Original Article

Effects of Seven Different Irrigation Techniques on Debris and the Smear Layer: A Scanning Electron Microscopy Study

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ABSTRACT

Aim: Conventional manual irrigation with a syringe and needle remains widely accepted technique in the irrigation procedures. However, its flushing action has some limitations. Currently, several techniques and systems are available and reported to improve the insufficiency of syringe irrigation. The aim of this study was to evaluate the effectiveness of 7 different irrigation techniques compared to standard irrigation. **Materials and Methods:** Straight roots from 80 extracted human maxillary central incisors were collected, and root canals were instrumented with K-files up to apical size 50. The teeth were randomly divided into 8 groups (n = 10), and final irrigation procedures were performed with 17% ethylenediaminetetraacetic acid and 5.25% NaOCl solutions using following irrigation agitation techniques: RinsEndo, EndoVac, Canal CleanMax, sonic, Canal Brush, NaviTip FX, manual dynamic irrigation, and conventional irrigation. The presence of debris and smear layer (SL) at coronal, middle, and apical thirds was evaluated by using a 5-grade scoring system with ×200 and ×1000 magnification, respectively. **Results:** Concerning debris removal, the MM 1500 sonic group reduced apical debris significantly better than the other groups tested ($P < 0.05$). There was no significant difference among the tested groups ($P > 0.05$) related SL removal in all levels. **Conclusions:** MM 1500 scored best with debris removal; however, there was no significant reduction in the SL in apical third with any of the methods tested.

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KEYWORDS: *Canal Brush, Canal CleanMax, EndoVac, NaviTip FX, RinsEndo*

INTRODUCTION

It is accepted that bacteria and their products play significant roles in the initiation and progression of pulpo-periapical pathology. The main principle of endodontic treatment is to control the microbial factors in the complex root canal anatomy, particularly in the apical one-third.[1]

Irrigation is a vital part of root canal therapy because chemo mechanical preparation alone does not predictably remove pulp tissue, dentin, debris, and the smear layer (SL) in infected root canals. Moreover, biomechanical instrumentation creates an SL that contains organic and inorganic material originating from dentin, odontoblastic processes, necrotic debris, and microorganisms along with their metabolic products.[2] During root canal therapy, an efficient irrigation system to flush out debris, dissolve organic tissue, kill microbes, destroy microbial by-products, and remove the SL is needed.[3]

If an irrigation system does not remove the SL, bacteria can remain in this layer and may survive, multiply,[4] and grow into the dentinal tubules.[5] In addition, to provide an environment suitable for microbial growth, the SL affects the penetration of intracanal medications and root canal sealers into dentinal tubules.[6] Although there is no clinical evidence on the treatment outcome in a recent systematic review, it was concluded that SL removal improved the fluid tight seal of root canal system.[7] Several studies have compared the efficacy of irrigation with ethylenediaminetetraacetic acid (EDTA) and NaOCl and their effects on SL removal. The most effective final flush has been reported to be 10 mL of 17% EDTA followed by 10 mL of 5.25% NaOCl; this removed the

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SL completely in middle and coronal thirds of the canal preparations but was less effective in the apical third.[8] Syringe irrigation is the standard procedure, but the effectiveness of irrigation solutions remains limited in the apical third of prepared canal.

Conventional manual irrigation with a syringe and needle remains a widely accepted technique.[9] However, its flushing action has several limitations, such as nonaccessible fields of the root canals, the diameter and rigidity of the needle,[10-12] and the curvature of root canals.[13-16]

Currently, several techniques and systems that have been reported to improve the efficacy of syringe irrigation are available. The RinsEndo (Dürr Dental, Bietigheim, Germany), EndoVac (Discus Dental, Culver City, CA, USA), and Canal CleanMax (Maximum Dental, Secaucus, NJ, USA) have introduced an irrigation technique using a combined irrigation and suction mechanism. While the RinsEndo works based on suction under hydrodynamic pressure, negative pressure pulls the irrigant down to the canal, and the high-speed suction siphons off the irrigant in EndoVac system. One of the advantages of both systems is eliminating extrusion of the irrigant into the periapical tissues. Desai *et al.*[17] showed no extrusion of irrigant with EndoVac system, compared with the RinsEndo, ultrasonic, EndoActivator, and manual irrigation. In addition, machine (CanalBrush; Coltène/Whaledent, Langenau, Germany) and nonmachine (NaviTip FX; Ultradent, South Jordan, UT, USA)-type brush systems are available to remove both the debris and the SL from root canals more effectively with a brushing motion. Furthermore, hand files, gutta-percha cones, and sonic and ultrasonic devices may be used to improve the efficacy of irrigation solutions.

