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Original article

EFFICACY OF FIVE TECHNIQUES FOR THE REMOVAL OF CALCIUM HYDROXIDE FROM STRAIGHT AND CURVED ROOT CANALS - MICRO-CT STUDY

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ABSTRACT

Introduction: The role of intracanal medications in endodontic treatment is indisputable, but their removal before endodontic treatment is imperative.

Purpose: To compare the effectiveness of five different calcium hydroxide removal techniques in teeth with straight and curved root canals by micro-computed tomography.

Material and Methods: Ninety-two extracted teeth, 46 with straight canals and 46 with curved canals, were prepared with ProTaper Next to full working length and filled with calcium hydroxide. They are randomly divided into 5 groups depending on the applied technique. Group 1 (n=8) syringe and needle, group 2 (n=8) passive ultrasonic irrigation, group 3 (n=8) laser (Er: YAG), group 4 (n=8) EndoActivator and group 5 (n=8) EndoVac, and control group (n=6) without medication. Micro-computed tomography was used to assess residual calcium hydroxide. IBM SPSS Statistics 26 software was used.

Results: The greatest difference in the volume of residual calcium hydroxide between straight and curved root canals was found in syringe and needle, and ultrasonic irrigation. In the apical third, the residual volume in straight canals is 0.200 mm^3, and in curved canals 0.666 mm^3. At an average position, it is 0.272 mm^3 for straight canals and 0.344 mm^3 for curved canals.

Conclusion: In straight root canals, the calcium hydroxide residue is found along the entire length of the canal, while in curved canals, it is mostly in the apical third. The average amount of residue in curved root canals is 3-4 times greater than in teeth with straight canals.

Keywords: EndoActivator, EndoVac, Er: YAG laser, Calcium hydroxide, micro-ÑT.

INTRODUCTION

Modern endodontic therapy should be performed with appropriate irrigation solutions and intracanal medications to maximally reduce the number of microorganisms and prevent their reproduction in the root canal system. The most widely used intracanal medication is calcium hydroxide [1]. The presence of moisture in the canal raises its pH to 12 and above (12.5). The average time is applied for 1-4 weeks. Its effectiveness is due to its antimicrobial, anti-inflammatory, mineralization stimulating effect and neutralizing acidic pH [2, 3].

Removal of intracanal medications before root canal obturation is required for canal obturation. Residues of the medication on the canal walls prevent the penetration of the sealer into the dentin canals, which reduces the bond strength values between them. Complete removal of intracanal medications, especially in the apical third of the root canal, is challenging because the balance between safety and efficacy is important. The complex anatomical morphology of the root canal system further creates challenges for the removal of the placed calcium hydroxide [4].

There are various methods and techniques for removing calcium hydroxide. Syringe and needle irrigation is a routinely practiced method and the most popular technique in use for over a century. Existing disadvantages of syringe and needle irrigation are insufficient cleaning in the apical third due to the formation of an air cushion (vapor lock effect) and iatrogenic damage to periapical tissues from apical extrusion of the solution. This can be overcome by using a device that simultaneously introduces and aspirates the irrigating solution using variable pressure [5] (EndoVac System). Dogandzhiyska V. [6] (2023) found that dental lasers can be used to remove intracanal medicaments (calcium hydroxide) as an alternative to conventional endodontic irrigation. Sound energy is also applied in irrigation using a lower sound frequency (1-6 kHz), which causes less stress. Another method available to the general practitioner is ultrasonic irrigation [5], which uses higher frequencies of low-amplitude oscillation. Boutsjoukis C, et al. [7] (2022) found that the use of NaOCl and EDTA delivered with a method of laser irrigation and negative pressure irrigation of removing the intracanal medicaments give better results. Laser irrigation relies on rapid heating of the irrigant from the laser radiation, which causes optical cavitation [6, 5]. The most used laser in endodontics is the photoacoustic effect, which occurs when light energy is pulsed in the irrigant. The photoacoustic shock wave created in the canals is directed three-dimensionally into the irrigant and thus effectively cleans the canals [7, 8].

Despite numerous studies, there are still problems in removing calcium hydroxide from straight and curved root canals, which is why the present study is relevant. The aim of the present study was to compare the ability of five techniques to remove calcium hydroxide in teeth with straight and curved root canals using micro-computed tomography (micro-CT).

