

ORIGINAL ARTICLE

## Effects of three different irrigating solutions and KTP laser irradiation on apical leakage: An electrochemical study

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### Abstract

**Objective.** The purpose of this study was to evaluate the effect of three different irrigating solutions (17% EDTA, 10% citric acid and 2.5% NaOCl) and KTP laser irradiation on apical leakage using an electrochemical method. **Materials and methods.** Sixty extracted single-rooted human teeth with mature apices were instrumented up to a size 35 K-file. After using each file and before proceeding to the next, canals were irrigated with 2 ml of 2.5% NaOCl. All teeth were then randomly divided into four groups. In group 1, the root canals were irrigated with a final flush of 17% EDTA. In group 2, the root canals were irrigated with a final flush of 10% citric acid. In group 3, the root canals were irradiated with KTP laser at 1 W, 4.45 J/cm<sup>2</sup>. In group 4, the root canals were irrigated with a final flush of 2.5% NaOCl. The root canals were then filled using the cold lateral condensation method. Apical leakage was evaluated using an electrochemical method over a period of 10 days. Data were analysed using Tukey HSD and Friedmann tests with  $p = 0.05$  as the level for statistical significance. **Results.** The 17% EDTA and 10% citric acid groups had statistically less apical leakage than the 2.5% NaOCl group at days 7, 8, 9 and 10 ( $p < 0.05$ ); however, no significant differences were found between the tested groups at the other time intervals ( $p > 0.05$ ). No significant difference was found between the KTP laser group and other groups tested at all time intervals ( $p > 0.05$ ). **Conclusion.** All groups were unable to eliminate apical leakage. However, final irrigation with 17% EDTA and 10% citric acid following root canal preparation reduced postobturation apical leakage compared with 2.5% NaOCl irrigation. When KTP laser and the other three irrigants were compared, no significant difference was found.

**Key Words:** apical leakage, citric acid, EDTA, KTP laser, smear layer

### Introduction

Intra-canal micro-organisms may remain active in the dentin tubules, even after vigorous chemomechanical preparation. Thus, perfect apical sealing is desirable to prevent the remaining bacteria and byproducts from reaching the root apex [1,2]. Apical leakage is a common cause of endodontic failure and is influenced by many variables such as different filling techniques, the physical and chemical properties of sealers and the presence or absence of a smear layer [1,3]. The smear layer is a combination of organic and inorganic particles on the canal walls after canal preparation and appears as an amorphous irregular layer under a scanning electron microscope [4]. McComb and Smith [5] suggest that the smear layer can create a space between the inner wall of the root canal and the filling materials, thus preventing the

complete locking and adherence of the root canal filling materials into the dentin tubules. According to Torabinejad et al. [6], the smear layer is one of the factors that can adversely affect the compromising of apical and coronal microleakage and consequently the long-term success of the treatment.

Adequate removal of the smear layer is not possible by sodium hypochlorite solution (NaOCl) alone because of the amorphous structure of this layer [4]. Thus, acids such as citric, tannic, polyacrylic or phosphoric acids or chelating agents such as EDTA or REDTA are required for the removal of the inorganic part of the smear layer [7]. The most widely used chemical for this purpose is EDTA, which reacts with the calcium ions in dentine and forms soluble calcium chelates. Goldman et al. [8] found that the use of a copious final flush with 17% EDTA followed by NaOCl effectively removes the smear layer. According

to Yamada et al. [9], to obtain a maximum cleansing effect after instrumentation, it is necessary to use a chelating agent such as EDTA. Calt and Serper [10] and O'Connell et al. [11] found that 17% EDTA is an effective irrigating solution in removing the smear layer of instrumented canals.

In endodontics, citric acid is widely accepted as an irrigant, showing its biocompatibility compared to EDTA and its effective smear layer removal. Wayman et al. [12] showed that canal walls treated with 10%, 25% and 50% citric acid solutions were generally free of the smeared appearance. In addition, Baumgartner et al. [13] showed that citric acid is an effective irrigant to remove the smear layer from the surface of prepared root canal walls. However, Di Lenarda et al. [14] reported no or negligible difference in smear layer removal with citric acid and EDTA. However, in some studies, citric acid left precipitated crystals in root canal walls [15].