The aim of this study was to evaluate the effectiveness of seven irrigation techniques versus standard irrigation.

Materials and Methods

Straight roots from 80 extracted human maxillary central incisors were collected and stored in tap water throughout the study. Inclusion criteria were as follows: Intact apices, and no root caries, fractures, or external root resorption.

The length of the working length was measured by inserting a size 10 K-type file (Dentsply Maillefer, Ballaigues, Switzerland) into the root canal until the tip of the instrument was just visible at the apical foramen. Each tooth was decoronated with water-cooled diamond-coated bur, and the roots were adjusted to a standardized length of 16 mm. The working length of root canals was adjusted to 15 mm. To simulate the clinical situation, the apex was sealed with sticky wax. Root canals were instrumented with K-files up to the apical size of 50 with standardized preparation technique and irrigated with 2 mL 5.25% NaOCl between each file. The teeth were divided randomly into 8 groups (n = 10) and final irrigation procedures were performed. Irrigation techniques used were:

Control group

No additional agitation of the irrigant was performed. The root canals were irrigated with a 27-gauge needle plus dental syringe with 5 mL 17% EDTA for 1 min and 10 mL 5.25% NaOCl for 2 min.

RinsEndo group

The irrigant was delivered and agitated by the activation of RinsEndo hand piece (Dürr Dental, Bietigheim, Germany) using the needle provided by the manufacturer (needle size 45 with a lateral opening of 7 mm). The delivery rate was set by the manufacturer at 6.2 mL/min. Each canal was irrigated with 5 mL 17% EDTA for 1 min and 10 mL NaOCl for 2 min delivered via the RinsEndo system.

EndoVac system group

Macro irrigation of each canal with 5.25% NaOCl was accomplished over a 30 s period using the EndoVac (Discus Dental Culver City, CA, USA) delivery/evacuation tip. The macro cannula was moved constantly up and down in the canal until it started to bind to a point just below the orifice, which was followed by 2 cycles of micro irrigation. During a cycle of micro irrigation, the pulp chamber remained full of irrigant while the micro cannula was placed at working length. First, 1 min with 17% EDTA and 1 min soaking was followed by 1 min with 5.25% NaOCl and 1 min of soaking in 5.25% NaOCl. At least 5 mL of 17% EDTA and 10 mL of 5.25% NaOCl were used in each canal.

Canal CleanMax group

Each canal was flushed with 5 mL 17% EDTA for 1 min and 10 mL 5.25% NaOCl for 2 min (final irrigation) with disposable "insert tubes." The insert tubes were connected to the nozzle of the suction head and inserted into the root canal system during irrigation. Fluid and debris from the root canal system were aspirated through the insert tubes. The "power control ring" of the Canal CleanMax hand piece (Maximum Dental, Secaucus, NJ, USA) was opened completely, so that the maximum water flow was delivered and the maximum negative pressure was produced during the irrigation.

MM 1500 sonic hand piece group

Each canal was flooded with 5 mL 17% EDTA solution and a size 15 rispisonic file was activated for 1 min. The procedure was repeated for 10 mL NaOCl solution for 2 min.

CanalBrush group

The final irrigation (5 mL 17% EDTA and 10 mL 5.25% NaOCl) solutions were activated using a polypropylene CanalBrush with a tip diameter of 0.25 mm (CanalBrush; Coltène/Whaledent, Langenau, Germany) in a hand piece set at 600 rpm for 1 min.

