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Endodontic cement penetration after removal of calcium hydroxide dressing using XP-endo finisher

Alyssa Sales dos SANTOS[(a)]
Maria Aparecida Barbosa DE SÁ[(a)]
Marco Antônio Húngaro DUARTE[(b)]
Martinho Campolina Rebello HORTA[(a)]
Frank Ferreira SILVEIRA[(a)]
Eduardo NUNES[(a)]

[(a)]Pontifícia Universidade Católica de Minas Gerais – PUC-MG, Graduate Program in Dentistry, Department of Dentistry, Belo Horizonte, MG, Brazil.

[(b)]Universidade de São Paulo – USP, School of Dentistry of Bauru, Department of Operative Dentistry, Endodontics and Dental Materials, Bauru, SP, Brazil.

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Corresponding Author:
Eduardo Nunes
E-mail: edununes38@terra.com.br

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Abstract: We aimed to evaluate the penetration of endodontic cement following the removal of calcium hydroxide ($Ca(OH)_2$) dressing using the XP-endo Finisher in association with different irrigating solutions. Sixty premolars were instrumented and applied with a $Ca(OH)_2$ dressing. To remove $Ca(OH)_2$, the teeth were divided into six groups, each with a different volume of sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA), as well as solution stirring time with XP-endo Finisher (0, 30, and 60 sec). Root canals were filled using the lateral condensation technique. Fluorescein dye was added to the cement for microscopic laser scanning analysis. In the generated images, linear measurements were taken in micrometers, and their averages were calculated. To analyze the perimeter penetration ratio of the cement, the total perimeter of the canal and the segment of the total perimeter of the canal where the endodontic cement penetrated into the dentinal tubules were measured in micrometers. We found that using an XP-endo Finisher in irrigation was more effective than using a needle and syringe during the extension and penetration of endodontic cement. Shaking with XP-endo Finisher with 17% EDTA increased the extent and perimeter of the penetration of the endodontic cement into the dentinal tubules. However, using the XP-endo Finisher with EDTA only was more efficient than using the instrument interchangeably in NaOCl and EDTA. Although XP-endo Finisher contributes to the removal of $Ca(OH)_2$, none of the protocols or instruments used removed all $Ca(OH)_2$ from the root system.

Keywords: Calcium Hydroxide; Microscopy, Confocal; Edetic Acid; Sodium Hypochlorite; Therapeutic Irrigation.

Introduction

A successful root canal treatment depends on appropriate access cavity preparation, as well as proper shaping, appropriate cleaning, and accurate tridimensional sealing of the root canal system.[1] However, removing every pathological entity present in the root canal system remains especially challenging.[2]

Since mechanical instrumentation and irrigation cannot completely eliminate microbiota,[3,4] an approach for supplementing the disinfecting effects of conventional chemo-mechanical procedures with intracanal medication has been recommended.[5] Calcium hydroxide ($Ca(OH)_2$) is considered the most favorable antimicrobial agent[3,6-8] and is a universally accepted inter-appointment intracanal medicament because of its biocompatibility, antimicrobial properties, and tissue dissolution ability.[9] However, $Ca(OH)_2$ is typically insoluble in most dental vehicles, which in association with the RCS complexity limits its complete removal.[10] Residues of dental vehicles can also significantly reduce the setting time and flowability of sealers; this increases the risk of void formation between gutta-percha, sealer, and dentin, and impairs its interaction with dentin collagen to limit stable adhesion to the substrate,[10-14] affecting adaptation of the filling material to the root canal walls and influencing the bond strength of dentin.

$Ca(OH)_2$ removal is as crucial as removing the smear layer and debris from the root canal before filling, to better adapt the filling material to the canal walls.[15] RCS complexity makes removal of the $Ca(OH)_2$ dressing, especially in the apical third, more critical when only the conventional syringe irrigation technique and needle are used [13,16.]

