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Original Article

Efficacy of five irrigation techniques in removing calcium hydroxide from simulated S-shaped root canals

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Abstract *Background/purpose:* Calcium hydroxide [$Ca(OH)_2$], a wildly used intracanal medicament, should be completely removed from the root canal before obturation to avoid negative effects on the treatment. This study evaluated the effectiveness of conventional needle irrigation (CNI), passive ultrasonic activation (PUI), photon-induced photoacoustic streaming (PIPS), XP-endo Finisher (XP) and EDDY for the removal of $Ca(OH)_2$ from S-shaped root canal.
Materials and methods: Eighty-four S-shaped root canals in resin blocks were prepared using Protaper Gold up to size #25/0.08 and filled with $Ca(OH)_2$. Five groups were established according to the removal techniques (n = 16): CNI, PUI, PIPS, XP and EDDY group. The positive and negative control group (n = 2) were also established. Sodium hypochlorite 3% was used as the irrigant. Digital radiographs were used to measure the remaining $Ca(OH)_2$. Statistical analysis of the data was performed by using the Kruskal—Wallis test, followed by Dunn's post hoc test with Bonferroni correction ($\alpha = 0.05$).
Results: All the tested techniques completely removed $Ca(OH)_2$ from the straight portion and coronal curve of the S-shaped root canal in 100% of cases. Regarding the apical curve, PUI, EDDY, PIPS and XP removed significantly more $Ca(OH)_2$ than CNI ($P < 0.05$), with no significant differences among these four groups ($P > 0.05$). The complete clearance of $Ca(OH)_2$ from the apical curve was observed in 75%, 62.5%, 56.3%, 43.8% and 0% of cases of PUI, EDDY, PIPS, XP and CNI group, respectively.
Conclusion: Irrigant activation enhanced $Ca(OH)_2$ removal from the apical region of the S-shaped root canal. CNI was significantly less effective than all activation techniques.

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Introduction

Intracanal medication comprises application of a chemical substance into the root canal in order to improve disinfection after chemomechanical preparation. Calcium hydroxide [$Ca(OH)_2$] is the most commonly recommended antimicrobial agent to be used as an interappointment dressing. However, this medication has to be removed before root canal obturation, to avoid any possible negative influence on treatment. The residual $Ca(OH)_2$ on the root canal walls might interact with zinc oxide eugenol and increase apical leakage after obturation when the zinc oxide-eugenol sealer is used.[1] Moreover, $Ca(OH)_2$ resides might prevent the penetration of sealers into dentinal tubules and provide a reduction in bond strength values of epoxy resin AH Plus (Dentsply Sirona, Konstanz, Germany).[2,3]

Nevertheless, complete removal of $Ca(OH)_2$ using various techniques remains a challenge in root canal therapy, especially in complex root canal system. The most frequently described method for $Ca(OH)_2$ removal is the recapitulation of the master apical file in combination with copious irrigation using conventional needle irrigation (CNI).[4] However, previous studies have shown the difficulty to remove $Ca(OH)_2$ from root canals using this conventional method.[5] Passive ultrasonic activation (PUI) is another extensively researched technique and is regarded as the gold standard for irrigant activation research.[6] Although PUI removed residual $Ca(OH)_2$ from the coronal and middle thirds of the root canal, it is remains a concern that the large amount of $Ca(OH)_2$ in the critical apical area and irregular areas of the complex root canal system.[5—8]

Promising results for the removal of $Ca(OH)_2$ have been shown using an erbiu:yttrium-aluminum-garnet (Er:YAG) laser coupled with a short radial-stripped tip in a technique known as photon-induced photoacoustic streaming (PIPS) (Fotona, Ljubljana, Slovenia). In this technique, Er:YAG laser is used with small energy (20 mJ) and very short pulses (50 μs), intracanal cavitations and shock waves generated as a result of photo-acoustic and photo-mechanical effect. PIPS provided complete removal of $Ca(OH)_2$ from artificial grooves in straight root canals.[8] Compared with PUI, PIPS showed significant higher removal of $Ca(OH)_2$ in the apical third of Weine Type II mandibular molars and isthmus in maxillary premolars.[7,9]