NaviTip FX group

A 30-gauge irrigation needle covered with a brush (NaviTip FX; Ultradent, South Jordan, UT, USA) was placed into the canal. Push-pull strokes were performed along the canal wall, each with 6 mm amplitude reaching 1 mm short of the working length. The strokes included concomitant delivery of irrigants, first with 5 mL 17% EDTA, and then 10 mL 5.25% NaOCl for 1 min.

Manuel dynamic irrigation group

Each canal was flooded with 5 mL 17% EDTA solution and was activated using a gutta-percha cone for 1 min in each canal. The frequency of activation used was 100 push-pull strokes/min. The canals were then flushed with 10 mL of 5.25% NaOCl and activated in the same manner.

In all groups, needles and brushes were introduced, until 1 mm short of the working length (apical size 50) exception for the EndoVac group, as described above.

After the final irrigation procedures, the actions of the irrigants were ended with 2 mL sterile saline with a dental syringe (27-gauge needle). A diamond disc was used to make a horizontal groove between the apical third and the coronal third, as well as a longitudinal groove in a buccolingual direction. Colored gutta-percha cones were fitted and used as markers to best gauge the groove depths and to avoid intrusion of the cutting disk into the canals. The roots were separated by applying slight pressure with a chisel in the horizontal groove, and 2 separated parts were obtained from each sample.

The specimens were coated with gold and analyzed with a scanning electron microscope (Quanta 400F Field Emission SEM, FEI Company, USA). Images were captured from the apical, middle, and coronal region of both root halves of each specimen at ×200 magnification for debris scores and ×1000 magnification for smear scores [Figure 1].

The amount of remaining debris was scored by a blinded observer using a 5-point system described, previously.,[18,19] The presence of debris was evaluated from scanning electron microscope (SEM) images using the following scores: (1) Clean canal wall and few small debris particles, (2) few small agglomeration of debris,

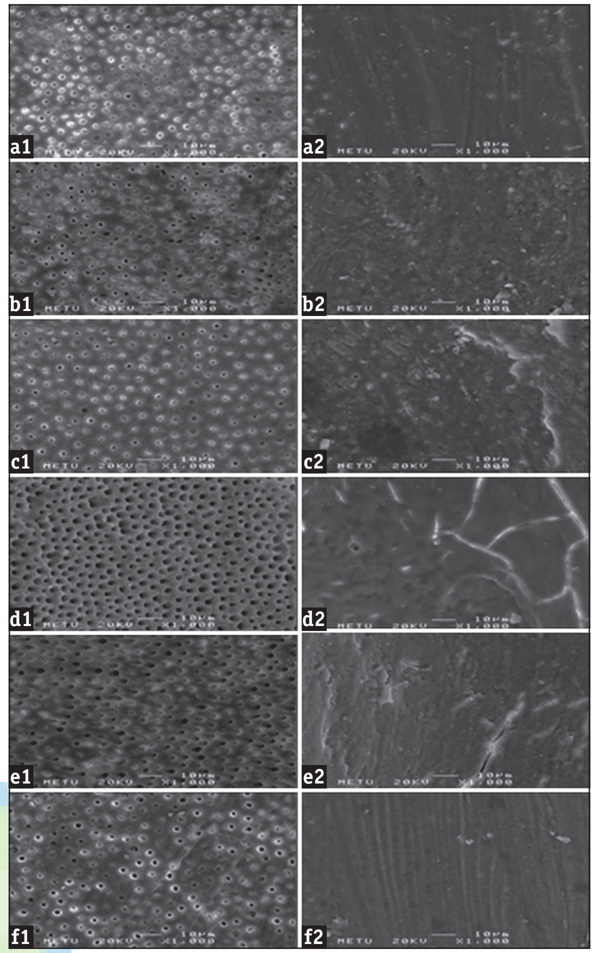

Figure 1: Representative scanning electron microscope micrographs (×1000) showing selected samples from the middle and apical segments, (respectively, from the left to the right) are representing the different irrigant activation techniques. (a1-a2) RinsEndo group, (b1-b2) EndoVac group, (c1-c2) Canal CleanMax group, (d1-d2) MM 1500 sonic group, (e1-e2) Canal Brush group, (f1-f2) NaviTip FX group

(3) many agglomeration of debris covering <50% of the canal wall, (4) more than 50% of the canal wall covered with debris, and (5) all or nearly all of the canal wall covered with debris.

