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ORIGINAL ARTICLE/ARTICOLO ORIGINALE

Efficacy of three different irrigation techniques in the removal of smear layer and organic debris from root canal wall: a scanning electron microscope study

Efficacia di tre diverse tecniche di irrigazione canalare nella rimozione del fango dentinale e dei detriti organici: analisi al microscopio elettronico a scansione

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KEYWORDS
Conventional irrigation;
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Organic debris;
Smear layer.

Abstract
Aim: Aim of this study was to compare the removal of smear layer and organic debris within the tooth canal among conventional needle irrigation, EndoVac and Endoactivator.
Methodology: Eighty single-rooted extracted human teeth were prepared with rotary NiTi instrumentation and randomly separated into 4 groups. Twenty teeth were used as positive control (Group 1), irrigated with only saline. Teeth assigned to Group 2 ($n = 20$) received irrigation with a conventional syringe and a 30-gauge needle (NaviTip, Ultradent, South Jordan, UT);

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samples in Group 3 ($n = 20$) were rinsed with an irrigation device based on apical negative pressure (EndoVac, Discus Dental, Culver City, CA) and teeth in Group 4 ($n = 20$) were treated with a sonic irrigation system (EndoActivator, Dentsply Tulsa Dental, Tulsa, OK, USA). The amount of residual smear layer and debris was evaluated under a scanning electron microscope, and a semi-quantitative score was assigned to each root at the coronal, middle and apical thirds; the chi-square test was used to compare the results of the S.E.M. analysis.
Results: EndoActivator performed the best cleansing for both smear layer and organic debris in all root canal thirds, followed by EndoVac and conventional irrigation ($p > 0.001$). EndoVac and conventional irrigation showed better cleaning in the coronal area, whereas EndoActivator performed an homogeneous cleansing at all levels.
Conclusions: The EndoVac system and the EndoActivator system demonstrated significantly more efficacy in cleansing root canal walls than conventional needle irrigation.

PAROLE CHIAVE
Irrigazione convenzionale;
EndoActivator;
EndoVac;
Detriti organici;
Fango dentinale.

Riassunto
Obiettivi: Lo scopo dello studio è quello di comparare la capacità di rimozione del fango dentinale e dei detriti organici di tre diverse tecniche di irrigazione canalare: Siringa convenzionale, EndoVac, EndoActivator.
Materiali e metodi: 80 denti monoradicolati sono stati alesati con strumenti in NiTi e divisi in 4 gruppi. 20 campioni sono stati utilizzati come controllo positivo ed irrigati quindi solo con soluzione salina (Gruppo 1). I denti del Gruppo 2 (n = 20) sono stati irrigati con siringa convenzionale (NaviTip, Ultradent, South Jordan, UT); i campioni del Gruppo 3 (n = 20) sono stati trattati con uno strumento di irrigazione a pressione negativa (EndoVac, Discus Dental, Culver City, CA) e quelli del gruppo 4 (n = 20) con un sistema di irrigazione sonica (EndoActivator, Dentsply Tulsa Dental, Tulsa, OK, USA). I residui di fango dentinale e di detriti organici all'interno del canale radicolare sono stati valutati tramite l'utilizzo di un microscopio elettronico a scansione ed un sistema di punteggio semi-qualitativo considerando tre diverse zone del canale: apicale, medio e coronale. I dati ottenuti sono stati sottoposti a test statistico (test chi-quadro).
Risultati e conclusioni: La miglior rimozione di fango dentinale e detriti organici è stata ottenuta con l'EndoActivator, seguito dall'EndoVac e dall'irrigazione convenzionale ($p < 0.001$). L'Endovac e l'irrigazione convenzionale hanno ottenuto i migliori risultati nella parte coronale del canale mentre l'EndoActivator ha deterso il canale a tutti i livelli.

L'EndoActivator e l'Endovac hanno mostrato una maggiore capacità di rimozione di fango dentinale e detriti organici rispetto all'irrigazione convenzionale.

Introduction

The aim of an endodontic treatment is to eliminate microorganisms from infected radicular canals using a biomechanical procedure combined with an antibacterial therapy to achieve the periapical tissue healing.[1] In clinical practice, the goal of instrumentation is to remove some hard tissue from the root canal, facilitate satisfactory delivery of irrigants to the apical anatomy and give the canal system a shape that allows both a predictable and a permanent root filling.[2] Mechanical instrumentation alone or with saline irrigation cannot predictably eliminate the bacteria from infected root canals,[2,3] whereas instrumentation combined with adequate irrigation is mandatory to complete the cleaning process and reduce the microbial load in the canal system.