$Ca(OH)_2$ may be eliminated by the mechanical action of instruments in the reaming motion[17] and the chemical and physical action of irrigants.[18] Several techniques have been proposed to remove the $Ca(OH)_2$ dressing from the root canal system, including the use of endodontic hand files,[19] sonic activation,[20] passive ultrasonic irrigation (PUI),[21] and nickel-titanium (NiTi) rotary instruments.[22,23] The most commonly described method for $Ca(OH)_2$ removal is instrumentation along with sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA) irrigant solutions combined with a "master apical file" at working length (WL).[24,25]

Although various systems for $Ca(OH)_2$ dressing removal have been cited in the literature, none have removed all of the $Ca(OH)_2$.[26] Studies on different $Ca(OH)_2$ removal protocols have also shown residual volumes of 3%–20%, mainly in the apical region.[22]

The XP-endo Finisher (FKG Dentaire, La Chaux de Fonds, Switzerland) is a rotary root canal instrument available in the market. It is a universal NiTi-based instrument measuring ISO 25 in diameter with zero taper, and it is indicated for use in instrumentation of canals with complex morphology and inaccessible areas. This file is highly flexible and can be expanded. The new technology behind XP-endo Finisher file manufacturing is based on the shape-memory principles of the NiTi alloy. These features help in dentine preservation and enable the file to access areas that are inaccessible to conventional instruments. In addition, the medication inside the canal and residual obturation material during retreatment can be removed.[27]

This study aimed to evaluate the penetration of endodontic cement following the removal of $Ca(OH)_2$ dressing with XP-endo Finisher in combination with different irrigating solutions.

Methodology

Sample Selection

Sixty single-rooted premolar teeth were selected after the study was approved by the research ethics committee (PUC Minas; no. 59289716.0.0000.5137). By evaluating two periapical radiographs (Kodak 2200, 70 kV, phosphor photoactive plate) of each tooth in the vestibular-palatal and mesiodistal directions, teeth with more than one canal, incomplete rhizogenesis, resorption (i.e., internal and external), fracture lines, root curvature, or instrumented or filled canals were excluded. The selected teeth were randomly distributed into six groups, each containing 10 specimens, which were stored in distilled water and 2.5% NaOCl, in a proportion of 10:1.

Criteria for root standardization and instrumentation

All the procedures were performed by a single endodontic specialist. Using a carborundum disc (SS White Dental Articles, Rio de Janeiro, Brazil), the crowns were removed at the amelo–cementitious junction and the roots were cut at the cervical portion, standardizing the total length to 14.0 mm.

Initially, canal patency length was visually determined by introducing a #10 K file (Maillefer, Ballaigues, Switzerland) until reaching the apical foramen, and the specimens were fixed in a lathe to facilitate the chemical–mechanical preparation. The teeth were instrumented with ProTaper Next

(Dentsply, Maillefer, Ballaigues, Switzerland) files to the X5 file (0.5 mm) from the apex (WL).

For canal irrigation, a 27-gauge hypodermic needle (Ultradent Products, South Jordan, USA) coupled with a 5-mL syringe was used. The canals were irrigated at each instrument exchange with 1 mL of 2.5% NaOCl solution and a size-10 K patency file (Maillefer, Ballaigues, Switzerland). After instrumentation, the canals were irrigated with 1 mL of 17% EDTA solution and 1 mL of 2.5% NaOCl solution to remove the smear layer. The canals were then dried with absorbent paper tips (ProTaper, Maillefer, Ballaigues, Switzerland).[28]

Calcium hydroxide P.A. (Biodynamic, Ibiporã, Brazil) intracanal dressing was handled with distilled water according to the manufacturer's recommendations. Using a thin-walled drill (Dentsply, Maillefer, Ballaigues, Switzerland), the $Ca(OH)_2$ slurry was drawn into the root canals, after which the teeth were sealed with temporary cement (Coltosol, Vigodente SA, Bom Sucesso, Brazil). The dressing was maintained for 14 days, and the teeth were stored in an oven at 37 °C under suitable conditions of 90%–95% humidity.

