apical third of root canal by different irrigation regimens using XP-endo Shaper: an *in vitro* SEM study

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Abstract

Background: Effective root canal therapy relies heavily on irrigation, as it is the sole method capable of reaching the internal anatomy of the root canal that remains inaccessible with mechanical instrumentation.
Aim: To compare the efficacy of different irrigation regimes on smear layer removal with XP-endo Shaper at the apical third of the root canal in lower premolars under a scanning electron microscope.
Materials and methods: Forty-four human single-rooted lower premolars were collected and decoronated to a standard length. Teeth were categorized into four groups based on the irrigation regimes: distilled water (DW Group), 5.25% NaOCl and 17% EDTA (SE Group), super-oxidised water and 17% EDTA (SPO Group), TWIN KLEEN solution (TK Group). Scanning electron microscopic evaluation was done at 3 mm from the apex to analyse the remaining amount of smear layer. Kruskal-Wallis test and Mann–Whitney U test were employed in this study.
Results: On comparing the ability of four different irrigation regimes to remove the smear layer, the SPO and SE Groups showed significantly higher smear layer removal ($p<0.05$) in the apical third of the root canal system than the TK and DW Groups.
Conclusion: In conclusion, the use of sodium hypochlorite or super-oxidised water throughout and post-instrumentation followed by chelator (EDTA) was found to be more efficient compared to a combination of NaOCl and HEBP solution in smear layer removal in the apical third instrumented with XP-endo Shaper.
Keywords: EDTA, Scanning electron microscope, Smear layer, Sodium hypochlorite (NaOCl), Super-oxidised water, XP-endo Shaper.

1. Introduction

Effective root canal therapy relies heavily on irrigation, as it is the sole method capable of reaching the internal anatomy of the root canal system that remains inaccessible with mechanical instrumentation [1]. The biomechanical procedure involving the instrumentation of canals leads to the development a smear layer on root dentin. This layer is characterized by its granular, amorphous, and irregular structure, obstructing the openings of dentinal tubules. The smear layer comprises both inorganic and organic components [2]. The smear layer hinders the entry of intra-canal medicaments and sealers into the dentinal tubules. Effective cleaning and shaping of the apical third of the root canal system are essential due to the presence of accessory canals and apical ramifications. Removing the smear layer in this region is crucial to achieve a fluid-tight seal during obturation and to enhance the effectiveness of root canal treatment [3].

Advances in endodontic rotary instruments, such as the XP-endo Shaper, have improved the efficiency of canal preparation. The XP-endo Shaper, manufactured by FKG Dentaire SA, performs an asymmetrical rotating action. It is equipped with a booster tip containing six cutting blades, which allows for more efficient canal preparation. The tip starts with an initial diameter of ISO 15 and subsequently expands to 30 while maintaining a taper of 0.01. After undergoing expansion, it achieves a canal preparation with a final diameter of 30 and 0.04 taper [4]. Using a single instrument has the potential to be more cost-effective and time-saving compared to employing sequential rotary instrument systems [5].

The most commonly used irrigation solution for disinfecting root canals is sodium hypochlorite (NaOCl) [6] due to its effectiveness against biofilms and its ability to

break down organic debris [7]. The interaction involving only the organic part is termed the 'soap effect' [8]. In contrast, the NaOCl solution cannot eliminate the accumulated hard tissue debris and inorganic constituents of the smear layer. Hence, it is commonly recommended to alternately apply ethylene-di-amine-tetra acetic acid (17% EDTA)to remove an inorganic portion of the smear layer [7].

Recently, other irrigating solutions, such as Super-oxidized water have demonstrated potent antimicrobial properties against bacteria, fungi, protozoa, and viruses. It consists of molecules that undergo dissociation into ions and free radicals. These entities promptly react and alter proteins, facilitating the removal of the smear layer [9,10]. Etidronic acid, also known as etidronate or HEBP (1-hydroxyethylidene-1,1-bisphosphonate) has been proposed as an alternative to chelators such as EDTA or citric acid [11]. The formation of a calcium complex by etidronic acid allows for short-term compatibility with sodium hypochlorite (NaOCl) [12]. A commercially available solution, TWIN KLEEN (HEBP + NaOCl), has been introduced to remove organic and inorganic debris.

