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# Assessment of Penetrability for Different Endodontic Irrigation Activating Techniques Using Cone-Beam Computed Tomography and Periapical Digital Radiography—An In Vitro Study

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**Abstract:** The elimination of necrotic and inflamed pulp tissue, dentin debris, and microorganisms is essential for the success of endodontic treatment. However, the root canal's complexity has led to incomplete cleaning and disinfection. This study aims to compare the efficacy of the penetrability of three different irrigation activating techniques to the apical third of the root canal. Sixty sound single-rooted human mandibular premolars are prepared with rotary instrumentation under continuous sodium hypochlorite irrigation. Three irrigation activation techniques are utilized: group 1 (n = 20), conventional needle irrigation (CN); group 2 (n = 20), side-vented endodontic needle irrigation (EN); and group 3 (n = 20), manual activation irrigation with gutta-percha cone (MA). The penetrability is assessed with the aid of a radiopaque irrigation solution using digital radiography in conjunction with cone-beam computed tomographic (CBCT) measurements. Data are analyzed using a statistical package for social sciences (SPSS), using multiple comparisons to compare the baseline and test values. One-way analysis of variance with post hoc analysis (Tukey honestly significant difference) is performed to detect the statistically significant differences between groups. Manual activation (MA) shows effective delivery of the irrigant into full WL, followed by endodontic needle (EN) and conventional (CN) methods of activation ($p < 0.001$). The results of the present study show that maximum penetrability of the irrigant is observed with manual activation (MA) using a gutta cone in comparison with the conventional needle (CN).

**Keywords:** irrigation techniques; endodontics; irrigation penetration; digital radiography; CBCT

## 1. Introduction

Endodontic treatment success depends on the complete elimination of all intra-radicular-affected/necrotic pulpal tissues, endotoxins, microorganisms, debris and smear layer that form during root canal instrumentation. An astute clinician must rely on techniques that can aid in the total eradication of those remnant tissues and microbial elements to achieve a favorable endodontic treatment prognosis. Therefore, a properly penetrant root canal irrigation technique that helps in total removal of all intra-canal debris is essential to achieve the desired optimal prognosis and successful endodontic treatment [1,2].

Endodontic irrigation solutions have an important role during and after instrumentation by eradicating microorganisms and dissolving debris, remaining dentin chips as well as tissue remnants from the prepared root canal through a flushing mechanism so as to assure a clean and disinfected environment that is suitable for receiving the proper obturating material [3–5].

The challenging complexity of the root canal morphology, as well as its unique and unlimited variations, could have a negative effect on the elimination of all bacteria and debris inside the root canal [6]. However, cleaning and shaping per se do not disinfect the root canal system [7]. Proper root canal instrumentation coupled with an effective irrigation delivery technique is required to provide optimal disinfection of the root canal system. Efficient irrigation techniques are capable of debriding the complete canal system by delivering an adequate volume of the irrigation solution to reach the full working length of the root canal [8,9].

Various irrigation devices and techniques were developed to improve active root canal irrigation, and to reach an ideally cleaned and disinfected root canal space. In recent years, several modifications have been introduced to the needle-tip design to improve irrigation effectiveness. There are two types of root canal irrigation activation techniques, namely: manual delivery agitation techniques using files and gutta-percha cones and machine-assisted irrigation agitation techniques using sonic and ultrasonic systems [10–14].

Sodium hypochlorite (NaOCl) is commonly used for irrigation due to its antibacterial nature and ability to remove organic necrotic remnants within the smear layer during endodontic treatment [12–14]. Sodium hypochlorite can be considered as the most well-known type of irrigation used that has the ability to disintegrate and totally remove the remaining bacterial biofilms which persist in the root canal space. However, and despite its tissue-dissolving and antibacterial capabilities, it should be always used with caution to avoid any detrimental drawbacks that may be related to its cytotoxicity and adverse effect on dentin properties. The recommended concentration of sodium hypochlorite is 0.5% to 2.5%, which provides sufficient and proper non-toxic concentrations for adequate disinfection potential [15–19].