Removal of the intracanal dressing

The $Ca(OH)_2$ dressing was removed from the canals differently in each experimental group (Table 1). XP-endo Finisher (FKG Dentaire, La Chaux de Fonds, Switzerland) was used with an X Smart endodontic motor (Dentsply Sirona, Ballaigues, Switzerland) at a speed of 800 rpm and torque of 1 N.cm.[29,30,31]

All solutions used were heated to 37°C following the method of Hamdan et al.[29] and Kfir et al.[31] The lateral condensation technique with endodontic cement (AH Plus, Dentsply Detrey GmbH, Konstanz, Germany) was used to fill the canals after drying with an absorbent paper cone. Fluorescein dye (Sigma-Aldrich, St. Louis, MO, USA) was added to the cement for microscopic laser scanning analysis. The teeth were carefully sealed with Coltosol (Vigodente SA, Bom Sucesso, Brazil). The samples were stored at 37 °C under 90%– 95% humidity for 48 h.

Analysis of teeth with confocal laser scanning microscopy

After 48 h, the teeth were cross-sectioned into 0.3-mm thick pieces using an Isomet™ 1000 precision cutter (Buehler Ltd., Illinois, USA) at 200 rpm with the continuous use of water under refrigeration at 3, 6, and 9 mm of the root apex.

The dentin segments were inserted into glass slides polished with progressive granulation sieves 300, 600, and 1,200 with the respective identification of the group and number of specimens analyzed. The slides were then examined using a TCS–SPE confocal laser scanning microscope (CLSM; Leica, Mannheim, Germany). The images were processed in a single focal plane of 512 × 512 pixels at 10× magnification, and excitation was performed with a 488-nm diode laser for fluorescein, following the method of Ordinola-Zapata et al.[28] and Silva et al.[32]

Data tabulation

The images obtained by CLSM were stored in a USB drive. For the analysis and tabulation of data, ImageJ (National Institutes of Health, Bethesda, USA) was used. In the generated images, four points were

Table 1. Experimental groups

Group	Protocol
Group 1 (G1)	2.5 mL NaOCl + 2.5 mL EDTA + 2.5 mL NaOCl (without XP use)
Group 2 (G2)	5 mL NaOCl + 5 mL EDTA + 5 mL NaOCl (without XP use)
Group 3 (G3)	2.5 mL NaOCl + 2.5 mL EDTA (XP 1 min) + 2.5 mL NaOCl
Group 4 (G4)	5 mL NaOCl + 5 mL EDTA (XP 1 min) + 5 mL NaOCl
Group 5 (G5)	2.5 mL NaOCl (XP 30 s) + 2.5 mL EDTA (XP 30 s) + 2.5 mL NaOCl
Group 6 (G6)	5 mL NaOCl (XP 30 s) + 5 mL EDTA (XP 30 s) + 5 mL NaOCl

standardized (vestibular, lingual, mesial, and distal) in each image based on the method proposed by Silva et al.,[32] Bitter et al.,[33] and Gharib et al.[34] Linear measurements were then taken in micrometers, and their averages were calculated (Figure 1). To analyze the perimeter penetration ratio of the cement, the total perimeter of the canal and the segment where the endodontic cement penetrated into the dentinal tubules were measured in micrometers.[33,34] Subsequently, the penetration perimeter value was divided by the total perimeter of the canal to obtain the penetration perimeter ratio (Figure 2). After calculation, all measurements were transferred to a Microsoft Office Excel 2010 worksheet (Microsoft Corporation, Redmond, USA), in which they were tabulated and prepared for statistical analysis.

Statistical analysis

The data were subjected to D'Agostino–Pearson's normality test, which showed non-normal distribution. Data were initially analyzed using descriptive statistics, including the median, minimum, and maximum.

