

Research Article

# Efficacy of Different Manual and Sonic Agitation Procedures to Remove Calcium Hydroxide from A 3D Printed Root Canal Model with Artificial Spherical Extensions

Stephan Deisenhofer<sup>1</sup>, Maximilian Eglseder<sup>1</sup>, Dragan Alexander Ströbele<sup>2</sup>, Wilhelm Frank<sup>3</sup>, Jörg Philipp Tchorz<sup>1\*</sup>

<sup>1</sup>Division for Endodontics, Center for Operative Dentistry and Periodontology, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, Krems, Austria

<sup>2</sup>Research Center for Digital Technologies in Dentistry and CAD/CAM, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, Krems, Austria

<sup>3</sup>Department of Health System Research, Faculty of Medicine and Dentistry, Danube Private University, Krems, Austria

**Correspondence author:** Jörg Philipp Tchorz, Division for Endodontics, Center for Operative Dentistry and Periodontology, Department of Dentistry, Faculty of Medicine and Dentistry, Danube Private University, Krems, Austria; E-mail: [joerg.tchorz@dp-uni.ac.at](mailto:joerg.tchorz@dp-uni.ac.at)

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## Abstract

The aim of this study was to evaluate and compare the efficacy of two different needle types and three agitation methods to remove Calcium Hydroxide (CH) from root canals. A total of 75 3D printed root canal models with artificial spherical extensions were produced, filled with CH and radiographs were taken from two directions. Five groups were established (n=15) according to the removal techniques: group 1, Syringe Irrigation (SI); group 2, Eddy Flex Cannula (EFC); group 3, Manual Dynamic Agitation (MDA); group 4, Endo Activator (EA); and group 5, SmartLite Pro Endo Activator (PEA). Sodium hypochlorite (2.5 mL, 5%) served as an irrigant and was agitated for 30 seconds in groups 3-5. After the procedure, additional radiographs were taken and CH remnants were measured. Best results in terms of total CH reduction were observed in the PEA group, followed by EA, MDA, EFC and SI. EA and PEA were significantly more effective than SI and EFC. No technique could achieve complete CH removal.

**Keywords:** Calcium Hydroxide; Eddy Flex.Cannula; Endoactivator; Manual Dynamic Agitation; Smartlite Pro Endoactivator; Syringe Irrigation

## Introduction

Microorganisms play a major role in pulpal and periradicular diseases [1]. The aim of endodontic treatments is to eliminate microorganisms and infected pulpal tissue and prevent a recolonization [2]. However, a complete chemo-mechanical disinfection of the root canal is difficult, due to complex anatomical variations [3-5]. Especially in teeth with irregular canal diameters, with grooves and isthmuses, a high percentage of root canal surface is left untouched during instrumentation [6-8]. In infected teeth, bacteria may persist in such difficult

to reach areas and lead to endodontic failure [9,10]. For this reason, intracanal dressings, such as Calcium Hydroxide (CH), are often used and recommended in cases, when root canal treatment cannot be performed in one single visit [11]. CH is not only useful for the elimination of microorganisms and inactivation of their by-products, but also helpful for the confirmation of initial signs of healing (e.g. resolution of a sinus tract) or during specific endodontic procedures, such as apexification [12-15]. Prior to final root canal obturation, however, CH should be fully removed again, because remnants can prevent sealer penetration into dentinal tubules and negatively influence sealing ability and bond strength [16-18]. It has been shown, that even in straight single rooted teeth, a standard Syringe Irrigation (SI) technique is not capable of removing CH completely [19]. Irregularities inside the root canal may lead to even higher percentages of CH remnants, as standard open-ended needles produce a rather laminar flow