The null hypothesis is that there is no difference in the cleaning ability of the five techniques used in the different parts of the root canal.

MATERIAL AND METHODS

The study included 92 extracted teeth, with fully root development, free from cracks (evaluated using a stereomicroscope "Leica S6"), denticles, external and internal resorption (evaluated by X-ray). Of these teeth, 40 have curved canals, and 40 have straight canals filled with calcium hydroxide. 12 teeth were left without intracanal medication - 6 from each type of canal. The samples are divided into 5 groups of 8 teeth each. The first group was treated with a syringe and needle, followed by passive ultrasound irrigation (U-file, Woodpecker China), laser assisted irrigation (Er: YAG laser 2940nm, Light Walker, Fotona Ljubljana Slovenia), sonic activation (EndoActivator, Dentsplay Sirona UK) and negative apical pressure (EndoVac, Sybron Endo, USA).

A preliminary digital radiograph was taken on all teeth to determine the curvature of the specimens. With curved root canals are those with a curvature of the root canal over 30^{o}. A radiographic method using the Duerr Dental Imaging computer program is used to determine the curvature.

Endodontic preparation of the experimental teeth

To standardize the samples, the coronal part of each tooth was removed using a high-speed handpiece and a diamond bur under water-air cooling, leaving a standardized length of 16 mm from the apex of the root.

The samples were endodontically prepared, and the working length was determined using a K-file ISO 10 (Dentsply Sirona, Ballaigues, Switzerland). The file was inserted until its tip was seen apically, then the working length was reduced by 1 mm. All root canals were enlarged using ProTaper Next machine Ni-Ti files (Dentsply Sirona Endodontics, Ballaigues, Switzerland). The standard endomotor program for this system is used (300 rpm speed and 2 N/cm torque). Curved root canals are processed up to X2 (0.25/06), and straight ones - up to X3 (0.30/07).

During treatment, irrigation with sodium hypochlorite was performed after each instrument. The final irrigation included 5 ml of 2.5% NaOCI (Cerkamed Stalowa Wola, Poland), then with 5 ml of distilled water and finally with 3 ml of 17% EDTA (Cerkamed Stalowa Wola, Poland) for 1 min, using an endodontic needle 27G inserted 1-2 mm shorter than the working length. The last wash is with 5 ml of distilled water. The canals were dried with paper points X2 for curved root canals and X3 for straight ones.

Calcium hydroxide placement

The intracanal medication Calcipast (Cerkamed Stalowa Wola, Poland) was introduced into the canal with a Lentulo spiral size 25 until the canal was filled 1 mm shorter than the working length. A sterile cotton pellet and a temporary filling were placed coronally. Control X-ray for determination of the level of intracanal medication was taken. The samples were stored in 100% humidity at 37°C for 7 days.

Calcium hydroxide removal

The prepared samples with straight and curved canals were divided into 5 groups based on the $Ca(OH)_2$ removal technique. These techniques included using the syringe and needle irrigation, passive ultrasound irrigation, laser assisted irrigation (Er: YAG laser 2940nm), sonic activation (EndoActivator, Dentsplay Sirona UK) and negative apical pressure (EndoVac, Sybron Endo, USA).

Group 1 (n=8), removal of the intracanal medication with a **syringe and needle in combination with a file**. A 27G bevel-tipped needle is used, which is inserted at a length 2 mm shorter than the working length. In addition to irrigation, a manual K-file No,30 is used, with which movements are made up and down along the length of the root canal. Start with a 5 ml 2.5% NaOCl irrigation and activation with the manual K-file, placing the first 3 ml of it and then scraping it with a No. 30 manual K-file, and then apply the remaining amount, after which is irrigated with 3 ml of distilled water with continuous movement of the washing needle and finally irrigated with 3 ml of 17% EDTA for 1 min, again with the movement of the needle. The last wash is with 5 ml of distilled water. The effectiveness of calcium hydrohide removal was confirmed when the rinsing solution became clear.