The current study has been conducted mainly to compare and contrast various traditionally available methods and techniques for irrigation activation and penetrability, which is an urgent demand nowadays in many regions in the world which practice endodontic treatment as a major branch of dentistry, together with the obvious deficiency in the recent novel electronic equipment for irrigation activation at those regions.

This in vitro study aims to compare and evaluate the efficacy of root canal irrigation solution penetrability using three different irrigation activation techniques: conventional needle irrigation (CN); side-vented endodontic needle irrigation (EN); and manual activation irrigation with gutta-percha cone (MA). The null hypothesis that is tested assumes that there is no difference in irrigation solution penetration, regardless of the used irrigation technique.

## 2. Materials and Methods

A pilot study was conducted before proceeding in our experimental research to calculate the sample size accurately using G*Power (Version 3.1) [20]. Accordingly, a total of sixty extracted human mandibular premolars were used in this study that were further divided into three main groups consisting of twenty samples for each group, in accordance with the previously calculated sample size. The teeth were characterized by being single-rooted premolars with a single-canal, completely formed apex and devoid of any caries, restorations or morphological anomalies. Any teeth with incomplete root development, root resorption, caries or fractures were excluded from the current study.

The 60 selected premolars were cleaned by immersion in a soln. of 5.25% NaOCl for 20 min and wiped with a soaked gauze to remove the organic debris and soft tissue remnants. This was followed by storing the premolars in normal saline soln. until the start of the experiment. Access cavity preparations were performed on all samples, and a size #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the canals to check for apical patency and maintain a glide path. The length of each canal was determined and then adjusted to be 0.5 mm from the apex.

Each sample was mounted on an acrylic block and numbered. All the canals were then prepared using EdgeFile X7 (Edge Endo; Albuquerque, NM, USA), size 17/0.04 and 25/0.04, respectively, with the aid of an X-Smart rotary contra-angle motor (Dentsply, Sirona, Canada) at a speed of 350 rpm and a torque of 2.5 Ncm, under constant irrigation with 2 mL of 5.25% NaOCl. Recapitulation using a 3mm syringe and a 27-gauge needle was performed in between the different files. At the end of the preparation, all canals were dried using paper points.

The 60 premolars were divided into three groups, twenty premolars each, according to the irrigation activation technique used, and a radiopaque solution (Omnipaque) was used for final irrigation to facilitate X-ray visualization of the solution penetration depth in millimeters. A digital X-ray image was obtained using (Kodak Dental Imaging Software 6.12.10.0) to record the penetration depth that was doublechecked once more using cone-beam computed tomography (CBCT) performed with the aid of a Galileos machine (Sirona Dental Systems GmbH, Bensheim, Germany), with scan parameters of 98 Kv, mA: 3–6 and exposure 14 s; field of view was 15 × 12 cm, and voxel size was 0.125 mm.

The three tested groups were classified as follows according to three different irrigation techniques:

Group 1: Conventional needle with passive irrigation (CN), n = 20.

Group 2: Side-vented endodontic needle (EN), n = 20.

Group 3: Manual agitation with fitted gutta-percha (MA), n = 20.

In the first group, the conventional needle "CN" (Monoject™ Endodontic Needles and Syringes) was placed inside the canal, and for final irrigation, iohexol (Omnipaque) solution was used passively. A radiograph was obtained to measure the penetration length compared to the working length (Figure 1).

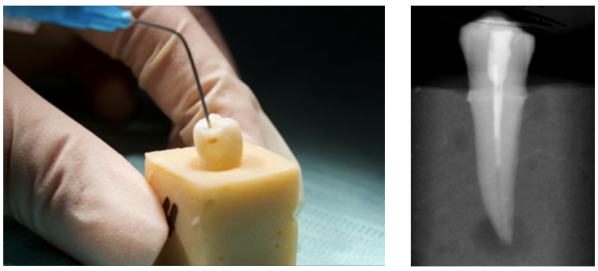

**Figure 1.** Irrigation with conventional needle (CN) and its digital radiographic image.

In the second group, a contrast medium was delivered into the canal using a side-vented endodontic needle "EN" (Max-I-Probe; Dentsply Limited, Weybridge, Surrey, UK). A radiograph was performed to measure the penetration length compared to the working length (Figure 2).