The presence of a SL was evaluated from SEM images using the following scores: (1) No SL, all dentinal tubules open, (2) small amount of SL, some dentinal tubules open, (3) homogeneous SL covering the canal wall, only a few dentinal tubules open, (4) complete canal wall covered with a homogeneous SL, no open dentinal tubules, and (5) heavy inhomogeneous SL covering the complete canal wall.

The independent observer was blinded to the coded specimens and had been trained in the scoring procedure, resulting in sufficient intraobserver reproducibility. The scored sections of the root canal were selected by chance.

In the statistical analysis, the conformity of the parameters to a normal distribution was tested. Differences among thirds were tested using Kruskal–Wallis test and Mann–Whitney U-test for pair-wise comparisons. Multiple comparisons were adjusted using a Bonferroni correction. All statistical analyses were performed with the SPSS software (version 18.0; SPSS, Inc., Chicago, IL, USA).

Results

The results of the SEM analysis of the canal walls concerning residual debris and SL are summarized in Table 1. Scores of 1 and 2 were accepted as clean canal walls, in terms of both debris and smear to simplify the data.

Debris scores of the coronal and middle thirds indicate clean canal walls in all of the experimental groups, with the exception of the control group. Considering the apical third, 6 of 10 samples in the RE group, 5 of 10 samples in the EV group, 9 of 10 in the CCM group, 2 of 10 in the MM1500 group, 5 of 10 in the CB group, 7 of 10 in the NFX group, and 8 of 10 samples in the MDI group, showed 3, 4, or 5 debris scores [Figure 2]. The MM 1500 group exhibited the best scores in the apical region, and there were statistically significant differences among the CCM, NFX, MDI, and control groups ($P < 0.05$). No difference was found among the RE, EV, and CB groups.

In terms of the SL scores in the coronal third, all experimental groups showed clean canal walls. The control group showed a heavy SL at all levels. Investigating the middle third, the RE, CCM, CB, and NFX groups showed clean canal walls. However, 2 samples in the EV and MM 1500 groups, and 1 sample in the MDI group showed "3" smear scores. In the analysis of the apical third, 6 of 10 samples in RE, 9 of 10 in EV and CCM, 7 of 10 in MM 1500, 8 of 10 in MDI, and all 10 samples in the CB, NFX, and control groups, showed smear scores of 3, 4, or 5 [Figure 3]. The EV group had the highest scores in the apical third, but there

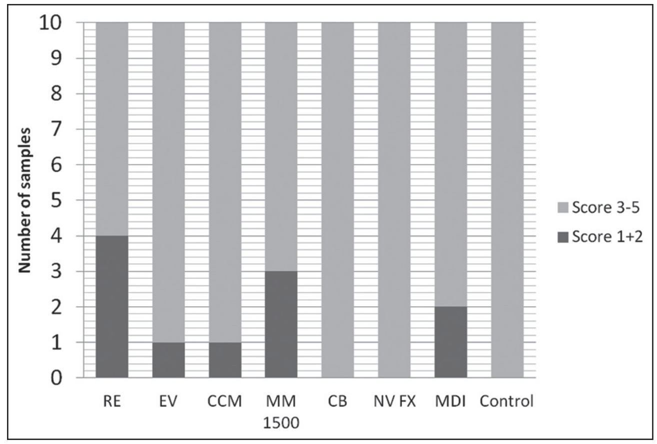

Figure 2: Distribution of debris scores at apical thirds. Data were dichotomized for graphic illustration: Scores 1-2 (clean canal wall) versus 3-5 (debris present)