The Friedman test followed by Dunn's *post hoc* test for the comparison of pairs was used to evaluate differences in cement penetration (*i.e.*, linear measurements and penetration perimeter ratio) between the apical third, middle third, and cervical third. Both tests were performed separately for each group.

The Kruskal–Wallis test followed by Dunn's *post hoc* test for the comparison of pairs was then used to evaluate differences in cement penetration (*i.e.*, linear measurements and penetration perimeter ratio) between the six groups. The tests were performed separately for all thirds, apical third, middle third, and cervical third.

All analyses were performed using GraphPad Prism (GraphPad Software, San Diego, USA).

Results

Once the cement penetration was assessed by linear measurements, when the thirds were compared within the same experimental group, a statistical difference was observed only in the G4 between the apical third (3 mm from the root apex) and the cervical third (9 mm from the root apex), with the latter showing more penetration of endodontic cement. When the experimental groups

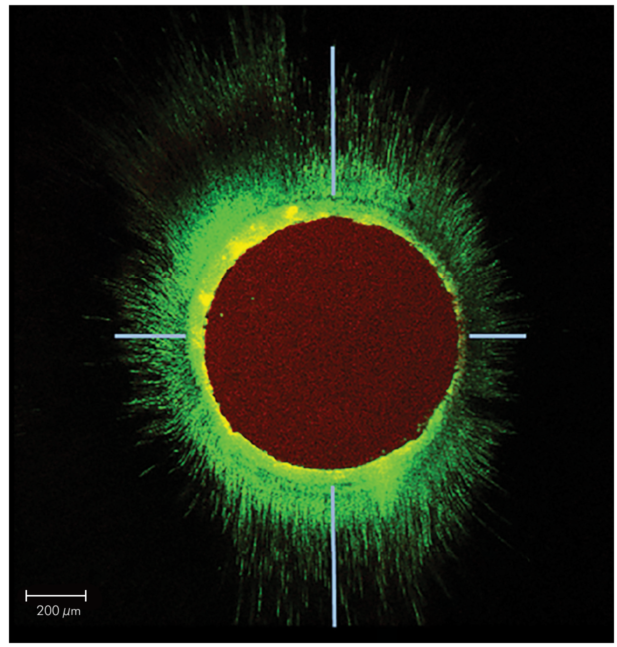

Figure 1. All teeth had their image recorded in the confocal laser scanning microscope with four standardized points (line blue) for linear gauging.

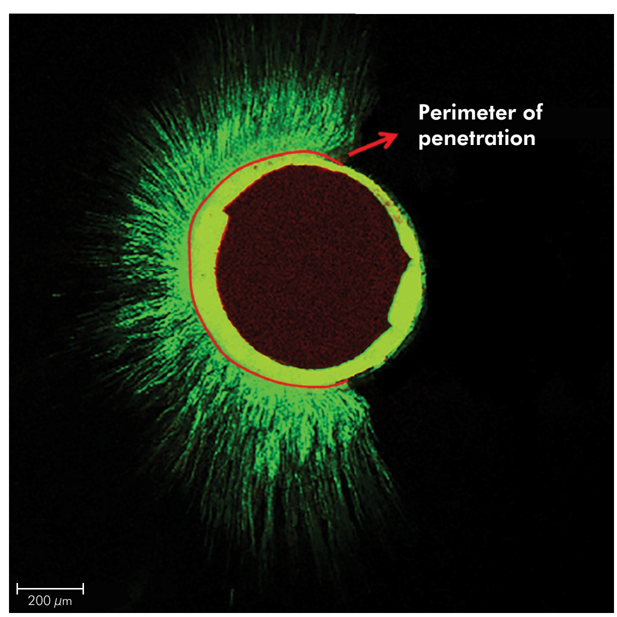

Figure 2. Image recorded in the confocal laser scanning microscope with penetration perimeter (red line).

were compared independently in each third, for all thirds grouped, the compared pairs G1-G3, G2-G3, G2-G5, G3-G4, G3-G5, and G3-G6 showed statistically significant differences, with G3 showing the highest value. In both the middle third (6 mm from the root apex) and cervical third (9 mm from the root apex), the compared pairs G2-G3 and G2-G4 showed statistically significant differences, with G2 showing the smallest values. In the apical third, no differences were observed between the experimental groups (Table 2).