The XP-endo Finisher (FKG Dentaire, La Chauxde-Fonds, Switzerland) was introduced to be used as a final step to improve root canal cleaning while conserving dentin. It is a size #25 non-tapered instrument made of MaxWire (Martensite-Austenite Electropolish Flex, FKG Dentaire). Because of this new alloy, the shape of the XP-endo Finisher changes according to the temperature. In room temperature, the file is in its martensitic phase (M-phase) and stands straight. When exposed to the temperature within the root canal, it changes to its austenitic phase (A-phase) assuming a spoon shape of 1.5 mm depth in the final 10 mm of its length. The C shaped tip enables the file to access and clean areas that other instruments might not have reached. The effectiveness of XP-endo Finisher in the removal of $Ca(OH)_2$ intracanal medicament have been investigated in premolar teeth, simulated internal resorption cavities, and artificial standardized groove.[3,10,11]

EDDY (VDW, Munich, Germany) is a polyamide tip with a size 25 and 0.04 taper, which is powered at a high frequency of up to 6000 Hz by airscaler. The vibration produced is transferred to the polyamide tip, which is moved in an oscillating motion at high amplitude. According to the manufacturer, this three-dimensional movement triggers cavitation and acoustic streaming attributed with higher cleaning efficiency.

Because of the considerable heterogeneity in the methodologies, including types of root canal system, types of $Ca(OH)_2$, irrigation times, irrigation solutions, and their concentration and outcome measurements, the outcomes of in vitro studies comparing the effectiveness of these activated irrigation for removing calcium hydroxide from root canals were conflict. Regarding the apical region of artificial grooves in straight root canals, EDDY and PUI were significantly more effective in the removal of calcium hydroxide than the XP-endo Finisher.[6] However, in simulated internal root resorption cavities created by bur plus additional 20% nitric acid protocol, EDDY and XP-endo Finisher produced similar results and removed more $Ca(OH)_2$ than ultrasonic irrigation.[12]

Moreover, none of the described technique could completely clean $Ca(OH)_2$ from the root canal. The complexity of root canal system is a crucial factor that might influence the efficacy of $Ca(OH)_2$ removal technique. Swimberghe and the colleagues assessed the influence of the canal curvature on the efficacy of sonically, ultrasonically, and laser activated irrigation in removing a biofilm-mimicking hydrogel (BMH) from simulated canal irregularities.[13] In the 40° canal curvature model, the highest BMH removal was observed for ultrasonic group (99.9%), followed by EDDY (99.4%) and PIPS (96.8%). In the 60° canal curvature model, ultrasonically activated irrigation removed 99.5%, followed by PIPS (82.5%) and EDDY (78.1%). The results indicated that canal curvature negatively affects the cleaning efficacy of different irrigation methods. Canals with double curvatures, also named as S-shaped canals, represent one of the most challenging canal configurations regarding preservation of the integrity of the root canal anatomy and maintenance of the location of the apical foramen.[14] The frequencies of S-shaped canals are reported to be 30%—40% and 35%—59% in the distobuccal root of maxillary molars and in the mesial root of mandibular molars, respectively.[15] Currently, calcium hydroxide removal studies conducted in models with S-shaped root canals are scarce. Therefore, the purpose of this study was to compare 5 different irrigation techniques regarding the removal of calcium hydroxide from S-shaped root canals: conventional needle irrigation (CNI), passive ultrasonic activation (PUI), laser-activated irrigation using photon-induced photoacoustic streaming (PIPS), mechanical activation using the XP-endo Finisher (XP) and sonic activation using EDDY.

Materials and methods

Simulated canals

Eighty-four S-shaped endo training blocks (Dentsply Maillefer, Ballaigues, Switzerland) with a taper of 0.02, an apical diameter of 0.15 mm, and a length of 16 mm were involved. The respective angles and radii of the curvatures were 30° and 5 mm for the coronal curvature and 20° and 4.5 mm for the apical curvature.