The goal of irrigants is to increase mechanical debridement by flushing out debris, disinfecting the root canal system and dissolving pulp tissue. At present, there is no unique irrigant that meets all the conditions listed above,[4] therefore, the method of choice has been the alternating use of ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite solutions.[5] Although this conventional irrigation has been widely used and accepted in contemporary clinical practice, its action is insufficient to completely remove debris from the irregularities of the root canal anatomy.[6] For this reason, numerous alternative irrigation methods have been proposed.[7]

The ability of an irrigant to reach the apical portion of the canal depends on the size of mechanical instrumentation, canal anatomy and delivery system;[8] for optimal effectiveness, irrigants must have direct contact with the entire root canal wall.[5] Therefore, different manual and mechanical agitation techniques have been proposed to deliver the irrigant solution into the apical area of the root canal: needle irrigation, hand files, rotary brushes, gutta-percha cones, ultrasonic and sonic devices.[7]

This study focused on apical-negative pressure irrigation and sonic systems.

The EndoVac system (Discus Dental, Culver City, CA) is the apical-negative pressure irrigation device, and it has been described by Schoeffel.[9]

It has been developed to overcome the vapour lock effect and grant a better and safer disinfection of the apical third of the root canal than other irrigation techniques.[4,9]

The "vapour lock effect" is a well-known physical phenomenon based on air entrapment by an advancing liquid front in a closed-end microchannel,[10] and the penetration capability of the fluids depends on the depth and diameter of the channel and the contact angle of the liquid.[11] During positive-pressure irrigation in the endodontic therapy, there could be air entrapment in the apical third of the root canal that could interfere with the proper advancement and disinfection of the irrigant solution. In fact, the canal behaves as a closed-end channel that causes gas entrainment at its closed end.[12] The use of EndoVac is supposed to provide a plausible solution to this problem because this method allows a safe delivery to working length with minimal chances of periapical extrusion, and it creates a constant flow of fresh irrigant in direct contact with the surfaces of the canal walls, which avoids air entrapment and grants its effective action.[4]

The EndoActivator system (Advanced Endodontics, Santa Barbara, CA) is a sonically driven canal irrigation device that produces vigorous intracanal fluid agitation. This sonic device seems to be more effective in the removal of bacteria and smear layer from the root canals than conventional irrigation.[13,14] The EndoActivator seems to have a minimal account of irrigant extruded out of the apex compared to other irrigation devices,[15] and the frequency of extrusion depends on apical preparation size.[16]

The aim of this *in vitro* study is to compare the efficacy of the EndoVac system, the EndoActivator device and conventional irrigation in the removal of organic debris and smear layer from root canal walls. The null hypothesis was tested that there is no statistical difference between systems.

Materials and methods

Eighty single-rooted extracted human teeth were used in this study. Criteria for tooth selection required no previous endodontic treatment and intact apices. Teeth with extensive restorations, root caries, fractures, immature apex and root length shorter than 11 mm were excluded from the study. The presence of a single canal was verified by radiographs taken in both mesiodistal and buccolingual directions.

The external surface was cleaned ultrasonically and a flat occlusal surface was made as a reference for working length. A manual size 10 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the canal until the tip of the file was visible at the apical foramen, and 1 mm was reduced to obtain the working length. The coronal portion was enlarged using #1, #2, and #3 Gates Glidden (Dentsply, Tulsa, OK).

To simulate the clinical situation, specimens were inserted in silicone (Putty Soft Normal Set, Elite HD+, Zhermack) to seal the apex.

The samples were randomly divided into four groups. All the shaping and cleaning procedures were performed by the same operator to avoid intraoperator variability.

The rotary nickel-titanium ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) were used to prepare the root canals with a crown-down technique up to a size F4 (300 rpm); the apical patency was maintained during the procedure using a #10 K-file to the working length. The irrigation was performed after each rotary instrument. Group 1 ($n = 20$) was used as control and it was irrigated only with saline solution. The other 60 root canals were rinsed with 3 mL NaOCl 5.25%, which was delivered by a syringe and a 30-gauge needle (NaviTip; Ultradent, South Jordan, UT) that was inserted as deep apically as possible without binding. Then, the samples of each group were subjected to different irrigation protocols.