Group 2 (n=8) - removal of intracanal medication with **passive ultrasound irrigation**. With an ultrasonic tip, the ultrasonic files are inserted 2 mm shorter than the working length (U-file, No. 20 Woodpecker China), irrigated with 5 ml of 2.5% NaOCl and activated for 30 s. For one canal, a total of 1 min, then irrigated with 3 ml of distilled water, then with 3 ml of 17% EDTA for 1 min and finally with 5 ml of distilled water to neutralize the effect of EDTA.

Group 3 (n=8) - removal of intracanal medications by activating the irrigant with an **Er: YAG laser 2940 nm** (Light Walker, Fotona Ljubljana Slovenia) with parameters 0.15 W 15 Hz 10 mJ and 50 µs pulse length, the size of the optical fiber is 300 ìm and 16 mm length. It is placed 2 mm shorter than the specified working length, and movements are made up and down the length of the root canal. Work without water and air by placing 5 ml of 2.5% NaOCl in the root canal and activating the laser for 30 s. It was then irrigated with 5 ml of 2.5% NaOCI, then with 5 ml of distilled water, then with 3 ml of 17% EDTA for 1 min and finally with 5 ml of distilled water to neutralize the effect of EDTA. It is considered that the medication has been removed when a clear liquid flows from the canal.

Group 4 (n=8) **- sonic irrigation (EndoActivator,** Dentsplay Sirona) was used to remove calcium hydroxide. The sonic tip was positioned 2 mm shorter than the working length, 2.5% NaOCl was filled in the root canal, and the solution was activated for 30 s, followed by irrigate on with 3 ml of distilled water, then with 3 ml of 17% EDTA for 1 min, and finally with 5 ml of distilled water to neutralize the effect of EDTA.

Group 5 (n=8) – removal of calcium hydroxide by a device using **negative apical pressure** (EndoVac System, Sybron Endo, USA). A macrocannula size of 0.32 mm and 12 laser-made evacuation holes at the end of the needle is used. Fluid is drawn through them, creating a vortex-like negative pressure that evacuates the irrigation solution along with the intracanal medication. The procedure involved using 5 ml of 2.5% NaOCI, then irrigated with 3 ml of distilled water, then with 3 ml of 17% EDTA for 1 min and finally with 5 ml of distilled water to neutralize the effect of EDTA.

Control group - 12 specimens, 6 of them with straight root canals and 6 with curved root canals, without applied calcium hydroxide.

The amount of residual calcium hydroxide after using different techniques for its removal is examined by micro-CT.

The study was conducted with a NIKON XT H 225 (Nikon Metrology, Tring, UK) – an industrial microcomputer tomograph. The system consists of a 225 kV microfocus X-ray emitter, a 5-axis rotary table, and a Varian 2520 flat detector with a pixel size of 127 µm with an exposure time of 500 ms at a continuous rotation of 360°. The voltage and strength of the energy are 105 kV and 106 µA, respectively. The maximum possible geometrical magnification allowed for obtaining a resolution of 16 µm. Images were reconstructed using CT Pro 3D version XT 3.1.3 (Nikon Metrology, Hertfordshire, UK). Rendered image generation and image segmentation, and measurement of required volumes were performed with VG Studio MAX version 2.2 (Volume Graphics, Heidelberg, Germany)

Statistical methods and processing were performed with IBM SPSS Statistics 26 statistical software, and graphical presentation was performed using Excel 2015. The following statistical methods are used:

· Descriptive statistics

· Student's t-test for difference between two independent groups.

• Chi-square test for association between two variables. If a relationship is found in this test, then Cramer's coefficient is used to estimate the strength of that relationship. The coefficient is normalized in the range from 0 to 1 and is positioned within the following conditional limits:

0 < | Cramer's V | < 0.3 – weak relationship
0.3 < | Cramer's V | < 0.5 – moderate association
0.5 < | Cramer's V | < 0.7 – significant association
0.7 < | Cramer's V | < 0.9 – high association
0.9 < | Cramer's V | < 1.0 – very high association