Root canal preparation

The patency of the canals was confirmed by passing a size 10 K-file (Dentsply Maillefer) just beyond the apex. A glide path was created with ProGlider instrument (tip size/taper: #16/0.02) (Dentsply Maillefer) at 300 rpm and a torque of 4.0 Ncm to full working length (WL). Then, the root canals were prepared using ProTaper Gold NiTi instruments to size F2 (tip sizes/taper: #25/0.08). The files were powered by an electric motor (X-Smart plus, Dentsply Maillefer) with the manufacturer's recommendations as follows: SX at 250 rpm and 3 Ncm torque, S1 at 250 rpm and 3 Ncm torque, S2 at 250 rpm and 1 Ncm torque, F1 at 250 rpm and 1.5 Ncm torque, and F2 at 250 rpm and 2 Ncm torque. Throughout the period, 5 mL 3% NaOCl was used as an intracanal irrigant solution by using a 30-G side-cut open-ended needle (Navitip, Ultradent, South Jordan, UT, USA) after each instrument. After completion of the mechanical preparation, a final rinse was applied using 5 mL 17% EDTA followed by 5 mL 3% NaOCl. The canals were dried with paper points.

$Ca(OH)_2$ placement

The apical foramen of each shaped canal was sealed with sticky wax to create a closed-end system. Then, all the root canals were filled with a water-based calcium hydroxide paste with barium sulfate (Well-Paste®, Lot.WS0N6100, Vericom, Gangwon-Do, Korea) by using a size #25 Lentulo spiral (Dentsply Maillefer). The $Ca(OH)_2$ paste was not applied to the negative control ($n = 2$). It was applied to the positive control ($n = 2$), but no removal procedure was carried out. Complete placement of $Ca(OH)_2$ inside the canals was confirmed by radiographs. The root canal orifice was sealed with a temporary filling material (3M™ Cavit™, Saint Paul, Minn, USA). All specimens were finally stored in 37 °C at 100% relative humidity for 1 week.

$Ca(OH)_2$ paste removal

After the storage process, the surface of each block except the orifice was covered with opaque stickers to reduce the manual interference in the following process. Then, the coronal access was opened, and a size 15 K file (Dentsply Maillefer) was introduced to the working length for $Ca(OH)_2$ loosening and creating space for the irrigation tips. Subsequently, the samples were randomly divided into 5 groups ($n = 16$) according to the removal techniques: conventional needle irrigation (CNI) group, passive ultrasonic activation (PUI) group, photon-induced photoacoustic streaming (PIPS) group, XP-endo Finisher (XP) group, and EDDY group. 3% NaOCl acted as irrigant. For each group, the volume and time were standardized at 12 mL and 2 min, respectively.

For CNI group, a 5-mL syringe with a 30-G side-cut open-ended needle (Navitip) was placed 2 mm short of the working length into the canal, and in-and-out movements with an amplitude of 5 mm were performed; 3 mL NaOCl 3% was applied over 30 s. This was repeated 4 times, resulting in a total of 2 min of irrigation with a total of 12 mL irrigant.[6]

For PUI group, an endodontic irrigation tip IrriSafe® #20/0.00 (Satelec®, Acteon, Mérignac, France) was used with ultrasonic unit P5 Newtron® XS (Satelec®, Acteon) at power setting 5. The ultrasonic file was prebent in order to avoid wall contact.[13] The tip was inserted to 1 mm short of the working length into the canal, and in-and-out movements with an amplitude of 5 mm were performed. Before each cycle of activation, 3 mL NaOCl 3% was applied to the root canal with a syringe. The irrigant was activated for 30s. Four applications were performed.

For PIPS group, an Er:YAG laser with a wavelength of 2940 nm (Fidelis AT, Fotona) was used with a 14-mm long, 300 μm diameter quartz laser tip. The laser parameters were pulse energy, 20 mJ; frequency, 15 Hz; pulse duration, 50 μs; and energy density, 2.06 J/cm^2 with the laser system water and air turned off.[16] The tip was positioned at the canal entrance, and remained stationary during activation. Before each cycle of activation, 3 mL NaOCl 3% was applied to the root canal with a syringe. The irrigant was activated for 30s.[17] Four applications were performed.

For XP group, the XP-endo Finisher NiTi file was powered by X-Smart plus motor at a speed of 800 rpm and a torque of 1 Ncm. The XP-endo Finisher file was placed 1 mm short of the working length, and in-and-out movements with an amplitude of 5 mm were performed. Before each cycle of activation, 3 mL NaOCl 3% was applied to the root canal with a syringe. The irrigant was activated for 30s. Four applications were performed.