Group 1 ($n = 20$): control group with saline solution

The same instrumentation protocol was followed, using a syringe and a 30-gauge needle (NaviTip), but only saline solution was used as irrigant.

Group 2 ($n = 20$): conventional irrigation

Samples were treated with 5 mL EDTA (17%) for 3 min and a final rinse with NaOCl (5.25%) for 3 min, 2 mm short of working length, using a syringe and a 30-gauge needle (NaviTip).

Group 3 ($n = 20$): EndoVac

After instrumentation, root canals were treated with "macroirrigation:" 6 mL NaOCl (5.25%) was delivered during a 30-s period by the master delivery tip, and the macrocannula was constantly moved from the cementum enamel junction to 5 mm from working length. The "microirrigation" is made up of three microcycles, with the microcannula placed at the beginning to length and moved 2 mm up every 6 s for an amount of 30 s. 5.25% NaOCl was used in the first microcycle, 17% EDTA in the second cycle and 5.25% NaOCl in the third microcycle. The EndoVac protocol was very similar to that used by Schoeffel and Siu.[17,18]

Group 4 ($n = 20$): EndoActivator

A rinse with 5 ml of 17% EDTA for 3 min and 5 ml of sodium hypoclorite at 5.25% (Niclor 5, Ogna; Italia) for 3 min was performed.

The irrigant was introduced into root canals by using conventional syringe. At the end of irrigations the root canal was filled before with EDTA and then with NaOCL and then they were sonically activated by using the appropriate bits (25.04) of the EndoActivator system to avoid the contact with the walls of the canal during use. The tip was left free and could reach up to 2 mm from working length. The EndoActivator device was used with "up and down" short vertical movements with an oscillation of 2—3 mm for 30 s. Remaining irrigant was removed with a syringe with a 30-gauge needle.

After preparation, two grooves were cut along the axis of each tooth using a diamond disk, and the samples were split longitudinally into halves using a chisel; the halves of each root were stored in 2% thymol solution at room temperature and then mounted on stubs, gold-sputtered, and examined under a scanning electron microscope (SEM) (DSM 960; Zeiss, Oberkochen, Germany). The amount of remaining debris and smear layer in the coronal, middle and apical regions of root canals was scored according to the following criteria: the presence of debris was evaluated from images at 700× magnification by two examiners. Scores