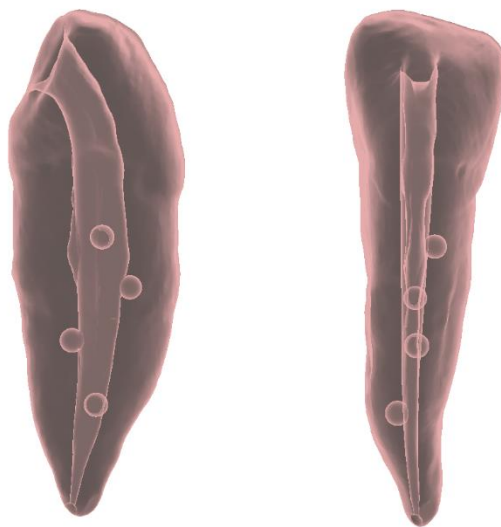
[20]. Fluid dynamics are different, when closed-ended/side-vented needles are used, such as the Eddy Flex. Cannula (EFC) (VDW, Munich, Germany), because they prevent straight outflow and produce laterally angled irrigant jets instead [21]. Different agitation techniques can also be applied to improve irrigant flow toward lateral root canal walls and improve transportation of disinfectants into remote areas [21]. Manual Dynamic Agitation (MDA) is the easiest technique to be adopted by general dental practitioners. No additional devices or instruments are necessary and only a well-fitting gutta-percha point is needed, to be moved in and outwards within the irrigant. The Endo Activator (EA) and the new SmartLite Pro Endo Activator (PEA) (Dentsply Sirona, Tulsa, Oklahoma, USA) are both small devices that use sonically driven special non-cutting polymer tips for agitation. The aim of this study was to evaluate and compare the efficacy of two different needle types (SI, EFC) and three agitation methods (MDA, EA and PEA) to remove CH from root canals with additional lateral extensions in a 3D printed artificial tooth models.

## Material and Methods

A total of 75 artificial tooth models were produced, filled with CH and randomly assorted into 5 test groups (n=15).

### *Sample Preparation*

First, a high-definition CBCT scan of a natural mandibular canine was acquired (Orthophos SL 3D, Dentsply Sirona, Bensheim, Germany). The DICOM data was then converted into a STL file using the open-source software InVesalius 3.0. In the next step, the STL data was edited using Autodesk Netfabb Premium 2021.1 (Autodesk, San Rafael, USA). Unwanted data was removed, the access cavity was redesigned and the cross-section of the root canal was processed to correspond to size .06/40 in the apical 3 mm. The middle and coronal part had a larger diameter and an oval shape in bucco-oral direction. To simulate the presence of lateral grooves, 4 spherical extensions were added in mesio-distal and bucco-lingual direction at different levels of the root canal (Fig. 1). The STL files were then nested and subsequently sliced using BEGO CAMcreator Print 1.32.0.0 (BEGO, Bremen, Germany). Nesting is a process in 3D printing where multiple parts are arranged in the most efficient way possible on the print bed to minimize waste and maximize the use of available space. The teeth were printed using the Varseo XS (BEGO, Bremen, Germany) DLP 3D-printer. During DLP printing, a digital micromirror device is used to cure a liquid photopolymer resin into a solid 3D object by projecting an image of each layer of the 3D object onto a vat of liquid resin. The projector then uses light of a wavelength of 385-405 nm to cure the resin layer by layer, building up the 3D object. Once the printing was completed, the artificial tooth models were removed from the printer and cleaned to eliminate any uncured resin using an ultrasonic bath and isopropanol. The final material properties were achieved using a BEGO Otofash (BEGO, Bremen, Germany) light polymerization unit with two xenon stroboscopic lamps with a flash frequency of 10 Hz and a light spectrum of 300-700 nm. In a final step, support structures were removed and the surface of the object was finished with a dental polishing bur. The artificial tooth models were randomly assorted into 5 test groups (n=15).



**Figure 1:** Design of the artificial tooth model with additional lateral extensions. Oval-shaped root canal in bucco-oral direction (left) and view from the buccal (right).

## Calcium Hydroxide Application

Patency was checked in all tooth models, before they were filled with a 35% CH paste (UltraCal XS, Ultradent, Cologne, Germany). Subsequently, all samples were numbered and incubated at 37° Celsius at 100% humidity for seven days. To ensure a complete filling, two radiographs were taken, one in mesio-distal and one in buccal-lingual direction. The tooth models were placed in a special designed fixture to facilitate the subsequent evaluation.

### *Group 1: Syringe Irrigation (SI)*

Conventional SI was performed using a 30-gauge open-ended needle (Miraject Endo; Hager Werken, Duisburg, Germany) attached to a 2.5 ml syringe. Sodium hypochlorite (NaOCl) was used in a 5% solution and the needle was placed 1mm short of the working length. After the entire 2.5 ml per sample were used up, the root canals were dried using paper points size .06/40.

### *Group 2: Eddy Flex Cannula (EFC)*

The irrigant was applied using EFC attached to a 2.5 ml syringe placed at 1 mm short of the working length. EFC was inserted into the access cavity from the buccal, so the two irrigant jets were directed to the mesial and distal root canal wall. During irrigation, EFC was moved up and down, until the entire 2.5 ml per sample were used up. The root canals were dried using paper points size 0.06/40.