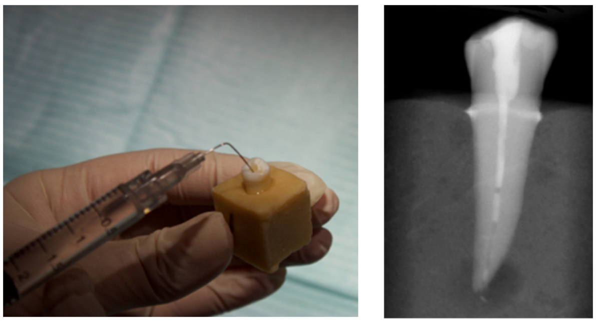

**Figure 2.** Irrigation with side-vented endodontic needle (EN) and its digital radiographic image.

In the third group, the first irrigation was delivered through the conventional needle. Then an apically fitting gutta-percha master cone (Dentsply Maillefer, Ballaigues, Switzerland) was placed inside the canal for manual agitation "MA". Pumping and up-and-down movements were performed with the gutta-percha point. The radiograph was obtained, and the measurement was recorded (Figure 3).

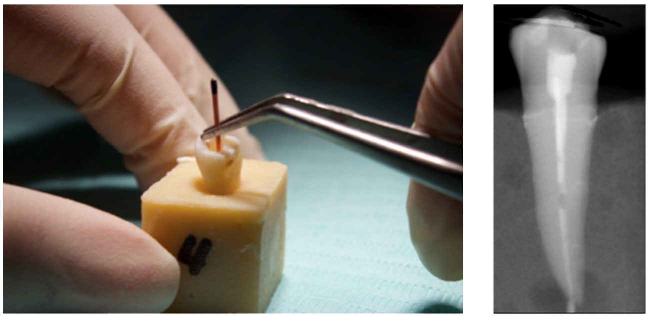

**Figure 3.** Irrigation with manual agitation using gutta-percha (MA) and its digital radiographic image.

With the contrast solution inside the canal, a digital X-ray image was taken for each tooth, and the distance between the working length and maximum penetration depth of irrigant was measured and assessed with the aid of image software (Kodak Dental Imaging Software 6.12.10.0) (Figure 4). The three groups were doublechecked again using digitized cone-beam computed tomography (CBCT) scanning (Figures 5 and 6), to obtain much more accurate measurements that were finally tabulated and analyzed.

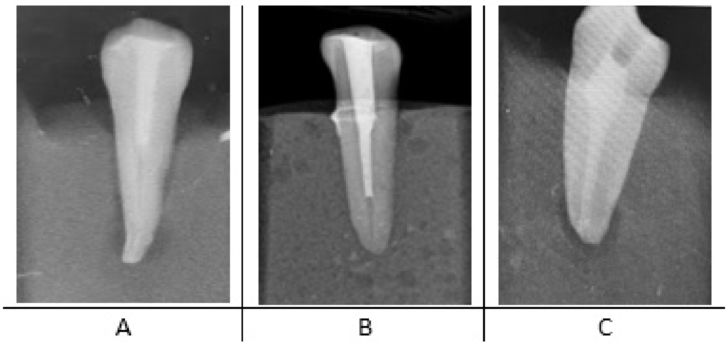


**Figure 4.** The radiographs show the penetration depth of the contrast medium in three different techniques: (**A**) with conventional needle "CN"; (**B**) with endodontic needle "EN"; (**C**) with manual agitation using gutta-percha cone "MA".