Despite the advantages of mechanical preparation with the XP-endo Shaper, there is limited research evaluating its efficacy in combination with different irrigation protocols, particularly for cleaning the apical third of the root canal system. The apical region poses unique challenges due to its complex anatomy, including accessory canals and apical ramifications. While various irrigation regimens have been studied individually, their effectiveness when combined with the XP-endo Shaper, specifically in removing the smear layer in the apical third, remains underexplored. Therefore, this study aimed to evaluate the efficacy of smear layer removal at the apical third of the root canal with different irrigation regimens using XP-endo Shaper.

2. Materials and methods

2.1 Selection of teeth

The sample size of 44 was calculated using G*Power 3.1 software based on a previous study [2], with an effect size (f) of 0.55, $\alpha = 0.05$, and power of 0.80 for four groups. This resulted in a critical F value of 2.84 and an actual power of 0.84, ensuring sufficient sensitivity to detect differences among the groups. Forty-four human mandibular single-rooted premolars extracted for periodontal or orthodontic purposes were chosen. Hard deposits and soft tissue remnants on teeth were removed using a scaler. A single and straight root canal configuration in each premolar was assessed on the radiograph. Teeth with caries, calcified canals, open apices, developmental anomalies, and previously root canal-treated teeth were excluded and samples were kept in physiological saline solution until use.

2.2 Preparation of canal space

The teeth underwent decoronation and were standardized to a root canal length of 14mm as a flat reference point [2]. Root canal patency was evaluated by placing a stainless steel 15 K-hand file (MANI, INC.) through the canal until it just appeared at the apical foramen. The working length was obtained as 1mm short from the apex. Teeth were categorized into four groups. XP-endo Shaper (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) was operated at a speed of 800 revolutions per minute and 1 N-cm torque was exerted to gently perform 3-5 strokes until the canal was fully prepared to the desired operating length [13]. In the DW Group, about 2ml of distilled water, in the SE Group and the TK Group, 2ml of 3% NaOCl (Prime Dental products, India) and in the SPO Group, 2ml of super-oxidised water (Oxum, Alkem Laboratories, India) were used during instrumentation, followed by rinsing with 3ml of distilled water with a side-vented needle. The final irrigation protocol was as follows:

DW Group: Canals were irrigated using 5ml of Distilled Water,

SE Group: Canals were irrigated using 2.5ml of 5.25% NaOCl (CERKAMED Medical Company, Polaska), followed by 2.5ml of 17% EDTA (Prevest Denpro Limited, India),

SPO Group: Canals were irrigated using 2.5ml of Super-oxidised water (OXUM, Alkem laboratories, India), followed by 2.5ml of 17% EDTA (Prevest Denpro Limited, India),

TK Group: Canals were irrigated using 5ml of freshly prepared TWIN KLEEN (Maarc dental, India) solution using a 30-Gauge side vented needle.

For thorough irrigation at the apical third of the root canal, the needle was restricted to 1 mm from the apex. The canals were dried with sterile paper points.

2.3 Preparation of specimens for scanning electron microscopic evaluation

A diamond disc was used to prepare two longitudinal parallel grooves on lingual and buccal surfaces of the specimens without penetrating the root canals and cut into two halves using a chisel. The part that includes most of the apical region was selected and appropriately marked. Next, the specimens with assigned codes were affixed onto metallic stubs, coated with gold, and scanning electron microscope images were captured at a magnification of 5000X. The apical third of each sample was evaluated at a distance of 3 mm from the apex [13].

2.4 Scanning Electron Microscopic (SEM) evaluation

Two investigators were blinded to both the irrigation regimen used and the specimen groupings, and scored amount of a smear layer on the surface of root canal or in the dentinal tubules at the apical portion (Figure 1) according to the Hulsmann scoring criteria [14] as described below.