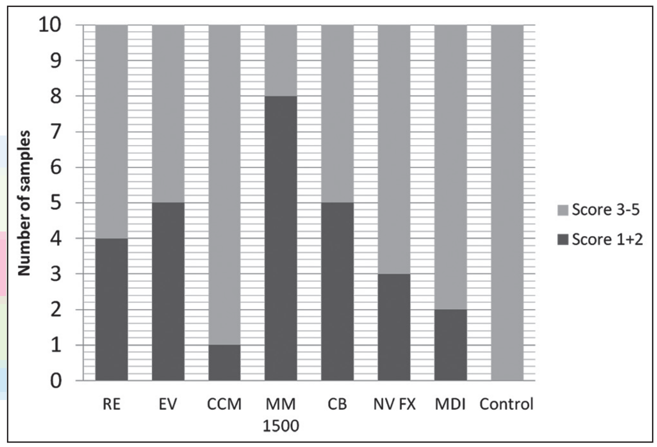

Figure 3: Distribution of smear scores at apical thirds. Data were dichotomized for graphic illustration: scores 1-2 (clean canal wall) versus 3-5 (smear present)

Table 1: Results of SEM evaluation of remaining debris and smear layer

Score	RinsEndo				EndoVac				Canal clean max				MM 1500				Canal brush				NaviTip FX				MDI				Control			
	C	M	A	Total	C	M	A	Total	C	M	A	Total	C	M	A	Total	C	M	A	Total	C	M	A	Total	C	M	A	Total	C	M	A	Total
Debris																																
1	7	4	1	12	4	6	0	10	9	9	0	18	9	6	0	15	10	5	0	15	9	8	0	17	8	4	0	12	0	0	0	0
2	3	6	3	12	6	4	5	15	1	1	1	3	1	4	8	13	0	5	5	10	1	2	3	6	2	6	2	10	0	0	0	0
3	0	0	6	6	0	0	3	3	0	0	9	9	0	0	2	2	0	0	5	5	0	0	7	7	0	0	8	8	1	0	0	1
4	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	9	25
n				30				30				30				30				30				30				30				30
Smear																																
1	8	6	2	16	6	3	0	9	10	10	0	20	7	6	0	13	8	3	0	11	5	7	0	12	5	3	0	8	0	0	0	0
2	2	4	2	8	4	5	1	10	0	0	1	1	3	2	3	8	2	7	0	9	5	3	0	8	5	6	2	13	0	0	0	0
3	0	0	4	4	0	2	3	5	0	0	6	6	0	2	6	8	0	0	7	7	0	0	7	7	0	1	4	5	0	0	0	0
4	0	0	0	0	0	0	4	4	0	0	3	3	0	0	1	1	0	0	0	0	0	0	2	2	0	0	3	3	2	0	0	2
5	0	0	2	2	0	0	2	2	0	0	0	0	0	0	0	0	0	0	3	3	0	0	1	1	0	0	1	1	8	10	10	28
n				30				30				30				30				30				30				30				30

SEM=Scanning electron microscopem, MDI: Manual dynamic irrigation was no significant difference among the groups tested ($P > 0.05$). In the apical third, the RE and MM 1500 groups had the lowest scores, but without any significant difference ($P > 0.05$).

Discussion

Several studies[16,19,20] to date have emphasized the poor performance of conventional irrigation in the removal of debris and SL, especially in the apical third. Canal curvature and apical preparation size remain a challenge for the delivery of irrigation solutions to the apical third, due to the penetration depth of irrigation needles.[20] The aim of this study was to evaluate the effectiveness of several irrigation systems such as; sonic irrigation, acoustic streaming, pressure-suction, and endodontic brushes in the removal of debris and SL.

Removal of the debris and SL during or after root canal instrumentation[21,22] requires the use of irrigants that can dissolve both organic and inorganic components. The method recommended for this purpose involves a final rinse with 15% or 17% EDTA solution followed by 1–6% NaOCl. However, there is no consensus with respect to the optimal volume,[4,23] time of application,[24,25] or the activation method to use with irrigating solutions.[26-29] We used 5 mL 17% EDTA and 10 mL 5.25% NaOCl solutions as a final rinse protocol for the effective removal of debris and SL in this study. Previous studies used smaller irrigant volumes.[19,30] Moreover, this may be the reason for the absence of significant differences among the tested groups. The high volume of irrigation may have eliminated the effects of the agitation methods.