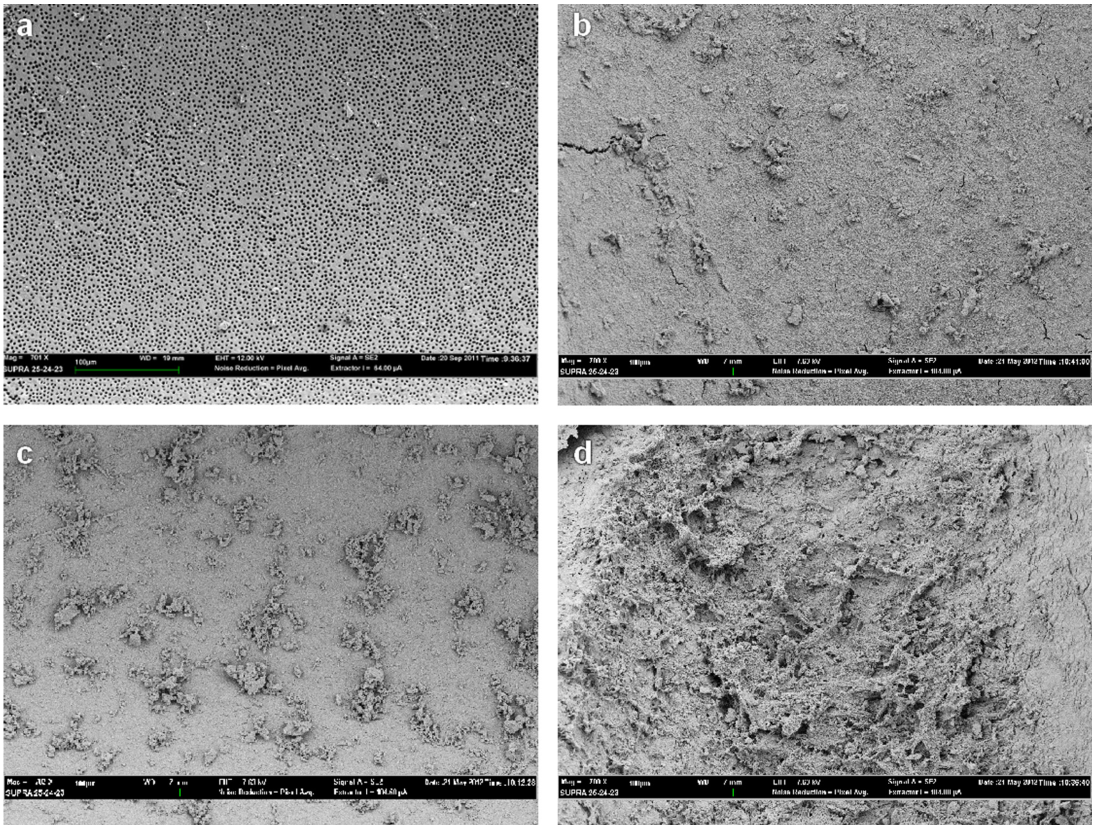


Figure 1 Examples of organic debris scores obtained under scanning electron microscopy (700×). Score 1 (a), score 2 (b), score 3 (c) and score 4 (d).

from 1 to 4 were assigned, following a semi-quantitative classification.[19,20]

1. a little or no superficial debris covering up to 25% of the specimen;
2. little to moderate debris covering between 25% and 50% of the specimen;
3. moderate to heavy debris covering between 50% and 75% of the specimen;
4. heavy amounts of aggregated or scattered debris over 75% of the specimen.

The presence of the smear layer was evaluated from images at 700× magnification. Scores from 1 to 4 were assigned with a semi-quantitative classification.[19,20]

1. a little or no smear layer covering up to 25% of the specimen; tubules visible and patent;
2. little to moderate or patchy amounts of smear layer covering between 25% and 50% of the specimen; many tubules visible and patent;
3. moderate amounts of scattered or aggregated smear layer covering between 50% and 75% of the specimen; minimal to no tubule visibility or patency;
4. heavy smear layer covering over 75% of the specimen; no tubule orifices visible or patent.

The scored sections of the root canal were selected by chance.

Representative SEM images of scores 1, 2, 3 and 4 are shown in Figs. 1 (organic debris) and 2 (smear layer).

Differences in discontinuous variable distribution were assessed by chi-square. The significance level was set at $p < 0.05$, and the null hypothesis was that there are no significant differences among the three groups in the removal of organic debris and smear layer either overall or at different regions of the canals.

Results

General remarks

The total cleaning evaluation for both smear layer and organic debris, obtained from the analysis of all data (i.e., apical, middle and coronal results), is reported in Graphs 1 and 2: EndoActivator showed the best results in total cleansing whereas control with saline solution showed the worst results.

Concerning debris, EndoActivator provided the best results, whereas control with saline solution provided the worst results ($p < 0.001$); conventional irrigation and EndoVac showed intermediate results although EndoVac removed more debris then conventional irrigation. Concerning the smear layer, control group with saline solution did not produce any cleansing, whereas EndoActivator provided the best results ($p < 0.001$); conventional irrigation and EndoVac showed a similar intermediate cleaning of the root canal, EndoVac being slightly better.

Comparison among devices

The results concerning debris stratified according to root canal area are summarised in Table 1.