Lasers can be used to vaporize tissues in the root canal, to remove the smear layer and to eliminate residual tissue in the apical portion of root canals [16]. The effectiveness of lasers depends on many factors, including the power level, the duration of exposure, the absorption of light in the tissues, the geometry of the root canal and the tip-to-target distance [17,18]. Several types of laser instruments have been evaluated for their effect on dental hard tissues; the carbon dioxide, the Nd:YAG and the Er:YAG are the most widely used. Recently, a frequency-doubled Nd:YAG laser was introduced (potassium titanyl phosphate (KTP) laser). This is a solid state laser that is designed to pass an Nd:YAG incident beam of 1064 nm through a KTP crystal to produce an intense visible green laser light of 532 nm. This process causes the 1064 nm wavelength to be shortened by half, to 532 nm, while doubling the beam's frequency [19]. These changes enhance energy absorption of blood-perfused tissues and avoid the requirement of a separate aiming laser [17].

The effectiveness of root canal filling materials and obturation techniques in providing an apical seal has been evaluated by various techniques: dye leakage and bacterial leakage, the electrochemical method, radioisotope labeling and fluid filtration. Dye leakage evaluation is the most commonly-used technique, likely because it is the simplest method to carry out the process. Despite the wide use of dye penetration as a method for leakage evaluation, it has significant limitations: The range of error is great and, if not controlled precisely, a number of variables could significantly change the results. In addition, quantitative measurements cannot be obtained [20]. Jacobson and von Fraunhofer [21] described an electrochemical method for leakage measurement. Delivanis and Chapman [20] found this method to be effective and reliable. They reported that this electrochemical method could provide quantitative measurements of

apical leakage and the opportunity to study leakage over a continuous time period.

The purpose of this study was to evaluate the effect of three different irrigating solutions (17% EDTA, 10% citric acid and 2.5% NaOCl) and KTP laser irradiation on apical leakage, using an electrochemical method.

## Materials and methods

### *Selection and preparation of teeth*

Sixty freshly extracted single-rooted human teeth were used. All the teeth were radiographed to verify the presence of a single canal, mature apex and absence of any resorption or endodontic filling. Teeth with caries, cracks and dilacerations were excluded. The external surfaces of the teeth were cleaned with curettes. The teeth were decoronated using a high-speed diamond disk with a cooling system to standardize the root length of 16 mm and were stored in saline solution until use.

All preparation and obturation procedures were carried out by one operator to reduce inter-operator variability. Apical patencies were determined with a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). The working length was established at 1 mm short of the apical foramen. Root canal preparation was performed with a modified step-back flare technique. The coronal portion was initially flared with sizes 1–3 Gates Glidden drills (Dentsply Maillefer). Canals were then prepared with K-files to a master apical file size 35 and step-back in 1 mm increments to a file size 55. Canal patency was maintained by inserting a size 15 K-file slightly beyond the apical foramen during recapitulation.

After using each file and before proceeding to the next, canals were irrigated with 2 ml of 2.5% NaOCl. Finally, the root canals were irrigated with 3 ml distilled water. After the completion of the preparation procedure, the teeth were randomly divided into four experimental groups consisting of 13 samples in each group. The remaining eight teeth were used for negative and positive control groups. In group 1, the root canals were irrigated for 3 min with 2 ml of 17% EDTA as a final flush, after which the root canals were irrigated with 2 ml of 2.5% NaOCl, followed by a final rinse with 3 ml of distilled water. In group 2, the root canals were treated in the same way as group 1 except 10% citric acid was used as a final flush. In group 3, the root canals were irradiated with KTP laser (SMARTLITE D, Deka, Calenzano Firenze, Italy) at 1 W, 4.45 J/cm<sup>2</sup> (Ton: 10, Toff: 50, emission mode: repeat). During laser irradiation, the optical fiber (diameter of 200 µm) was inserted into the canals passively to within 1 mm of the apex, kept in contact with the root canal walls, then moved coronally with a spiral movement. One lasing cycle comprised five

irradiations of 5 s each, in 15 s intervals. Total irradiation time for each root canal was 25 s. In group 4, the root canals were irrigated with 2 ml of 2.5% NaOCl as a final flush followed by a final rinse with 3 ml of distilled water. All the irrigating solutions were introduced into the canal using a 27-gauge stainless steel beveled needle. The needle was placed within 1–2 mm of the working length in each canal. The root canals were finally irrigated with 3 ml of distilled water to remove any precipitate that might have formed.