Score 1: No smear layer, dentinal tubuli open.

Score 2: Small amount of smear layer, some dentinal tubuli open.

Score 3: Homogenous smear layer covering the root canal wall, only few dentinal tubuli open.

Score 4: Complete root canal wall covered by a homogenous smear layer, no open dentinal tubuli.

Score 5: Heavy, non-homogenous smear layer covering the complete root canal wall.

2.5 Statistical analysis

The obtained data were analysed using the statistical Package for Social Sciences, SPSS 26.0, IBM Corporation, USA. The data were statistically analysed using the Kruskal-Wallis test and Mann-Whitney U test. The statistical significance level (p-value) was set at 0.05.

3. Results

The mean scores of smear layer removal in the apical third of the root canal system were given in Table.1. The mean smear layer removal scores among groups were as follows (where a lower score indicates better removal): SPO Group (1.636 ± 0.674) > SE Group (2.091 ± 0.539) > TK Group (3.363 ± 0.809) > DW Group (4.818 ± 0.404).

On comparing the smear layer removal efficiency of four different irrigation regimes from the apical third of the root canal system, all groups were showed a statistically significant difference (p=0.000) in smear layer removal compared to the DW Group (Table 1). SPO Group and SE Group significantly showed a higher smear layer removal in the apical third of the root canal compared to the TK Group.

On pair-wise comparison, DW group exhibited significant differences with the other groups (p=0.000). SPO Group and SE Group significantly showed a higher smear layer removal in the apical thirds of the root canal compared to the TK Group (p=0.001, and p=0.000, respectively). However, no significant difference between the SE Group and SPO Group was observed (Table.2).

Table 1. Comparison of mean scores of smear layer removal in the apical third of root canal using Kruskal-Wallis test (5000 X)

Groups	Mean	Standard Deviation	F value	P-value
DW Group	4.818	0.404	32.870	0.000*
SE Group	2.091	0.539		
SPO Group	1.636	0.674		
TK Group	3.363	0.809		

*Significant difference.

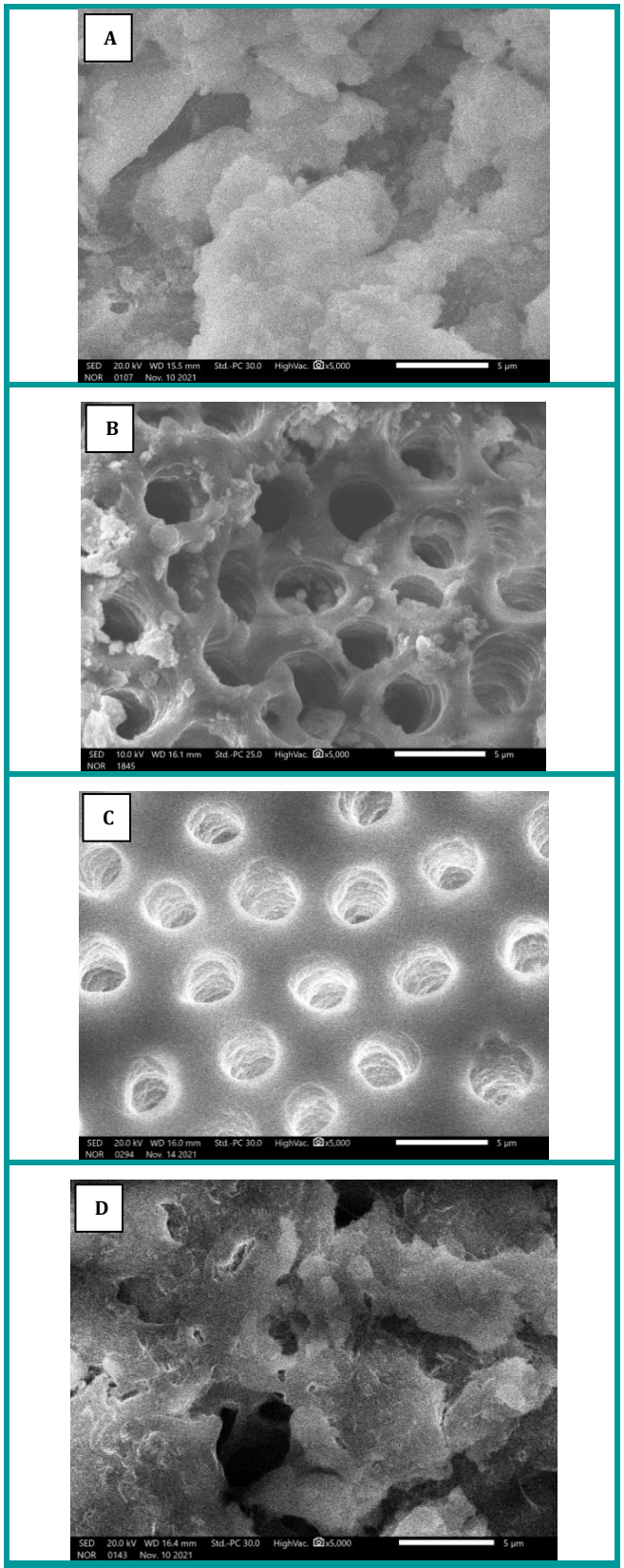
Table 2. Pair-wise comparison of mean scores of smear layer removal from apical third using Mann-Whitney U Test (5000 X)