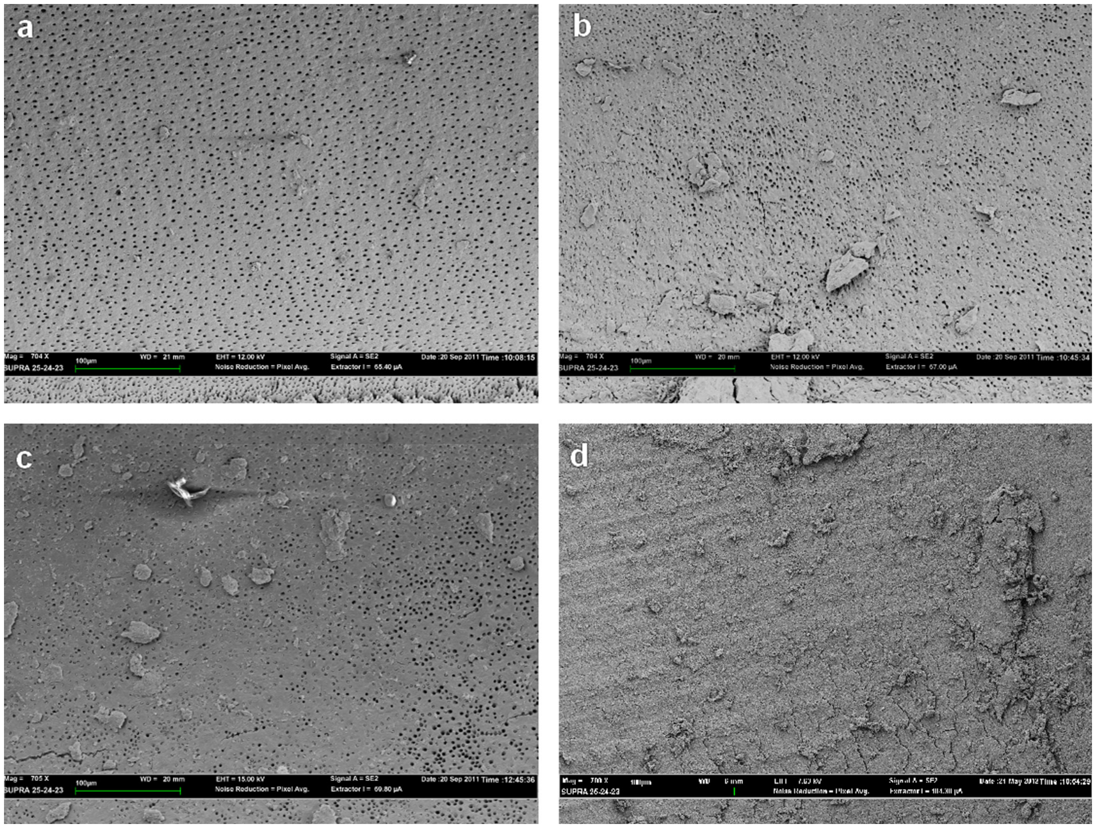


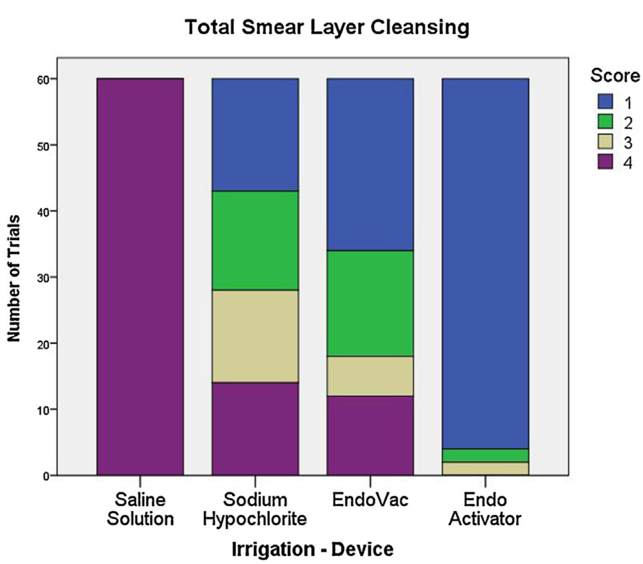
Figure 2 Examples of smear layer scores obtained under scanning electron microscopy (700×). Score 1 (a), score 2 (b), score 3 (c) and score 4 (d).

EndoActivator showed the best results in all canal areas followed by EndoVac which expressed its best in the coronal area ($p < 0.001$). In the apical third, no samples of saline solution and conventional irrigation obtained score 1 ($p < 0.03$).