For EDDY group, a non-cutting polyamide size 25, 0.04 tip operated by an airscaler (Sonic S SS-M4, Shenghua Co.,Ltd., Guangzhou, China) was used in the canals at 1 mm from the working length and used in an up and down movement over 5 mm at maximum intensity (frequency 6000 Hz). Before each cycle of activation, 3 mL NaOCl 3% was applied to the root canal with a syringe. The irrigant was activated for 30s. Four applications were performed.

X-ray exam and evaluation

Any remaining $Ca(OH)_2$ in the simulated root canal was determined using periapical radiographs. Digital radiographs (CS2100 Intraoral X-ray System, Carestream Health, Rochester, NY, USA) from the same angles (vertical and horizontal angles were parallel with the axial and sagittal planes respectively) were taken of each specimen and coded to prevent identification of the specimens.[18] All exposures were standardized at 60 Kv, 7 mA, a film-focus distance of 10 cm.

Images were analyzed using Photoshop CC software program (Photoshop CC, Adobe, San Jose, CA, USA). The 1-mm incremental reference lines were positioned perpendicularly to the long axis of the resin blocks. Thus, the S-shaped root canal was divided into three portions: points 0 to 3 corresponded to the apical curve, points 3 to 7 corresponded to the coronal curve, and points 7 to 10 belonged to the straight portion of the canal (Fig. 1).[19] Tow calibrated operators blinded to the groups independently evaluated the amount of the remaining $Ca(OH)_2$ in each portion of the root canal using the following criteria: 0, empty canal; 1, <50% of the canal is filled with $Ca(OH)_2$; 2, >50% of the canal is filled with $Ca(OH)_2$; and 3, the canal is completely filled with $Ca(OH)_2$ (Fig. 1).[6]

Statistical analysis

Statistical analysis of the data was done by using IBM SPSS 20 Software (IBM SPSS Inc., Armonk, NY, USA). Inter-examiner agreement was analyzed by using the kappa test. The Shapiro–Wilk normality test was used to test the data distribution of $Ca(OH)_2$ for the different groups and revealed a nonnormal data distribution. Subsequently, differences in $Ca(OH)_2$ scores among the experimental groups were explored with Kruskal–Wallis test followed by Dunn's post hoc test with Bonferroni correction. The testing was performed at the 95% level of confidence ($P < 0.05$).

Results

The Cohen kappa value was 0.826 for inter-examiner agreement indicating good reproducibility of the results.

All the experimental techniques achieved complete clearance of $Ca(OH)_2$ from the straight portion and coronal curve of the S-shaped root canal in 100% of cases (score = 0). The positive controls showed a score of 3, and the negative controls showed a score of 0 (Fig. 1).

However, none of the tested methods could completely clean the $Ca(OH)_2$ from the apical curve. The results of $Ca(OH)_2$ removal scores of different removal techniques in the apical curve were shown in Table 1. Fig. 2 presented the distribution of the scores for the removal of $Ca(OH)_2$ from the apical curve. PUI, PIPS, XP and EDDY removed