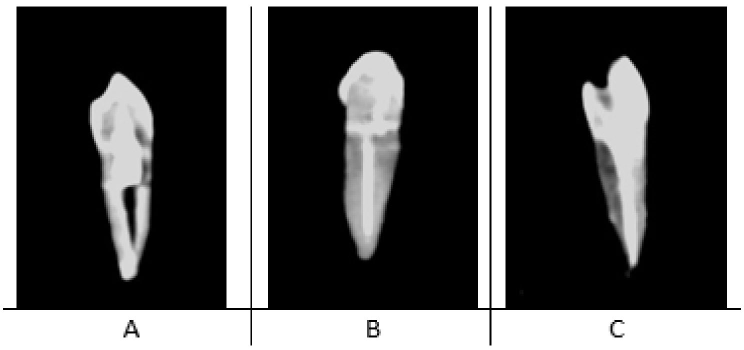


**Figure 5.** Photographs for digitized cone-beam computed tomographic scanned images showing the penetration depth of the contrast medium using the three different irrigation techniques: (**A**) with conventional needle "CN"; (**B**) with endodontic needle "EN"; (**C**) with manual agitation using gutta-percha cone "MA".

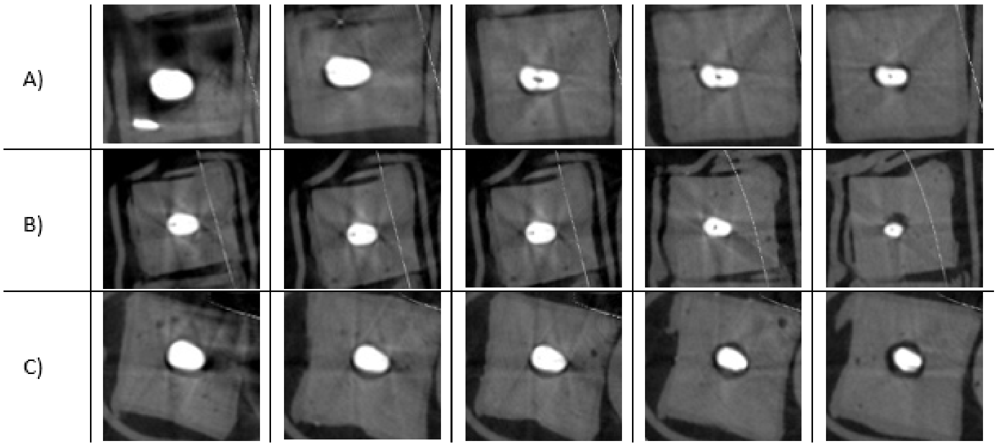


**Figure 6.** Photographs for selected digitized cone-beam computed tomographic scanned images showing the penetration depth of the contrast medium at different levels of the root canals from the coronal portion toward the apex, with the three different irrigation techniques: (**A**) with conventional needle "CN"; (**B**) with endodontic needle "EN"; (**C**) with manual agitation using gutta-percha cone "MA".

*Statistical Analysis*

Data were analyzed using a statistical package for social sciences (SPSS), using multiple comparisons to compare the baseline and test values. One-way analysis of variance with post hoc analysis (Tukey honestly significant difference) was performed to establish statistically significant differences between groups at ($p < 0.05$).

Statistical analysis was performed, and data were analyzed using a statistical package for social sciences (IBM SPSS Statistics version 20.0).

## 3. Results

The penetration depth of the irrigating solution inside the root canal system was measured in millimeters, and the mean values for irrigation penetration depth of the three groups as well as the standard deviations are listed in Table 1. Maximum irrigant infiltration was observed with the manual activation group (MA) by 0.9630 ± 005713, whereas the passive irrigation with conventional needle (CN) showed minimal irrigant infiltration by 0.6905 ± 0.11727 as shown, and finally irrigation using endodontic needle (EN) showed and intermediate level of irrigation by 0.8230 ± 0.14680.