In terms of differences in cement penetration according to the penetration perimeter ratio, when the thirds were compared within the same group, a statistical difference was found only in G4 group between the apical third (3 mm from the root apex) and cervical third (9 mm from the root apex), with the latter showing the highest penetration perimeter ratio. When the experimental groups were compared independently in each third, for all thirds grouped, only the compared pair G2-G4 showed a statistically significant difference, with G4 showing a higher value. No differences were observed between the experimental groups in the apical third, middle third, and cervical thirds (Table 3).

Discussion

To avoid negative interactions between the obturator material and the intracanal dressing and to maximize the adaptation of the sealant to the root walls, the temporary medication must be removed completely before filling the root canal. However, root canal morphology and its complexities can affect this process. Numerous studies have suggested attempts for removing $Ca(OH)_2$ from the root canal walls.[24,26,35] However, the current status of $Ca(OH)_2$ removal remains uncertain, as its removal has been difficult and incomplete.[36]

The present study used CLSM to analyze materials marked with fluorescein to show the extent and perimeter of penetration of endodontic cement into the root canals after removal of the $Ca(OH)_2$ dressing with XP-endo Finisher, associated with NaOCl and EDTA.[28]

Labeling materials detected by CLSM, as used in this study, seems to be an adequate and economical way of assessing the penetration of the materials present inside the dentinal tubules.[29,37,38]

CLSM has several advantages over scanning electron microscopy (SEM), including reliable identification of marked materials and simpler sample preparation in the absence of prior processing, which

Table 2. Cement penetration assessed by linear measurements (median, minimum, maximum, and comparisons)

	All thirds grouped (n=30)	Apical third (3 mm from the root apex) (n= 10)	Middle third (6 mm from the root apex) (n= 10)	Cervical third (9 mm from the root apex) (n= 10)	$p<0.05$[1]
G1	175.7 (0.0–785.2)	86.36 (0.0–450.0)	284.8 (31.53–593.1)	177.4 (0.0–785.2)	---
G2	85.86 (0.0–356.9)	69.87 (8.19–158.2)	68.87 (0.0–313.8)	120.7 (41.67–356.9)	---
G3	443.5 (11.29–1063)	362.4 (11.29–578.8)	514.3 (104.3–1048)	455.4 (266.7–1063)	---
G4	115.3 (54.09–637.1)	293.7 (4.83–503.0)	355.9 (151.8–534.5)	555.4 (234.0–740.4)	B
G5	192.2 (10.83–1130)	143.3 (10.83–592.8)	181.4 (14.75–1130)	241.4 (33.33–286.4)	---
G6	148.6 (33.87–677.7)	125.4 (41.66–319.2)	151.1 (68.00–504.5)	171.4 (33.87–677.7)	---
$p<0.05$[2]	b, f, h, j, k, l	---	f, g	f, g	

[1] p values obtained by the Friedman test followed by the Dunn's *post hoc* test for comparison between pairs, as follows: [A] Apical third (3 mm from the root apex) vs. middle third (6 mm from the root apex); [B] Apical third (3 mm from the root apex) vs. cervical third (9 mm from the root apex); [C] Middle third (6 mm from the root apex) vs. cervical third (9 mm from the root apex)