In this study, the MM 1500 group (sonic irrigation) had the lowest scores in both smear and debris removal. Sonic irrigation has been compared with ultrasonic irrigation and showed no significant difference between them,[27,31] but exhibited better results than conventional needle irrigation. In accordance with the previous studies,[19,27,28,31] better results were achieved with sonic irrigation in the current study.

The lack of efficacy of conventional syringe irrigation has been reported previously. The irrigating solution was delivered only 1 mm deeper than the tip of the needle.[32] To enhance the efficacy of irrigation, MDI was used. This was recently confirmed by the studies of McGill *et al.*[33] and Huang *et al.*[15] Their studies demonstrated that MDI was significantly more effective than an automated dynamic irrigation system (RinsEndo) and static irrigation. Rödig *et al.*[16] concluded that passive ultrasonic irrigation was more effective than syringe irrigation or RinsEndo in removing debris from the artificial extensions. However, Vivan *et al.*[34] found no difference in the cleaning ability of the RinsEndo system versus conventional irrigation. The RE group had the lowest smear removal scores in our study. In total, 24 of 30 specimens showed clean dentin walls, but there was no significant difference between the study groups and the control group.

Many researchers have tested endodontic brushes to improve removal of debris and SL from the root canals in *in-vitro* settings,[35,36] but the CanalBrush did not improve SL removal in one *in-vitro* study.[37] Garip *et al.*[29] showed a cleaner surface in the narrower parts of the root canal (middle and apical), where it was in closer contact with the root canal surface. In the present study, the NaviTip FX and CanalBrush were evaluated. There was no significant difference between the brush systems and the other groups, tested in terms of debris and smear removal. Both brush systems displayed results identical to the control group in smear at the apical third, but it was effective in removing debris in the coronal and middle thirds.

The size of the aspirator tip of the Canal CleanMax irrigation system was about #60 K-file, and this could reach to 1 mm short of the working length; thus, the canals prepared were set to #50 K-file. To our knowledge, no study regarding this irrigation system has been reported. In this study, we showed that the CCM system was successful in the coronal and middle thirds, but showed unsatisfactory results in the apical third, as did in the other irrigation systems.

During the sample preparation in the EV group, one of the complexities was the blockage of the microcannula. Nielsen *et al.*[38] reported a similar problem in their study. To eliminate blockage, a macrocannula was used until the apical size of the canals reached number 35, reducing the amount of material that might clog the microcannula. With the EndoVac, the irrigant is pulled into the canal and removed by the negative pressure at working length. Nevertheless, it was not effective in the apical portion, unlike the coronal and middle portions. In addition, Mancini *et al.*[39] showed that EV had significantly lower smear scores at 1 mm from the apex. The mean score in the EV group (3, 70) in the apical third was lower than Mancini's (3, 94).

In the apical third, none of the tested irrigation devices could remove the SL and debris completely. The RinsEndo and MM 1500 resulted in more open dentinal tubules than the other tested devices, but the difference was not significant. In a clinical situation, debris-filled root canal extensions or isthmus are challenges to clean. The teeth were embedded in a sticky wax, representing a closed system. The fluid behavior in the apical region of this model may have influenced the irrigation performance. Adequate irrigant replacement is prevented in a closed system because of a "dead-water zone" in the apical region.[40] Although the use of small-diameter needles via insertion to within 1 mm of the working length appeared to be a logical conclusion from the simulation studies, the contribution of the apical vapor lock to canal debridement had not been appropriately addressed.[41]

Conclusion

Several agitation techniques were evaluated. Significantly better results were found with the MM 1500 (sonic) in debris removal, but no significant difference among the groups in SL removal was evident. The clinical use of irrigation techniques has become more important in terms of handling properties, apical extrusion of irrigants, frequency of occurrence, and need for sterilization. In addition, from a practical point of view, no evidence-based study that attempted to correlate the clinical efficacy of these devices with improved treatment outcomes has been reported to date.[20]

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Conflicts of interest

There are no conflicts of interest.

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