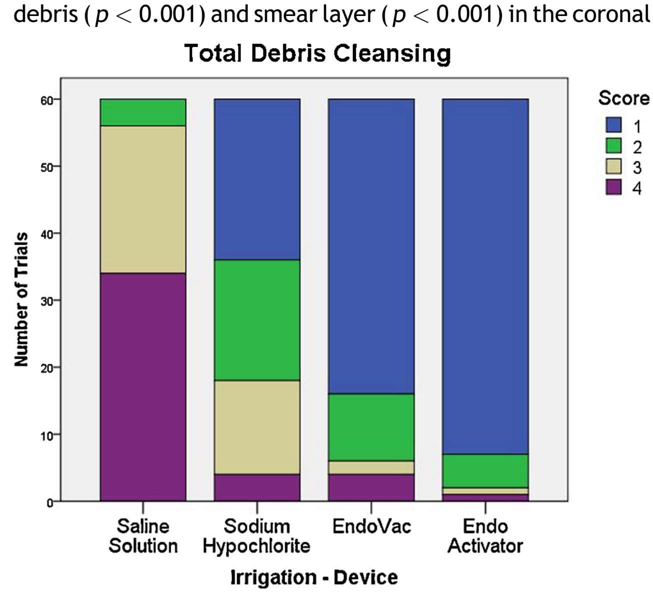
The results concerning smear layer stratified according to root canal area are summarised in Table 1: EndoActivator showed the best results in all canal areas ($p < 0.001$), followed by EndoVac in apical and middle thirds and by conventional irrigation in coronal third. Control with saline solution did not remove the smear layer.

Comparison within the same device

Conventional irrigation and EndoVac group removed more debris ($p < 0.001$) and smear layer ($p < 0.001$) in the coronal



Graph 1 Represents the total smear layer detersion. Statistically significant differences were found among groups ($p < 0.001$).



Graph 2 Represents the total debris detersion. Statistically significant differences were found among groups ($p < 0.001$).

Table 1 Presence of debris and smear layer in the apical, middle and coronal third.

		Control with saline Group 1 (*n* = 20) Score				Conventional irrigation Group 2 (*n* = 20) Score				EndoVac System Group 3 (n = 20) Score				Endoactivator system Group 4 (*n* = 20) Score			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Apical*	Debris	—	—	4	16	—	6	10	4	12	2	2	4	17	3	—	—
	Smear layer	—	—	—	20	2	2	2	14	6	6	—	8	18	2	—	—
Middle*	Debris	—	—	6	14	10	8	2	—	14	6	—	—	17	2	1	0
	Smear layer	—	—	—	20	2	8	10	—	8	4	4	4	19	—	1	—
Coronal*	Debris	—	4	12	4	14	4	2	—	18	2	—	—	19	—	—	1
	Smear layer	—	—	—	20	14	4	2	—	12	6	2	—	19	—	1	—

* Chi-square test among different irrigation device: $p < 0.001$.

and middle thirds than in the apical portion of the samples, whereas no statistically significant differences were found among the coronal, middle and apical thirds in the removal of both smear layer and debris ($p = 0.307$ and $p = 0.331$) in EndoActivator group.

Discussion

The purpose of this study was to compare the differences in root canal debridement among different irrigation techniques including EndoVac and EndoActivator; these ones have significantly less extruded irrigant into the periapical region when compared to other root canal irrigation systems.[15,16]

The irrigation of the root canal system includes a risk of extrusion of sodium hypochlorite in the periapical region that could lead to tissue necrosis and evoke pain sensation.[21,22]

Most of the pertinent literature is available on debridement of various irrigant delivery devices,[7] although the difference between an apical negative pressure system and a sonic device in the removal of smear layer and organic debris has never been described before. A previous study compared the efficacy in the removal of *Enterococcus faecalis* of these three irrigation technique and no statistically significant differences were found among groups.[23]

Smear layer is a layer of organic and inorganic material that may also contain bacteria and their by-products;[5] although no clinical trials indicate removal of the smear layer for success in endodontic therapy, many authors recommend its removal because it may result in a more thorough disinfection of the root canal systems and it may ensure better adaptation between the root canal walls and the filling materials.[24,25] Among the different irrigant solutions intended to remove the smear layer, EDTA is at present the best substance for this purpose;[24,26] in the present study, a final rinse of 17% EDTA followed by 5.25% NaOCl was used after instrumentation because it was consistent with previous studies.[24,27] However, there is no consensus with respect to the optimal volume or the activation method of the irrigating solutions.[5,24]