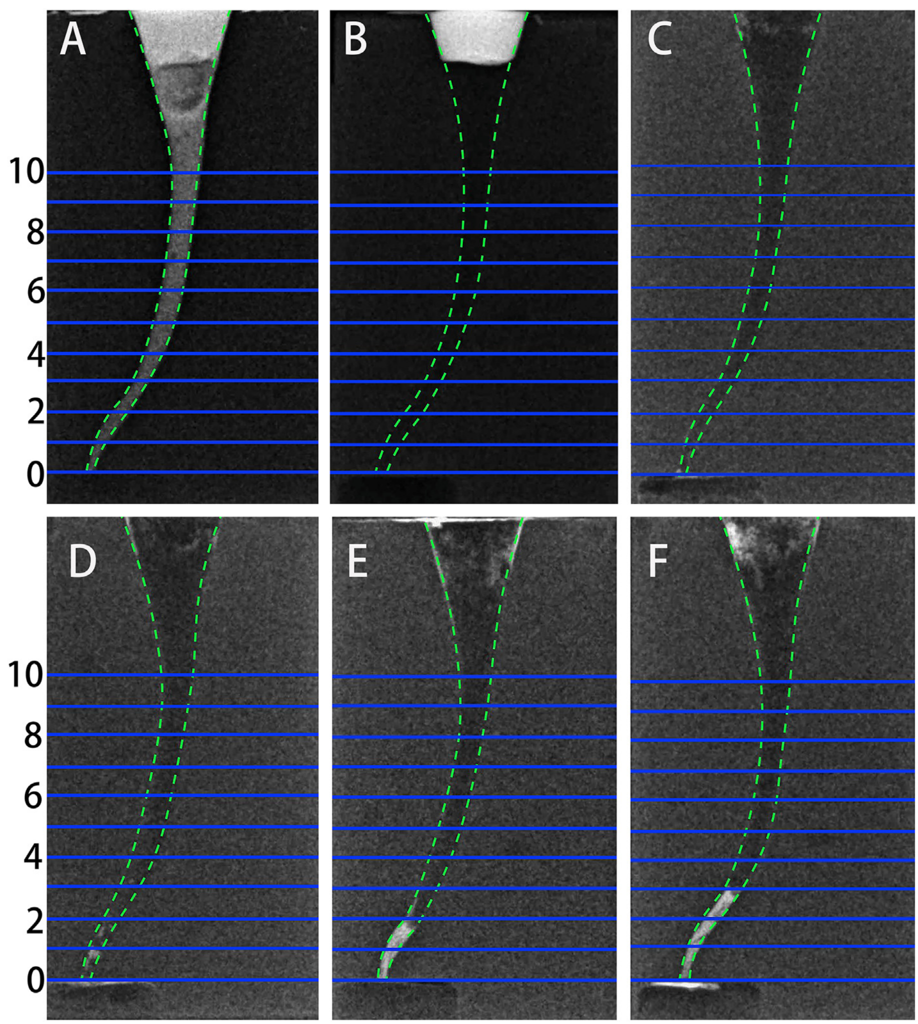

Figure 1 Representative images of scores were showed. (A) Positive control (score 3). (B) Negative control (score 0). (C) The apical curvature was empty (score 0). (D) Less than half of the apical curvature was filled with $Ca(OH)_2$ remnants (score 1). (E) More than half of the apical curvature was filled with $Ca(OH)_2$ remnants (score 2). (F) The complete apical curvature was filled with $Ca(OH)_2$ remnants (score 3).

Table 1 The scoring results of $Ca(OH)_2$ removal from the apical curve of the S-shaped root canal.

Group	Median	Interquartile range	Minimum	Maximum
CNI	2.0[a]	1.0	1.0	3.0
PUI	0.0[b]	0.75	0.0	1.0
PIPS	0.0[b]	1.0	0.0	2.0
XP	1.0[b]	1.0	0.0	2.0
EDDY	0.0[b]	1.0	0.0	2.0

Values with different superscript letters were significantly different at $P < 0.05$. CNI, conventional needle irrigation. PUI, passive ultrasonic activation. PIPS, photon-induced photoacoustic streaming. XP, XP-endo Finisher.

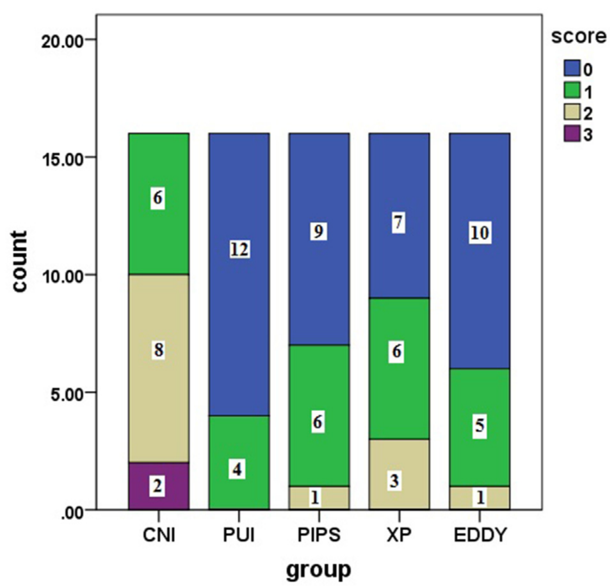

Figure 2 The distribution of scores for the removal of $Ca(OH)_2$ paste from the apical curvature of the S-shaped root canal according to the experimental groups. CNI: conventional needle irrigation, PUI: passive ultrasonic activation, PIPS: photon-induced photoacoustic streaming, XP: XP-endo Finisher.