[2] p values obtained by the Kruskal–Wallis test followed by the Dunn's *post hoc* test for comparison between pairs, as follows:
[a] G1 vs. G2; [b] G1 vs. G3; [c] G1 vs. G4; [d] G1 vs. G5; [e] G1 vs. G6; [f] G2 vs. G3; [g] G2 vs. G4; [h] G2 vs. G5; [i] G2 vs. G6; [j] G3 vs. G4; [k] G3 vs. G5; [l] G3 vs. G6; [m] G4 vs. G5; [n] G4 vs. G6; [o] G5 vs. G6

Table 3. Cement penetration assessed by penetration perimeter ratio (median, minimum, maximum, and comparisons)

	All thirds grouped (n=30)	Apical third (3 mm from the root apex) (n= 10)	Middle third (6 mm from the root apex) (n= 10)	Cervical third (9 mm from the root apex) (n= 10)	$p<0.05$[1]
G1	69.08 (0.0–100.0)	56.58 (0.0–100.0)	82.28 (46.02–100.0)	71.25 (9.64–97.74)	---
G2	60.10 (26.35–100.0)	58.91 (31.09–99.81)	56.90 (26.35–98.70)	71.62 (36.56–100.0)	---
G3	94.75 (34.29–100.0)	66.16 (34.29–98.16)	91.17 (48.66–100.0)	97.65 (77.10–100.0)	---
G4	95.44 (22.91–100.0)	75.15 (22.91–97.75)	95.91 (74.67–99.71)	98.74 (43.54–100.0)	B
G5	86.73 (17.07–100.0)	80.92 (19.43–100.0)	81.75 (17.07–99.78)	96.84 (54.65–100.0)	---
G6	67.93 (15.93–100.0)	81.74 (15.93–100.0)	73.28 (38.52–98.11)	67.93 (29.95–98.52)	---
$p<0.05$[2]	g	---	---	---	

[1] p values obtained by the Friedman test followed by the Dunn's *post hoc* test for comparison between pairs, as follows: [A] Apical third (3 mm from the root apex) vs. middle third (6 mm from the root apex); [B] Apical third (3 mm from the root apex) vs. cervical third (9 mm from the root apex); [C] Middle third (6 mm from the root apex) vs. cervical third (9 mm from the root apex);
[2] p values obtained by the Kruskal–Wallis test followed by the Dunn's *post hoc* test for comparison between pairs, as follows: [a] G1 vs. G2; [b] G1 vs. G3; [c] G1 vs. G4; [d] G1 vs. G5; [e] G1 vs. G6; [f] G2 vs. G3; [g] G2 vs. G4; [h] G2 vs. G5; [i] G2 vs. G6; [j] G3 vs. G4; [k] G3 vs. G5; [l] G3 vs. G6; [m] G4 vs. G5; [n] G4 vs. G6; [o] G5 vs. G6

allows observation as close to normal conditions as possible and minimizes artifact production.[39]

Regarding the removal of the $Ca(OH)_2$ dressing and the consequent endodontic cement penetration in the tubules, in this study, XP-endo Finisher promoted greater penetration of the endodontic cement compared with conventional irrigation with needle and syringe, which suggests its greater efficiency in removing calcium hydroxide and confirms previous results.[30,31,40]

A similar study compared the efficacy of Xp-endo Finisher and PUI in removing $Ca(OH)_2$ paste from the root canals and the apical third, and the results showed superiority in removing the dressing by P-Endo® Finisher when compared to PUI.[29] In parallel, Gokturk et al.[41] observed that PUI removed more $Ca(OH)_2$ than XP-endo Finisher in the apical region of the teeth and found no statistically significant difference between PUI and XP-endo Finisher in removing $Ca(OH)_2$ in the coronal and middle thirds. The same was observed by Lu Shi et al., who found greater efficacy of PUI when compared to other activation techniques, although without a statistically significant difference, noting that the complete removal of $Ca(OH)_2$ from the apical curvature of the S-shaped root canals remains a challenge for irrigation protocols.[42]

In another study using only optical microscopy to analyze $Ca(OH)_2$ residue, Wigler et al.[40] observed that XP-endo Finisher and PUI removed significantly more $Ca(OH)_2$ than conventional needle irrigation, corroborating the present results.