#### *Root canal filling*

The root canals were filled using the cold lateral condensation method with gutta-percha and AH 26 sealer (Dentsply DeTrey, Konstanz, Germany). A master gutta-percha cone size 35 was selected and tug-back was checked. After AH 26 sealer was mixed according to the manufacturer's instructions, the master cone was coated with sealer and positioned into the canal. The first finger spreader (size 30; Dentsply Maillefer) was inserted between the master cone and the canal wall to within 1 mm of the working length. Cold lateral condensation was performed using size 25, 20 and 15 accessory gutta-percha points until the canal was completely filled. The filling was complete when a size 15 finger spreader could not penetrate beyond the coronal third of the canal. A heated plugger was used to remove 2 mm of the gutta-percha coronally. The root canal filling was compacted vertically with a cold plugger. The roots were radiographed in buccolingual and mesiodistal directions to confirm the adequacy of the root filling. After the filling procedures were completed, all roots were stored at 100% humidity for 24 h to allow complete setting of the sealer cement.

#### *Electrochemical method*

The apical leakage of the roots was evaluated using an electrochemical method [21]. The coronal gutta-percha was removed using Gates-Glidden drills of sizes 3 and 4 (Mani, Tochigi, Japan), leaving only the apical 5 mm of the root filling. Copper wires (anode) were inserted into the canals as experimental electrodes in contact with the remaining gutta-percha (Figure 1). The contact of the wires to the gutta-percha was confirmed by radiographs. The teeth were attached to the copper electrode by using sticky wax and the roots were covered with two coats of nail varnish except the apical 2 mm. Eight teeth were biomechanically prepared and not obturated. The root surfaces of four teeth were entirely covered with two coats of nail varnish and served as negative controls. The other four teeth were covered with two coats of nail varnish except the apical 2 mm and served as positive controls.

All the specimens were placed in vials. The copper wire was then extended to the outside of the vial cap

and fixed in place using sticky wax. The stainless steel wire that acted as a standard electrode (cathode) was passed through the cap and fixed in place using sticky wax. A 0.9% NaCl solution (to act as an electrolyte) was placed in the bottle until the apical half of the roots were covered (Figure 2). The experimental system was connected to a multimeter (Torward Electric Instruments Co., Ltd., Taiwan) and the electrical resistance was measured at baseline, 1, 2 and 4 h on the first day. The resistance was then measured at 24 h and then once a day for 10 days.

#### *Statistical analysis*

Tukey HSD test was used to determine the significance between all groups and Friedman test for repeated measures to determine the significance within each group. Results were analyzed with a 95% confidence interval, where  $p < 0.05$ .

### **Results**

The positive controls exhibited an immediate current flow and apical leakage higher than all experimental groups; in contrast, no leakage was seen in the negative controls. The mean electrochemical leakage values in all time periods are shown in Table I and Figure 3. All of the tested groups showed low initial leakage that increased over the next 10 days. When apical leakage scores during those 10 day periods were compared, statistically significant differences were found between the groups tested ( $p < 0.05$ ).

After 10 days, the 17% EDTA group showed the least mean apical leakage, followed by the 10% citric acid, KTP laser and 2.5% NaOCl groups, respectively. No significant difference was found between the KTP laser group and other groups tested at all time intervals ( $p > 0.05$ ). The 17% EDTA and 10% citric acid groups had statistically less apical leakage than the 2.5% NaOCl group at days 7, 8, 9 and 10 ( $p < 0.05$ ); however, no significant differences were found between the tested groups at the other time intervals ( $p > 0.05$ ).

### **Discussion**

The aim of this study was to evaluate the influence of different irrigation solutions and KTP laser irradiation on the post-obturation apical leakage. To achieve standardized procedures throughout the study, only one operator conducted the experiments to avoid variables during the preparation of samples.