significantly more $Ca(OH)_2$ than CNI ($P < 0.05$), with no significant differences among these four groups ($P > 0.05$) (Table 1). The complete clearance of $Ca(OH)_2$ from the apical curve (score 0) was observed in 75%, 62.5%, 56.3%, and 43.8% of cases of PUI, EDDY, PIPS, and XP group, respectively. CNI was the least efficient method of $Ca(OH)_2$ removal, leaving 12.5% of the apical curve completely covered with $Ca(OH)_2$ (score 3), while none of the cases in the other four groups received this score (Fig. 2).

Discussion

The models previously developed to investigate $Ca(OH)_2$ remnants in root canals include simulated internal root resorption cavity, standardized groove, simulated curved root canals resin blocks and extracted human teeth with different type of root canal system, for example C-shaped root canals, Weine Type II systems, and so on.[5–7,10,20] According to the fluid dynamics theory, the pattern and effect of the fluid flow are largely dependent on the geometry of the container in which the fluid is located.[21] Irrigation efficiency may be affected by apical preparation size, root canal taper and root canal morphology.[22–24] In the present study, the effectiveness of 5 irrigation techniques on $Ca(OH)_2$ removal in S-shaped root canals were compared. A limitation of the present study could be the in vitro design with the use of simulated S-shaped root canals in resin blocks. But on the other hand, the use of standardized root canal is conducive to reduce the sampling error.[20]

In vitro studies have used several methods to measure residual $Ca(OH)_2$ in root canals, such as direct visualization, digital microscopy, scanning electron microscopy, micro-computed tomography and periapical radiographs.[5,12,18] The amount of remaining Ca $(OH)_2$ in a canal was calculated by measuring the surface area of the residues on the canal walls, or assessing the percentage of volume of residual $Ca(OH)_2$ in the canal. In the present study, periapical radiographs were taken and a scoring method was used. The images were contrasted with the negative and positive control. The radiopacity image was recognized as residual $Ca(OH)_2$ regardless of the intensity. Comparing radiographic projections is a good way of reproducing clinical conditions. Positive correlation between stereomicroscope and radiographic analyses confirmed the validity of radiography to depict medicament removal.[18] However, because of the limitation of the sensitivity and the two-dimensional nature of radiographs, minuscule amounts of medicament were sometimes not detected in radiographs, while, sometimes the amounts of medicament were overestimated.[18] This method can only determine whether there is residual calcium hydroxide, but can not precisely quantify the amount of the remnants. The amount of remaining $Ca(OH)_2$ was represented by the area occupied by the residues on the root canal image. In the present study, X-ray photography parameters were standardized to allow the remnant $Ca(OH)_2$ to be imaged under the consistent conditions and to minimize the impact of X-ray image superimposition.

In this study, all of the tested techniques resulted in highly effective removal of $Ca(OH)_2$ from the straight portion and coronal curvature of the S-shaped root canal. This finding is in agreement with previous studies, which could be attributed to the larger diameter in these areas, exposing dentin to a higher volume of irrigants and making $Ca(OH)_2$ removal easier.[5,20] However, none of the protocols could completely remove $Ca(OH)_2$ from the apical curvature. It remains difficult for the current irrigation techniques to remove the intracanal medicaments from the apical part of the root canal.[5,7,10] Consistent with previous studies, conventional needle irrigation was significantly less effective than all activation techniques. The flushing action of irrigants helps to remove organic and dentinal debris and microorganisms from the canal. Irrigants must be brought into direct contact with the entire canal area and especially with the apical portions of narrow root canals for optimal effectiveness.[25] The flushing action created by syringe irrigation is relatively weak and dependent not only on the anatomy of the root canal system but also on the depth of placement and the diameter of the needle.[26] 30-G needle is the finest needle currently used in endodontic treatment with an external diameter of 0.3 mm. Theoretically, in a straight root canal with a preparation width of 0.25 mm, regardless of the taper of 0.06 or 0.08, the 30-G needle could easily be placed 1 mm from the apex. However, in the S-shaped root canal, because of the restriction of the double curves and the limitation of the elasticity of the needle, the 30-G needle could only be placed 2 mm from the apex in the present study. Based on the result of a computational fluid dynamics study, it was suggested that irrigation needles should be placed to within 1 mm from working length to ensure fluid exchange.[23]