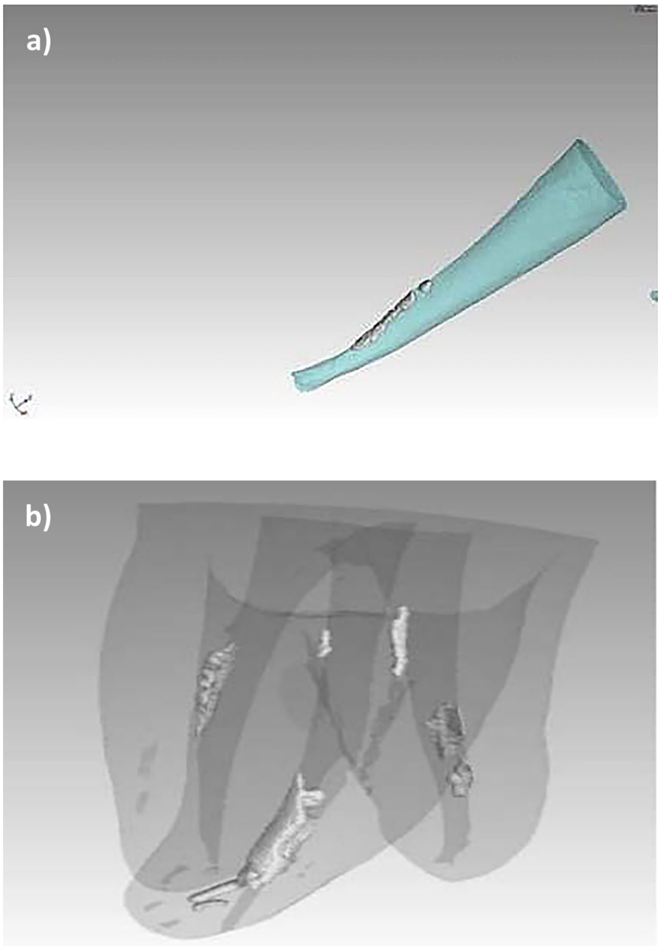
· Calculation of significance level (p-value) – this is the limit where the null hypothesis is accepted or rejected.

Making a decision - if the level of significance is greater than the error accepted at the second stage, the null hypothesis is accepted. If the level of significance is less than or equal to the error accepted at the second stage, the alternative hypothesis is accepted.

RESULTS

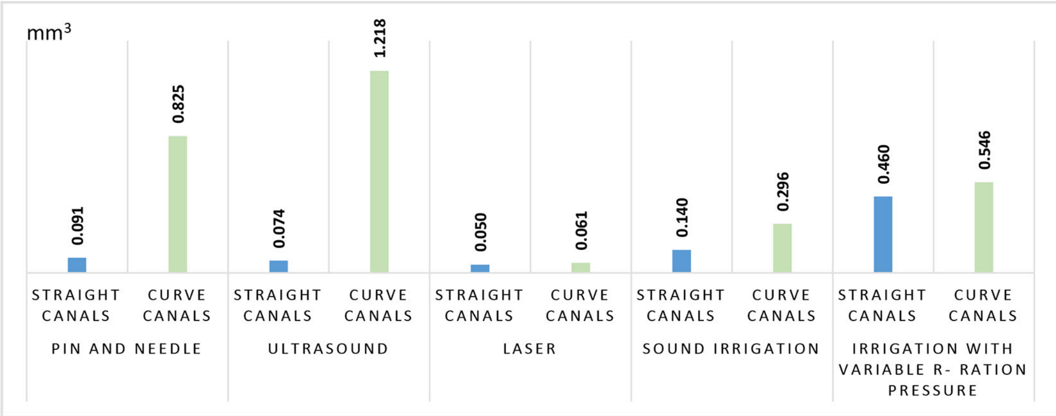
The calcium hydroxide residue found in teeth with straight root canals is less than in teeth with curved root canals. In teeth filled with calcium hydroxide, the mean residual volume in teeth with straight canals was 0.146 mm^3, while in teeth with curved canals, it was 0.668 mm^3. The average amount of residue in curved root canals is 3-4 times greater than in teeth with straight canals (fig. 1 a, b). In the control group, due to the absence of calcium hydroxide, the value is equal to zero and is not included in the hypothesis testing.

Fig. 1. The residual calcium hydroxide visualized by **micro-CT** is represented by a) straight canals and b) curved canals.