Concerning smear layer removal, the EndoActivator provided the best results in the overall root canal length ($p < 0.001$), and no statistical differences were found among the coronal, middle and apical third of the root canals. Consequently, EndoActivator seems to increase the efficacy of smear layer debridement not only in the apical region, but also in the whole root canal length uniformly. Our study is in agreement with previous reports and it reaffirms the advantages of sonic activation methods.[14,28] However, Uroz-Torres found that there was statistical difference ($p < 0.05$) in the debridement among coronal, middle and apical regions of root canals treated with EndoActivator,[29] where the sonic device eliminated a greater amount of the smear layer in coronal and middle thirds than in the apical third, which showed the worst results. This finding may be attributed to the lesser volume of final rinse used and the shorter time of application (1 ml of 17% EDTA followed by a final flush of 3 ml of 4% of NaOCl for 1 min). Furthermore, Rödig et al. reported that sonic and ultrasonic systems improved smear layer removal only in the straight coronal portion of curved root canal: the authors speculated that their results might have been due to the fact that a potential dampening effect of the apical root canal could have restrained the displacement amplitude of the EndoActivator, resulting in a decreased agitation energy.

The EndoVac system removed more smear layer in the apical, middle and coronal third than conventional irrigation and saline solution ($p < 0.05$).[13]

Our results are in partial agreement with those reported by Abarajithan,[30] who found significant differences ($p < 0.05$) in the reduction of smear layer only in the apical third of teeth rinsed with the EndoVac system compared with conventional irrigation, although no significant difference was reported in the coronal and middle thirds.

The EndoVac's ability in the smear layer removal has been investigated in further studies: Parente showed that the EndoVac system was more effective than manual dynamic irrigation in the elimination of smear layer and debris in a closed canal system. Furthermore,[31] Saber reported that the EndoVac system removes more smear layer from root canal walls than passive ultrasonic irrigation (PUI).[32]

Our results showed that the EndoVac system removes statistically more debris ($p < 0.05$) than conventional irrigation not only in the apical third of the root canal, but also in the coronal and middle portions of the specimens. The results of this study are in partial agreement with other authors,[18,33] who concluded that the EndoVac system is more effective than conventional irrigation in the removal of debris at 1 mm from working length ($p < 0.05$), but they did not find any significant differences at the 3-mm level.

The difference between our results and those obtained by Nielsen and Baumgartner may be due to the use of the microcannula: in their study,[33] it was placed at 2 mm from working length for 6 s and moved back to working length for 6 s. After 30 s of this up-down motion, the microcannula was removed from the root canal, so the turbulence created with the help of the negative pressure of the EndoVac system did not involve the middle and coronal regions of the root canal. In the present study, the microcannula was moved 2 mm up from working length to the coronal portion every 6 s. This apical-coronal motion continued until 30 s had elapsed, so when the timer was over, the microcannula was placed at 10 mm from working length and its flux had reached the middle and coronal thirds of the canal, adding its cleaning effects to those obtained by the use of the macrocannula.

We chose to use the same amount of irrigant regardless of the irrigating method, although Nielsen and Baumgartner used a different volume of irrigant in the two groups.[33]

Concerning organic debris, EndoActivator showed the best results in the whole canal area, especially in the apical and middle thirds ($p < 0.001$). Our findings are in agreement with those obtained in previous published studies,[34,35] where sonic activation of the irrigant resulted in significantly more debris removal and in better obturation of lateral and accessory canals than syringe irrigation in straight root canals.

The results of our study showed better efficacy of EndoActivator compared with the EndoVac system and conventional irrigation in total cleansing of root canal walls, even if none of the techniques completely removed organic debris and smear layer from root canal surfaces. The null hypothesis was rejected.

Conclusions

When compared with the conventional irrigation, the EndoVac system and the EndoActivator were significantly more effective in cleaning the root canal surfaces in the apical, middle and coronal regions. However, none of the techniques was able to remove organic debris and smear layer completely from the root canal.

Even though our study detected significant differences between the EndoActivator and the other irrigation techniques in the removal of debris from the whole root canal length, more studies in extreme clinical conditions, such as curved and narrow root canals on posterior teeth, are needed. Further studies may also be necessary to compare the ability of organic debris and smear layer removal between the EndoActivator and the EndoVac system and other irrigation delivery systems, such as ultrasonic devices.

Clinical relevance: The EndoActivator and the EndoVac improved the cleaning of the root canal and could be used in addition to conventional irrigation to have better results in root canal therapy.

Conflict of interest

The authors have no conflict of interests to declare.

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