In a systematic review of in vitro studies, ultrasonically activated irrigation was found to be superior to syringe irrigation and apical negative pressure irrigation regarding $Ca(OH)_2$ removal, but insufficient evidence was found to indicate its superiority over the other irrigation techniques such as sonically activated irrigation, the Self-Adjusting File, (ReDent-Nova, Ra'anana, Israel) and the RinsEndo, (D€urr Dental, Bietigheim, Germany).[27] In the present study, PUI showed a higher $Ca(OH)_2$ removal from the apical curve of the S-shaped root canal, followed by EDDY, PIPS and XP-Endo finisher. 75% samples in PUI group were completely clean. The sonic or ultrasonic agitation causes the generation of streaming motion with a thin boundary layer, which subsequently generates a large shear stress on the surface of the instrument and root canal wall. The ultrasonic agitation of the instrument also generates a large-scale streaming pattern. The streaming flow at the end of the instrument can penetrate into the region of spent resident irrigant located at the apical portion of the root canal system and it is this that is likely to play an important role in debriding the apical anatomy.[28] Moreover, in a curved root canal, EDDY undergoes elastic deformation and is under tension. This will dampen its three-dimensional movement, and reduce the oscillation in the irrigant. The more severe the curve, the greater the dampening effect.[13] In S-shaped root canal, EDDY underwent a more severe deformation due to the double curvatures with different direction, which may further impede the oscillation. The contact between the ultrasonic tip and the root canal wall has been shown to significantly decrease PUI efficacy. Therefore, pre-bending the ultrasonic tip facilitated the placement of the tip in S-shaped root canal by avoiding the wall contact. Thus, the dampening effect on EDDY's oscillation and pre-bending the ultrasonic tip may explain the better result of PUI than EDDY.

Among the 4 agitation techniques, Xp-endo Finisher showed a relatively less efficiency. The mode of action of Xp-endo Finisher is based on its rotation at 800 rpm and the physical contact between the rotating instrument and the canal walls. As a consequence, the irrigant is agitated and the $Ca(OH)_2$ is removed from root canal. It was reported that prolonged activation of XP-endo Finisher showed a superiority over the PUI in removing the $Ca(OH)_2$ from the apical third in single-rooted teeth.[29]

Previously published studies on $Ca(OH)_2$ removal involving PIPS remarked that the use of PIPS improved the results. The cleaning efficiency of PIPS was equal to or better than that of PUI. They also performed better than EndoActivator, XP-endo Finisher file, and CanalBrush and CNI.[7–9,30] In the present study, PIPS removed relatively lower $Ca(OH)_2$ than PUI and EDDY, yet the differences were not statistically significant. To date, no studies have been reported on the cleaning efficacy of PIPS in S-shaped canals. Swimberghe's results demonstrated that the canal curvature does influence the efficacy of PIPS, although the difference in debridement between the 2 curvature models (40° and 60°) was small.[13] In moderately curved canals, PIPS caused higher average fluid speeds when compared to PUI, both close and distant from the instrument.[31] However, there is a lack of more detailed studies of the PIPS mechanism of action in more challenging root canal configurations like S-shaped root canal or severely curved root canal. The impact of canal curvature on the irrigant flow and the cleaning efficacy of the current irrigation activation techniques deserves further investigation to define the best strategy for the complete cleanliness of the root canal walls.

In conclusion, complete removal of calcium hydroxide from the apical curvature of S-shaped root canals remained as a challenge for any of the tested techniques. CNI was significantly less effective compared with all other activation techniques. PUI seemed to be more effective than other activation techniques, although no statistically significant difference was found among the 4 activation techniques. No difference was found in the coronal section.

Declaration of competing interest

The authors have no conflict of interest relevant to this article.

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