The presence of calcium hydroxide after using the different techniques of their removal is presented in fig. 2.

Fig. 2. Presence of residual calcium hydroxide in straight and curved root canals for each method of their removal (in mm^3).



The greatest difference in the volume of unremoved calcium hydroxide between straight and curved root canals was found in syringes and needles and ultrasonic irrigation. It brews in the order of 9-12 times in favor of the straight canals (a smaller amount of calcium hydroxide is found there). In sonic irrigation, a difference of the order of two times in favor of straight canals is also observed. With the rest of the removal methods, the differences are not clear.

Table 1. Results of the examination of the difference between the removal techniques in straight and curved root canals.

	Difference between the removal techniques:	P-value
Residual calcium gydroxide in straight and curved canals	Syringe and needle	P<0,001
	Ultrasound	P=0,001
	Laser	P=0,808
	Sonic Irrigation	P=0,155
	Negative apical pressure irrigation	P=0,505

The level of significance for the use of a syringe and needle [p<0,001] and for ultrasound [p=0,001] shows that there is a significant difference between the treatment methods for straight and curved root canals, and it is in favor of straight canals. There, the calcium hydroxide residue is statistically significantly less. These treatments perform better on straight root canals versus teeth with curved canals. The level of significance between laser irrigation [p=0,808], sonic irrigation [p=0,155] and negative apical pressure irrigation [p=0,505] in both types of root canals had no statistically significant difference (table 1).

Regarding the percentage distribution of residual calcium hydroxide by its position in the root canal in teeth with straight and curved canals, the distribution in straight root canals of calcium hydroxide is more uniform, while in curved root canals, it is mainly in the apical third (76.3%). In straight root canals in the coronal position, the residual calcium hydroxide is the least (2.1%), the same result is found in curved canals (2.6%). In the middle position, residual calcium hydroxide in straight canals it is 21.3%, in curved canals it is less 13.2% (table 2).

Table 2. Percentage distribution of residual calcium hydroxide relative to its position in the root canal.

Position of the residual Calcium hydroxide	**%**	
	Straight canals	**Curved canals**
Coronal position	23.4	
Middle position	21.3	13.2
Apical position	19.1	76.3
Apical and coronal position	10.6	7.9
Coronal and middle position	2.1	2.6
Apical and middle position	21.3	
All position	2.1	
TOTAL	**100**	**100**

In straight root canals, calcium hydroxide is found along the entire length of the canal (almost uniformly), while in curved canals, it is mostly in the apical third, very rarely in the middle third, and least of all in the coronal third.

In teeth with straight root canals, the residual calcium hydroxide is, on average, less than in teeth with curved root canals. The largest difference between the volume of the remainder of the medication is in the apical third. The residual volume for the straight channels is 0.200 mm^3, and for the curves, it is nearly three times more at 0.666 mm^3. In the middle position, the results are in straight canals, calcium hydroxide residue is 0.272 mm^3, and in curved canals, it is 0.344 mm^3 (fig.3).

Fig. 3. Mean volume of residual calcium hydroxide versus its position in the canal (in mm^3).

At the significance level at the mean position [p=0,624], there was no significant difference between the calcium hydroxide residue found in straight and curved canals. The level of significance at the apical position [p=0,029] had a significant difference between the residual medicaments detected in the straight and curved canals in favor of the straight canals. There, the remainder is statistically significantly less (table 3).

Table 3. Results of checking the difference between the two types of canals at different positions.

Difference between:	P-value	
Residual calcium hydroxyde in straight and curved canals	Middle position	Apical position
	p = 0,624	p = 0,029

DISCUSSION

Other studies have shown similar results: ultrasonic irrigation was found to be more effective than syringe and needle irrigation in removing calcium hydroxide Ca $(OH)_2$ from the apical part of a root canal. Syringe and needle irrigation is standard irrigation, but unfortunately it is ineffective at the apical end of the root canal or curved root canals. For the success of passive ultrasonic irrigation, the main role is played by the formation of acoustic microvortex and cavitation, which lead to more removed areas with medication from the root canal [9]. Passive ultrasonic irrigation has been successfully applied to remove calcium hydroxide in many studies and has been suggested to improve the cleanliness of the dentin walls [10]. The results of the present study on passive ultrasonic irrigation are similar to those of previous studies in that most of the $Ca(OH)_2$ was removed, although not completely. Jiang LM et al.[22] showed that the cleaning efficiency increased in parallel with the power of the ultrasonic device and by the constant addition of fresh solution Galic V, et al. [11].