Assessment of linear dye penetration is a common method of exploring apical leakage of root fillings. However, this method has been criticized for providing semi-quantitative results and yielding a high level of variation [22]. Spangberg et al. [23] suggested that air inside the root canal filling may prevent the penetration of dye. The electrochemical test method used

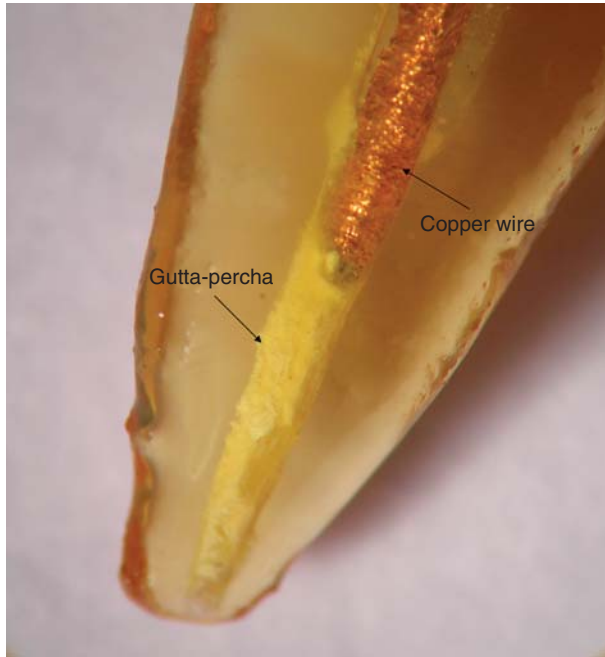


Figure 1. Representative stereoscopic photograph of a tooth with inserted copper wire (clearing technique, magnification  $\times 6$ ).

in the present study was reported to be easily comparable and subject to analysis, and it provides the opportunity to study leakage in a continuous time period, with the advantage of being able to record the time when maximum leakage occurs [20,24].

Delivanis and Chapman [20] compared the electrochemical method to the dye penetration and radioisotope methods and found a correlation at the two ends of the electric score ranges. Martell and Chandler [25] compared three root-end restorative materials using electrochemical and dye penetration

methods and found a correlation between these two methods. However, Modaresi et al. [26] found no correlation between the dye penetration and electrochemical test methods. Similarly, Pommel and Camps [27] found no correlation between the dye penetration, electrochemical and fluid filtration methods. They stated that the lack of correlation among the leakage evaluation methods is related to the difference in criteria. The dye penetration method is a passive method depending on capillary fluid movement, whereas the electrochemical leakage evaluation is based on the principle that an electric current will flow between two pieces of metal when both are immersed in an electrolyte solution and are connected by an external power source. It is assumed that the magnitude of the current is directly proportional to the degree of leakage. Current magnitude is controlled by diffusion of electroactive ions through the interface between the filling material and the tooth structure. Any change in ion concentration can affect the results [26]. In this study, the magnitude of the current was measured as the electric resistance between standard and experimental electrodes. During the test period, the level of NaCl solution was carefully checked so that the possible changes in the level of the solution did not affect the electric scores.

Electrochemical test results showed a penetration increase during 10 days in the present study. Similarly, Delivanis and Chapman [20] showed that penetration increases during the first 10 days and maximum leakage occurs at  $\sim 11$ –14 days of immersion. A possible reason for this increase of leakage after 10 days may be that the filling materials set and become dimensionally stable because of their hygroscopic and physical characteristics [28]. Alhadainy et al. [29] stated that

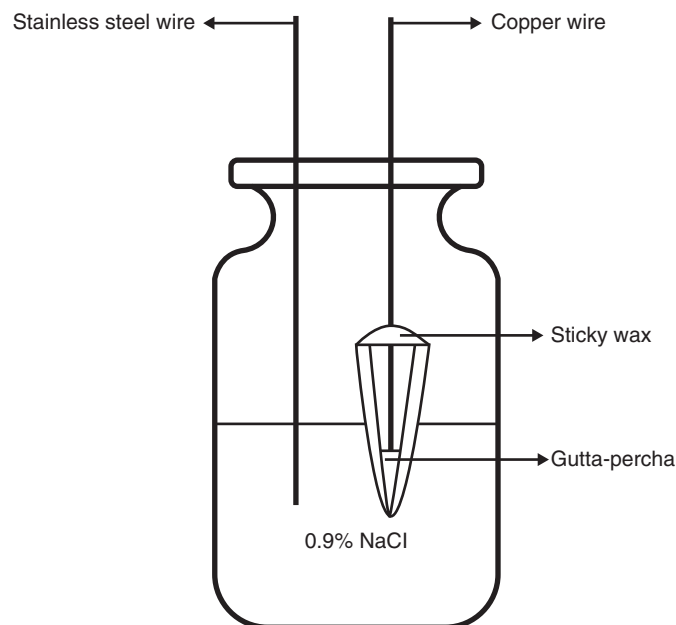


Figure 2. Schematic drawing of the test system.