The results of a similar study in which the effectiveness of Ultrasonic, EndoActivator®, EDDY®, XP-endo® Finisher, and XP-endo® Shaper instruments for removing $Ca(OH)_2$ remnants was verified using optics and scanning electron microscopy. Two of the root canals demonstrated the inability of all instruments tested to completely remove $Ca(OH)_2$ slurries from the canals, altough EDDY® and XP-endo® Finisher were associated with less $Ca(OH)_2$ remaining when creating the bur/acid cavity analyzed by SEM.[16]

Consistent with the findings of this study, Denna et al.[27] and Kfir et al.[31] showed that XP-endo Finisher is a superior method for removing $Ca(OH)_2$ from the apical third,[31] although it is also unable to completely remove $Ca(OH)_2$ from the channel. For Denna et al., this result can be justified because of the lack of sufficient contact time between the file and the channel wall during the 1-min window indicated by the manufacturer's instructions. More testing would be worthwhile, keeping XP running longer or using it for several cycles to see if it could perform more effectively in removing $Ca(OH)_2$.[27,31]

Silva et al. then observed that PUI and XP could remove a greater amount of $Ca(OH)_2$ in the middle third than in the cervical third, differing from this and other studies comparing the removal of $Ca(OH)_2$ by thirds.[43]

Solutions such as NaOCl and EDTA, alone and in combination, have been used to remove $Ca(OH)_2$.[44] For a long time, NaOCl at different concentrations was the main irrigation solution used for disinfecting root canals. This solution has a broad spectrum of antimicrobial activity against microorganisms and biofilms that are difficult to eradicate. Meanwhile, EDTA is the most approved chemical for removal of the smear layer. It is also the most widely accepted irrigation solution and a recognized procedure in endodontic therapy for disinfection. As indicated by several studies, switching between these solutions during channel preparation procedures reduces the accumulation of debris and results in cleaner channels.[45]

With a methodology similar to that described by Hamdan et al.[29] and Kfir et al.,[31] the final irrigation solutions in this study were heated to 37° C to simulate body temperature, in an attempt to improve the effectiveness of XP-endo Finisher. According to the manufacturer, exposing the instrument to temperatures above 35 °C causes its molecular conformation for the austenitic phase, expands the instrument, and ultimately improves the cleaning of channels.

Several studies claim that $Ca(OH)_2$ removal by ultrasonic agitation is superior to techniques with irrigators only.[21] However, Balvedi et al.[18] reported that there was no significant difference between syringe irrigation and PUI in the apical third of the root canals.

A recent study also evaluated the influence of irrigation protocols used to remove $Ca(OH)_2$ on the adhesion of tricalcium silicate-based materials used as an apical barrier. Their results did not show a statistically significant difference between the irrigation techniques used in terms of resistance to biodentin displacement. However, less resistance to displacement was detected after using XP-endo Finisher compared to the other techniques in the groups, corroborating the results of the present study. The authors associate this fact with the superiority of XP-endo Finisher in removing $Ca(OH)_2$ from irregularly shaped root canals, whose presence can interfere with the adhesion of these cements.[46]

Although not statistically significant, the apical third (3 mm from the root apex) often showed smallest values of cement penetration (linear measurements and penetration perimeter ratio) than the middle third (6 mm from the root apex) and cervical third (9 mm from the root apex). This may be due to the transport and accumulation of residual $Ca(OH)_2$ to the apical region, with smaller area receiving a smaller volume of irrigating solution, and the complex anatomy of the periapical region.[27]

Other factors that may have influenced cement penetration were sclerotic dentin and a low density of dentinal tubules in the apical region.[28] The proportion of penetration of endodontic cement into the dentinal tubules was different in each experimental group. In all groups, irrigation with 17% EDTA was used to promote $Ca(OH)_2$ chelation and facilitate its removal by NaOCl.[47]