Laser irrigation allows better cleaning in all anatomical features of the root canal due to the property of the resulting cavitation bubbles to expand and contract and cause implosion [12, 13]. The highest amount of remaining $Ca(OH)_2$ was observed with syringe and needle irrigation and ultrasound [14]. Ultrasonic irrigation showed a total of 8.33% $Ca(OH)_2$ remaining in the root canal system without removal of the medication from the apical third. For the conventional lavage group, 47% $Ca(OH)_2$ remained in the apical third. Unlike the first two methods, laser cleaning does not detect any remaining medication in the entire root canal system. Even the most apical region of the root canal is free of $Ca(OH)_2$ [15]. There is also a difference between laser and negative apical pressure irrigations, where there is a statistically significant difference between the volume of residual calcium hydroxide. Previous studies have shown that PIPS (Photon induced photoacoustic streaming) technology based on Er: YAG laser is very effective in removing intracanal contents [13] as well as double and triple antibiotic paste [16].

This may be attributed to the ability of laser-driven irrigation to create a cavitation effect and turbulent flow by creating a gas bubble at the laser tip as the irrigant evaporates, causing the bubble to expand as the laser continues, to emit energy and vaporize the irrigant in front of the laser tip Anis Motiwala M, et al. [17] Denna J, et al. 18]. On the contrary, it has been reported that the removal of Ca $(OH)_2$ in the apical third is more efficient than its removal in the coronal part [19]. In contrast, Silva et al.[9] observed a higher percentage of remaining $Ca(OH)_2$ in the apical region than in the coronary region Pabel AK, et al. [19].

Previous studies have shown difficulties in completely removing calcium hydroxide paste from the root canal system in curved root canals, especially from the apical third [20].

The complex anatomy of the root canal system (lateral canals, isthmuses and accessory canals) not only prevents the penetration of irrigants and medicaments into a mechanically untouched space but also prevents the removal of intracanal medicaments from the root canal space. Residual $Ca(OH)_2$ remains mainly in the apical part of curved root canals and is most often found in the region 0–1 mm from the tip, followed by a region 1–3 mm from the tip of the apex [14]. However, in some in vitro tests, sound activation and passive ultrasonic irrigation methods have been reported to have similar irrigant penetration and result in better cleaning in the apical third of curved root canals than the syringe and needle method. This result coincides with the results of Blank-Gonçalves LM, et al. [21], but it is different from the results of Jiang LM et al. [22], ho reported that ultrasound activated irrigation was superior to sonic irrigation [22].

The irrigations during the preparation of the root canal, as well as during the removal of intracanal medications in our study, were performed with the most commonly used irrigants in the field of endodontics - 2.5% NaOCl and 17% EDTA, with irrigations in between with distilled water. Sodium hypochlorite (NaOCl) [23, 24] shows a much greater dissolution effect on necrotic tissues than on vital tissues. Since, as mentioned above, hypochlorite is only active against organic matter, substances removing inorganic matter - EDTA - must be used. According to the authors, EDTA should be used for 2 to 3 minutes at the end of instrumentation and after NaOCl irrigation. Topçuoðlu HS, et al. indicated that the combination of these irrigants (NaOCl, EDTA) improved their efficiency in calcium hydroxide removal [25].

In the present study, the residual medication was examined by micro-computed tomography *(Micro-CT)*. It assesses the 3-dimensional volume of $Ca(OH)_2$ at high resolution, requires no sample preparation, and is thus a noninvasive technique.

CONCLUSION

With the limitation of the present study, the average amount of residue of calcium hydroxide in curved root canals is 3-4 times greater than in teeth with straight canals. The level of significance for laser irrigation, sonic irrigation, and negative apical pressure irrigation for the two types of root canals had no statistically significant difference. In straight root canals, the calcium hydroxide is found along the entire length of the canal (almost uniformly), while in curved canals, it is mostly in the apical third.

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