### *Group 3: Manual Dynamic Agitation (MDA)*

A total of 2.5 ml NaOCl was used for each sample, applied by a 30-gauge open-ended needle. First, the root canal was rinsed using approx. 25% of the irrigant. Then, the NaOCl was agitated by moving a size .06/40 gutta-percha point approximately 2 mm up and down for 30 seconds. This step was repeated three times. The final 25% of the irrigant was used to rinse the canal again before it was dried using corresponding paper points.

### *Group 4: Endo Activator (EA)*

As described in group 3, the total irrigant volume was applied in steps. Sonic agitation was applied three times for 30 seconds using the red plastic tip, which corresponds to tip size 25 with a 0.04 taper. The EA tip was inserted from the buccal and it was moved up and down during agitation at the highest intensity level.

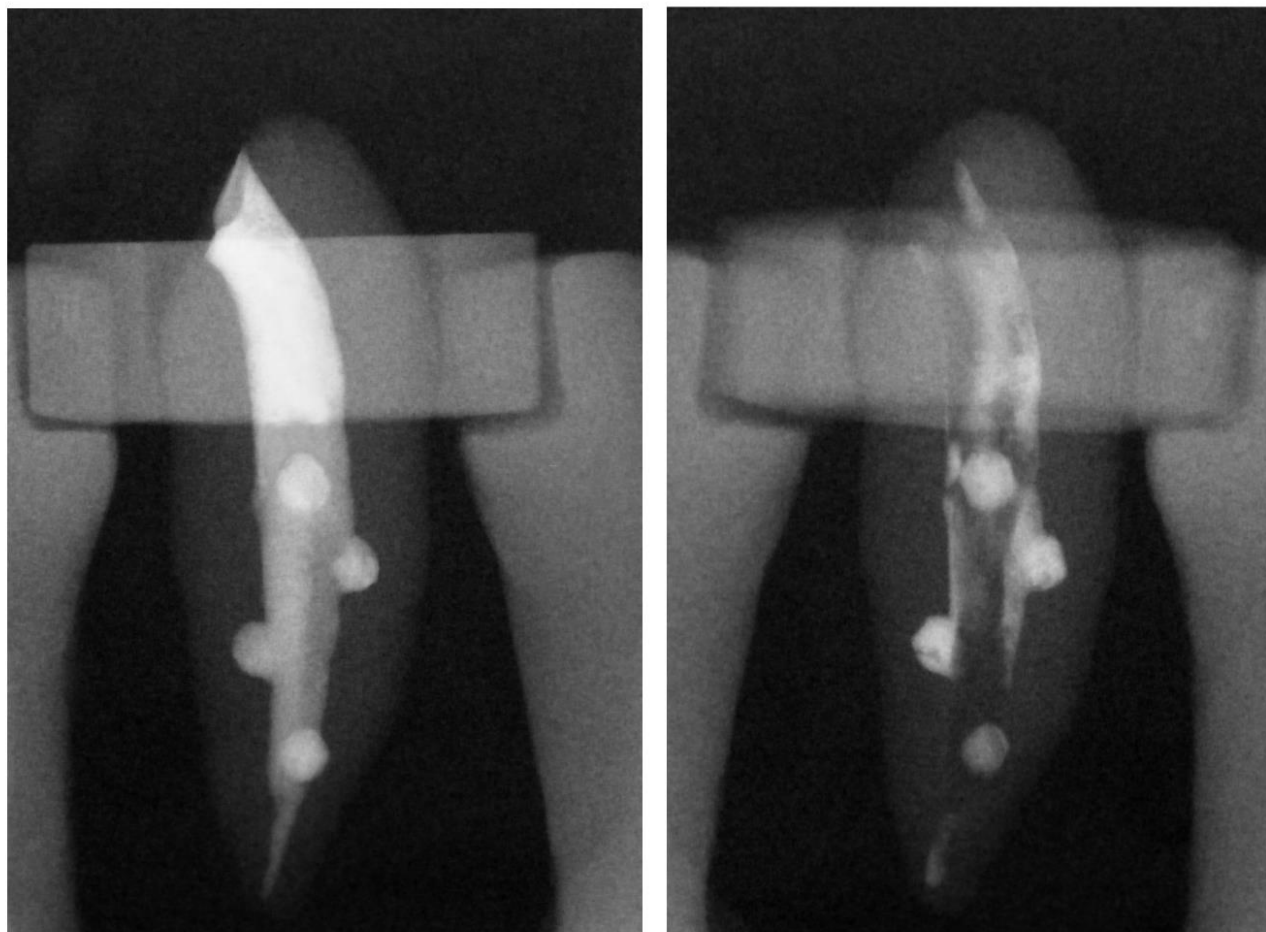
### *Group 5: SmartLite Pro Endo Activator (PEA)*