Groups		Mean difference ± Standard Error	Significance
DW Group	SE Group	2.727 ± 0.306	0.000*
	SPO Group	3.182 ± 0.306	0.000*
	TK Group	1.454 ± 0.306	0.000*
SE Group	SPO Group	0.454 ± 0.306	0.578
	TK Group	1.273 ± 0.306	0.001*
SPO Group	TK Group	1.728 ± 0.306	0.000*

*Significant difference.

In the SEM analysis, the specimen in DW Group (Figure 1A) showed a dense smear layer covering the entire root canal wall. The surface appeared to be rough, and no visible open dentinal tubules were observed. The smear layer was thick and homogeneous.

The specimen in SE Group (5.25% NaOCl and 17% EDTA) demonstrated a well-cleaned surface with a significant number of open dentinal tubules (Figure 1B). The smear layer was mostly removed, the tubules were visible and open. Some minor remnants of the smear layer may still be present, but overall, the surface was clean.



fFigure 1. Scanning electron microscope images (5000X) for all groups. Where, A. DW Group; B. SE Group; C. SPO Group; and D. TK Group).

The specimen in SPO Group (Super-oxidised water and 17% EDTA) displayed a very clean surface with clear and well-defined open dentinal tubules (Figure 1C). No visible smear layer on the canal wall was observed; the tubules

were fully exposed and open, indicating excellent smear layer removal. The specimen in TK Group (TWIN KLEEN solution) exhibited a smear layer covering most of the root canal wall and a few dentinal tubules were visible in certain regions (Figure 1D). The smear layer removal was non-homogeneous.

4. Discussion

Cleaning and shaping the apical third of the root canal system is recognized as particularly challenging because of the complex anatomy, that is, the ramifications and the tortuosities [15]. Considering its narrow diameter, achieving complete removal of the smear layer particularly in the apical third of the root canal, is notably challenging. Because of complex anatomy and narrow diameter, conventional irrigation systems commonly fail to reach the apical third adequately. During irrigation, the irrigant solution cannot flow up to the apical third because of remaining fluid and gas particles in the apical third [16]. In this study, a 30-gauge side-opening needle was utilized, which effectively enhanced the contact of the irrigant to the canal walls for smear layer removal [2].

In this study, mandibular premolars were used because of the oval-shaped anatomical configuration, which presents a challenge to any instrumentation technique by having a higher percentage of the unprepared surface with intact debris along the root canal walls [17-19].