In this study, EDTA agitation with the XP-endo finisher for 60 s promoted the endodontic cement penetration, as well as expanded its penetration perimeter in comparison with the groups in which the agitation lasted only 30 s, probably due to the greater chelation of $Ca(OH)_2$.[47]

The present study has limitations resulting from an *in vitro* investigation, as well as those related to the methodology used. One of these limitations is the anatomy of root canals; although they have similar volumes, they could have been flatter and therefore influenced the results. Moreover, because a sample size calculation was not performed, the lack of statistical significance between peer comparisons should be carefully considered, as it may be due to low statistical power. Despite this, the results of this study can provide information that can help clinicians select the best protocol for use in clinical practice. However, more experiments are needed to identify an irrigation protocol that can effectively remove $Ca(OH)_2$ residues and allow cement penetration into root canal spaces (Figure 3).

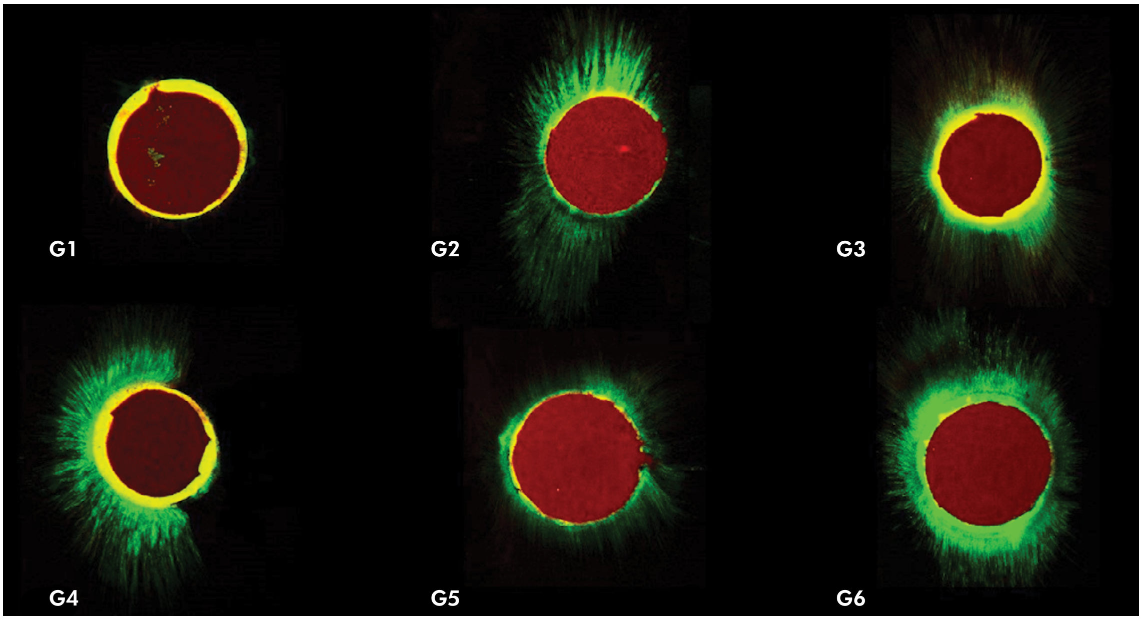

Figure 3. Demonstrative confocal laser scanning microscope images of each group (apical third), showing the cement penetration into root canal spaces.

Conclusion

Using XP-endo Finisher in irrigation was more effective than when using a needle and syringe in extending the penetration and penetration perimeter of endodontic cement. Stirring with XP-endo Finisher with 17% EDTA solution also contributed to an increase in the extent of penetration of endodontic cement into dentinal tubules, as well as the perimeter of penetration. Finally, the exclusive use of XP-endo Finisher and EDTA was more efficient in extending the penetration and perimeter of endodontic cement than when the instrument was used interchangeably with NaCOL and EDTA.

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