Table I. Mean apical leakage values of experimental groups ( $M\Omega^{-1}$ ).

Groups		Time period													
		0	1 h	2 h	4 h	24 h	48 h	72 h	96 h	120 h	144 h	168 h	192 h	216 h	240 h
17% EDTA	Mean	0	0	0	0	0.030	0.044	0.055	0.066	0.081	0.089	0.092	0.098	0.114	0.115
	SD	0	0	0	0	0.027	0.040	0.040	0.044	0.042	0.046	0.046	0.053	0.070	0.071
10% Citric acid	Mean	0	0	0	0	0.025	0.038	0.057	0.065	0.071	0.095	0.110	0.120	0.128	0.131
	SD	0	0	0	0	0.026	0.036	0.054	0.054	0.061	0.055	0.082	0.093	0.099	0.113
KTP laser	Mean	0	0	0	0.011	0.039	0.056	0.088	0.100	0.152	0.129	0.190	0.198	0.218	0.232
	SD	0	0	0	0.023	0.042	0.054	0.067	0.086	0.183	0.120	0.151	0.143	0.180	0.213
2.5% NaOCl	Mean	0	0	0	0.016	0.061	0.080	0.114	0.133	0.199	0.194	0.283	0.307	0.305	0.303
	SD	0	0	0	0.034	0.066	0.074	0.049	0.069	0.105	0.104	0.114	0.132	0.121	0.120

SD, standart deviation; NaOCl, sodium hypochlorite.

increased leakage may be due to the conical shape of gutta-percha root canal fillings that had a smaller apical circumference than coronal portion; therefore, the electrical resistance was small in the root apex and increased toward the coronal portion. In addition, copper wires in the present study were inserted into the root canals until they contacted the remaining gutta-percha similar to previous studies [20,28,30,31].

Although the electrochemical test is reliable, effective and advantageous compared with other methods, it has two main disadvantages: The electrolytes must penetrate to the full length of the filling material to measure the leakage; and partial leakage cannot be measured [29]. In addition, it demonstrates accumulation of corrosion products over time or the filling material undergoes changes in composition. Finally, released ionic compounds may affect the results of the electrochemical leakage determination [26].

Leakage through a filled root canal is expected to take place at the interfaces between sealer and dentin or sealer and gutta percha or through voids within the sealer. The presence or absence of a smear layer may play an important role in the adhesiveness of some sealers to the root canal walls [3]. Many authors

showed that root canal surfaces without smear layer permit penetration of filling materials into patient dentinal tubules, increasing the contact surface, improving mechanical retention and reducing the possibility of microleakage through the filled canal [32–34]. In the present study, we compared the efficiency of 2.5% NaOCl, 17% EDTA, 10% citric acid as a final irrigant and KTP laser irradiation on post-obturation apical leakage. The result of the present study showed that removal of the smear layer from the root canals reduced the apical leakage similar to previous studies [32–34]. In the present study, 2.5% NaOCl showed the most apical leakage, which is consistent with results previously reported by some authors [11,35]. Irrigation with NaOCl alone can only remove the organic portion of the smear layer. Therefore, to eliminate the smear layer completely, it should be combined with chelating agents and acids for removal of inorganic dentin. In the present study, 17% EDTA and 10% citric acid demonstrated significantly less apical leakage compared with that of 2.5% NaOCl. Additionally, no significant difference was found between 17% EDTA and 10% citric acid on apical leakage. This result may be due to the