Compared to other instrument systems, the root canals prepared with XP-endo Shaper, particularly in oval-shaped canals led to a notably reduced smear layer and remaining debris [13]. This could be due to the unique adaptive core property of XP-endo Shaper, allowing enough space for debris to escape while expanding to cover the 3-dimensional morphology of the canal. The M-phase of XP-endo Shaper has an initial diameter of 15 and 0.01 taper which upon expansion achieves a final canal preparation with a diameter of 30 and 0.04 taper [20]. For the effective flow of irrigant solution at the apical third of the root canal, the minimum instrumentation size needed is a #30 file which was reported in the study conducted by Abbasali Khademi *et al.* [21]. A scanning electron microscope under 5000X magnification was used in this study as it allows it to cover finer details even in smaller surface areas with more accurate information [13].

In the present study, SE and SPO groups were more efficient in smear layer removal than the TK and DW groups. However, no significant difference was observed between the SE and SPO groups in smear layer removal. This efficiency in smear layer removal in the SE group and SPO group could be because of the serpentine-like configuration of XP-endo Shaper, which might facilitate the flow of respective irrigants during instrumentation (3%NaOCl in the SE group, super oxidised water in SPO Group) into the apical third of the root canal system, making an asymmetric motion. This might create powerful streaming turbulence enough to detach much of the smear layer from the walls of the root canal at the apical third.

In the SPO group, super-oxidised water was used instead of sodium hypochlorite (NaOCl) during and after instrumentation. It has plenty of reactive oxygen species and contains dissolving agents like, hypochlorous acid, sodium hypochlorite, ozone, hydrogen peroxide, and chlorine dioxide [9], which might facilitate the elimination of any remaining organic components of the smear layer. Super oxidised water, also called oxidative potential water (OPW), used as an endodontic irrigating solution throughout and post-instrumentation, showed better results in smear layer removal owing to its demineralizing activity, as corroborated in a study conducted by Hata G *et al*. [22]. Superoxidised water acts on inorganic and organic components of the smear layer without altering the dentinal surface [23], which, combined with 17% EDTA, a chelator, significantly removed the smear layer.

In the SE Group, 5.25% NaOCl followed by 17% EDTA was used as a final irrigation regimen. Literature suggests that NaOCl dissolves only the smear layer's organic matter, which is a blend of organic and inorganic components. So, an alternative application of chelating agent, i.e., 17% EDTA is used in the present study, which dissolves the inorganic components of the smear layer. In the present study, 5.25% NaOCl followed by 17% EDTA showed better results owing to the additive effect of both 5.25% NaOCl and 17% EDTA [7].

In the TK group, freshly prepared TWINKLEENsolution, which combination of 3% NaOCl and 9% (wt/vol) etidronic acid (1-hydroxy-ethyl-idene-1, 1-bisphosphonate; HEBP) comparatively showed lesser efficacy in smear layer removal from root canal system at the apical terminus. This could be because a relatively low concentration of NaOCl, i.e.,3%, was used. Hypochlorite-compatible chelator (HEBP) can reduce but not entirely prevent the smear layer, as 9% (wt/vol) etidronic acid (HEBP) is a less potent chelating agent than 17% EDTA. This is consistent with findings from the previous study by Paqué F *et al*. [24,25].

As the present study was evaluated in in-vitro conditions, further clinical research should be done to evaluate the effectiveness of different irrigation regimes under various irrigant activation methods in removing the smear layer in the curved and complex anatomical configuration of the root canals.

5. Conclusion

Within the limitations of this in vitro study, using sodium hypochlorite or super-oxidized water during and after instrumentation, followed by EDTA, was more effective in removing the smear layer at the apical terminus compared to the combination of NaOCl and HEBP, when using the XP-endo Shaper system.

6. Clinical Significance

Sequential use of Super-oxidised water+17% EDTA and 5.25% NaOCl+17% EDTA solution was found to be more efficient than Etidronate and 3%NaOCl in smear layer removal in the apical third of root canal instrumented with XP-Endo Shaper.

Conflicts of interest: Authors declared no conflicts of interest.

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