As described in group 3, the total irrigant volume was applied in steps. Sonic agitation was applied three times for 30 seconds using the red plastic tip, which corresponds to tip size 25 with a 0.04 taper. The EAP tip was inserted from the buccal and it was moved up and down during agitation at the highest intensity level

## Evaluation and Statistical Analysis

Radiographs of all specimens were taken from two different directions, after CH placement and after CH removal (Fig. 2). The area filled with CH was measured in both radiographs using the open-source software ImageJ and reduction was calculated by subtraction.

For a descriptive analysis, means and standard deviations were computed. After checking data for normal distribution using Jarque-Bera-test, a single-factor analysis of variance with post-hoc test and significance adjustment (Benferroni) was performed. The level of significance for statistical testing was set to 5%. All calculations were performed with the statistical software SPSS Version 29.0 (IBM, Armonk, NY, USA).



**Figure 2:** Radiographs taken in mesio-distal direction before (left) and after (right) the applied removal technique to evaluate the amount of CH remnants in the oval-shaped bucco-oral diameter.

## Results

Results of the descriptive analysis and corresponding significant differences among groups are shown in Table 1. The applied agitation methods were more effective in removing CH from artificial root canal models compared to both syringe/needle techniques. Best results in terms of total CH reduction were observed in the PEA group, followed by EA ( $p=0.128$ ), MDA ( $p=0.111$ ), EFC ( $p<0.001$ ) and SI ( $p<0.001$ ). EA and PEA were significantly more effective than SI and EFC. Significant differences between MDA and PEA were only observed in the bucco-oral direction ( $p=0.003$ ). SI, EFC and MDA achieved higher percentage reduction in mesio-distal direction, compared to the oval-shaped bucco-oral diameter. In contrast, EA and PEA performed equally when comparing both views.

| Method | <i>n</i> | Reduction [%]<br>mesio-distal         | Reduction [%]<br>bucco-oral           | Reduction [%]<br>total                |
|--------|----------|---------------------------------------|---------------------------------------|---------------------------------------|
| SI     | 15       | -10,15 ( $\pm 6,79$ ) <sup>A</sup>    | -06,67 ( $\pm 6,74$ ) <sup>A</sup>    | -8,88 ( $\pm 4,37$ ) <sup>A</sup>     |
| EFC    | 15       | -15,49 ( $\pm 10,63$ ) <sup>A,B</sup> | -08,29 ( $\pm 10,19$ ) <sup>A</sup>   | -12,62 ( $\pm 9,73$ ) <sup>A,B</sup>  |
| MDA    | 15       | -31,97 ( $\pm 13,28$ ) <sup>C</sup>   | -18,15 ( $\pm 12,14$ ) <sup>A,B</sup> | -26,03 ( $\pm 10,16$ ) <sup>B,C</sup> |
| EA     | 15       | -27,61 ( $\pm 12,07$ ) <sup>B,C</sup> | -24,25 ( $\pm 11,09$ ) <sup>B,C</sup> | -26,28 ( $\pm 11,22$ ) <sup>C</sup>   |
| PEA    | 15       | -39,39 ( $\pm 24,17$ ) <sup>C</sup>   | -35,99 ( $\pm 20,02$ ) <sup>C</sup>   | -38,11 ( $\pm 21,50$ ) <sup>C</sup>   |

**Table 1:** Mean CH reduction values and standard deviations. Measurements were performed in mesio-distal und bucco-oral radiographs and total reduction was calculated. Values with the same superscript letters are not significantly different within columns ( $p<0.05$ ).