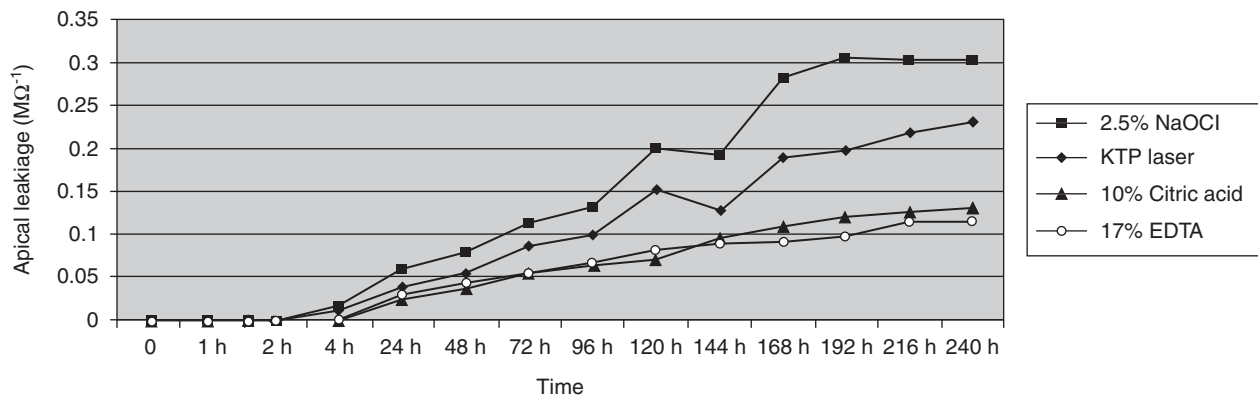


Figure 3. Distribution of apical leakage values for the electrochemical method.

similar effect of both irrigants on the smear layer, as some previous studies reported a minor or no difference in smear layer removal with citric acid and EDTA [8,14,16,35].

Laser irradiation has the potential to aid in endodontic treatment. In recent years, numerous authors have described different laser systems in endodontic treatment as feasible and effective tools for root canal cleansing and disinfection [16–18,31,36]. However, very few observations have been made on the use of KTP laser and this present study is the first to assess apical leakage with KTP laser. The results of this present study showed that mean apical leakage values of 17% EDTA and 10% citric acid were lower than that of KTP laser at 1 W. However, no significant difference was found between KTP laser and both irrigants tested in the present study, possibly because the KTP laser irradiation at 1 W might be insufficient for the desired action on the smear layer. However, increased surface porosity of the remaining smear layer after KTP laser irradiation might be reduced apical leakage. Tewfik et al. [17] found that laser dentin covered by a smear layer revealed the presence of areas of undisturbed smear layer interlaced with areas where the smear layer had undergone surface changes. These changes seemed to increase the porosity of the surface of the smear layer but did not expose any tubule orifices. Miserendino et al. [37] described reduced leakage after Nd:YAG laser irradiation and reported a bridge of glass-like materials that partly occluded lateral canals. They attributed the reduction in leakage to the deposition of resolidified silica glass on the root canal wall surface. Thus, another factor for reduced apical leakage after KTP laser irradiation might be bridge of this glass-like material on the root canal surface because KTP laser is a frequency-doubled Nd:YAG laser that might have effects similar to those of the Nd:YAG laser.

One of the concerns about laser application inside root canals is the conversion of light energy into caloric energy during the interaction with dentinal structures, which could generate a temperature increase in the external portion of the root and adjacent structures. Among the possible consequences of the thermal variations, damage to the cement layer is most likely to occur, predisposing to reabsorption of roots and periodontal ligament fibers, alveolar bone necrosis and pain. The severity of these effects is determined by the quantity of heat generated and the time it persists in the region [38,39]. According to Eriksson and Albrektsson [38], a temperature of 47°C (10°C above body temperature) for 1 min is sufficient to cause necrosis of the alveolar bone.

Although increased temperatures at the root surfaces were not observed in our study, some studies have demonstrated which power levels and exposure times might safely be used in clinical situations. Machida et al. [36] found that increases in temperature were

maintained below a safety threshold level of 7°C, during exposure at appropriate parameters with KTP laser (1 W for 6 s, 2 W for 3 s and 3 W for 2 s). In another study, Schoop et al. [40] found a temperature rise of less than 7°C on the surface of the samples when the samples were irradiated with KTP laser using parameters at 1 W and 1.5 W for 5 s, repeated five times at 15 s cooling intervals between each irradiation with a fiber tip (diameter 200 µm). They also stated that this temperature rise should not produce any adverse effects when the tested laser systems were applied *in vivo*.

The present results allowed us to conclude that all groups were unable to eliminate apical leakage. However, final irrigation with 17% EDTA and 10% citric acid reduced the post-obturation apical leakage compared with 2.5% NaOCl. Although mean post-obturation apical leakage values of 17% EDTA and 10% citric acid were lower than that of KTP laser, no significant difference was found between the KTP laser and both irrigants. Further studies should be conducted to evaluate the post-obturation apical leakage using KTP laser following root canal preparation.

**Declaration of interest:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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