## Discussion

The aim of this study was to evaluate the efficacy of different methods for CH removal. For the purpose of standardization, artificial tooth models with lateral spherical extensions were constructed. Similar 3D printed resin models have been used previously for the evaluation of different endodontic procedures [22-24]. The major advantage of 3D printing is that any desired anatomy can be designed and all produced samples are perfect replicas. To simulate an anatomy that is usually difficult to clean, an oval-shaped root canal with spherical extensions was designed and the entire space was filled with CH. Due to different setups and study designs it is not easy to compare certain results between studies. Most studies, however, have in common that they observed difficulties in removing all remnants of CH from root canals [18,19,25-28]. Only few studies showed a complete removal [29]. Moon, et al., for example, observed clean canals in straight and moderately curved roots, with both methods, needle irrigation and sonic agitation [29]. Only in root canals with a severe curvature, sonic agitation with the EA removed significantly more CH compared to conventional needle irrigation. The good cleanliness was maybe due to the morphology of the chosen samples, because only single rooted teeth were used. A smooth and round canal without any irregularities might facilitate CH removal in general. The advantages of agitation are more likely be observed, when complex canal anatomies and isthmus cleanliness are evaluated [30-33]. Adl, et al., prepared standardized grooves at three different depths in split natural roots [32]. After these grooves were filled with CH, they reassembled the roots and incubated them for 7 days at 37°C and 100% humidity. They compared the efficacy of EA, passive ultrasonic agitation and the Ultra X handpiece and evaluated the amount of CH remnants using a 4-grade scale. All groups had a median score of at least 1, which was classified by visual remnants <50%. Statistical differences between groups were only observed in the apical groove, where ultrasonic agitation with the Ultra X resulted in the cleanest grooves.

Many studies compared the efficacy of different agitation techniques for CH removal with conventional SI, but only few studies have included different needles types into their evaluation. Gokturk, et al., compared the efficacy of CH removal from simulated root canal irregularities and included in their investigational groups, among other techniques, SI and a double side-vented needle [34]. They observed inferior cleanliness scores with both needles, compared to the other techniques. As observed in the current study, differences between the two needle types were minimal. The EFC is a 30-gauge flexible cannula made of polypropylene. It has a closed-ended tip and two ports located at 180° from each other. Compared to conventional needle types, it has a 4% taper. Its flexibility allows the cannula to be inserted easily in curved root canals and its design minimizes the risk of accidental over pressing of irrigants [35]. The design of the EFC leads to an angled flow towards the lateral root canal wall, which should help in transporting irrigants into irregular geometries. In the present study, the EFC was inserted from the buccal side, as this would be the easiest direction in a clinical setting when a mandibular canine is treated. However, this meant that the two ports were directed to the mesial and distal and not towards the oval-shaped bucco-oral direction. Possibly, the EFC could have performed better, if it was rotated during irrigation. Although EFC was not as effective as the evaluated agitation methods, it performed better than SI in the present study. This may be attributed by the side-vented design, which enhances wall contact of the irrigant flow [36].

MDA can be seen as the easiest and most cost-effective agitation method. The movement of the gutta-percha point in and out of the root canal generates a fluid movement in diagonal apical direction. Saber and Hashem compared different techniques for smear layer removal in single rooted teeth that were enlarged to a predefined size and observed better results, when MDA was applied, even compared to ultrasonic agitation [37]. Others authors, however, found ultrasonic agitation to be more effective [38]. One possible explanation for different observations in the literature regarding the effectiveness of MDA might be the congruence between chosen gutta-percha and the root canal. Whereas MDA, EA and PEA achieved similar results mesio-distally, both sonic agitation groups performed better in the oval-shaped bucco-oral direction in the present study. It can be assumed, that MDA is more effective, if the chosen gutta-percha and the corresponding root canal fit well. As sonically activated instruments have high deflections at the tip and generate a flow towards the lateral, they might perform better in larger root canal diameters, compared to MDA.

EA and PEA both consist of two components, a handpiece and different activation tips that are driven by sonic energy. According to the manufacturer, the EA reaches up to 10000 cpm at highest intensity. The PEA uses improved multidirectional movements and activates its tip up to 18000 cpm. The higher speed and improved tip movement of PEA, compared to EA, might improve fluid agitation and explain the higher amount of CH removal in the present study. As the PEA is new to the market, there are no

comparable studies yet. Whilst Alturaiki, et al., compared different techniques for CH removal and observed the highest efficacy in the EA group, others observed even higher removal rates when ultrasonic instruments were used instead [31,32,39,40]. In summary, it can be concluded that any improved irrigation or agitation techniques promotes CH removal in root canals, compared to conventional SI [25-28,41,42]. Although the use of 3D resin printed teeth has advantages regarding standardization, there are certain limitations as well. The structure of the artificial root differs from natural dentin and is possibly smoother. This could simplify the removal of CH. At the same time, however, CH might react differently in resin, compared to a natural tooth. Although we tried to simulate a clinical condition, in terms of humidity and temperature, drier CH would be more difficult to remove. This could explain the higher percentage of remnants compared to other studies, where natural teeth were used [29,32].

## Conclusion

None of the applied methods removed CH completely. PEA removed the highest percentage of CH and was significantly more effective than both evaluated needle types.

## Conflict of Interest

The authors have no conflict of interest to declare.

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