**Table 1.** Average values for irrigation penetration depth of three groups and standard deviation: group 1 (conventional needle); group 2 (manual activation); group 3 (endodontic side-vented needle).

| Groups | N | Mean | Standard Deviation | *p* Value |
|---|---|---|---|---|
| Group 1<br>Conventional needle (CN) | 20 | 0.6905 | 0.11727 | |
| Group 2<br>Endodontic needle (EN) | 20 | 0.8230 | 0.14680 | |
| Group 3<br>Manual activation (MA) | 20 | 0.9630 | 0.05713 | <0.001 |

The one-way analysis of variance (ANOVA) test was used to analyze the differences between groups at 0.05 significance level. The multiple comparison test showed statistically significant differences between the manual activation technique (MA) with apically fitting gutta-percha and both of the other two activations techniques, namely, the conventional activation syringe group (CN) and the endodontic needle group (EN) at ($p < 0.05$) (Table 2).

**Table 2.** Statistical analysis between groups ($p < 0.05$).

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 0.743 | 2 | 0.371 | 40.036 | 0.000 |
| Within Groups | 0.529 | 57 | 0.009 | | |
| Total | 1.271 | 59 | | | |

## 4. Discussion

Incomplete debridement of the root canals in the apical third presents a true challenge during disinfection. The null hypothesis to be tested in the current study, which assumed that there was no difference in irrigation solution penetration regardless of the used irrigation technique, was rejected, and the difference between the three methods of irrigation activation was clearly obvious and significantly detected.

The current experimental in vitro study was planned to compare and evaluate the efficacy of root canal irrigating solution penetrability using three different irrigation activation techniques, namely: conventional needle irrigation (CN); side-vented endodontic needle irrigation (EN); and manual activation irrigation with gutta-percha cone (MA). A pilot study was conducted, and the sample size was calculated with the aid of G*Power (Version 3.1) (Faul et al., 2009) [20]. The lowest mean values obtained in the pilot study (Group 1: 0.13, Group 2: 0.16, and Group 3: 0.06) with a SD of 0.11 were used to calculate the effect size, which was found to be 1.0023. Considering the actual power of 0.95 with an alpha of 0.05, there was a 97.2% chance of correctly rejecting the null hypothesis of no difference between the test scores for three groups with a total of 21 samples, or 7 samples per group.

Accordingly, our study was performed on a total of sixty extracted human mandibular premolars, which were then subdivided into three groups, each of them composed of a total of twenty samples per group.

Studies have shown that irrigation with the conventional needle method (CN) using a syringe and metal needle results in ineffective irrigation [8,21]. To achieve a successful endodontic treatment, various irrigation techniques have been developed to facilitate the infiltration of the irrigation solution to reach the apical part of the canal. Several modifications to the needle-tip design have been proposed in recent years to improve irrigation effectiveness. Such modification encompasses the use of side-vented endodontic needles (EN) [20], as well as the use of apically fitting gutta-percha cones in an up-and-down motion at the working length (MA) [22,23].

The use of a wide range of radiopaque substances to improve the contrast and visuality of a root canal system has long been advocated, with the goal of studying canal morphology and detailed anatomy. Contrast media are radiopaque solutions that can be introduced into various organs inside the human body to alter their contrast and to facilitate their radiographic visualization [24]. Similar principles of removing the pulp tissue and introducing radiopaque material with the aid of centrifuging or vacuum were limited in their use [25–27]. Diatrizoate sodium powder (Hypaque) has been used in some endodontic research. Hypaque can be dissolved in water with a similar viscosity and density to sodium hypochlorite. The use of iohexol (Omnipaque) as a contrast solution in this study is justified because it is a low osmolar agent, non-ionic, water-soluble and monomeric in structure. It has a viscosity and density similar to 5.25% NaOCl [28].

The results of this study revealed that irrigation with a conventional needle (CN) was ineffective in delivering irrigation to the apical third. Similar studies have shown that irrigation using traditional methods (CN) were insufficient for proper cleaning of the canal system to its full working length. Others have proven that using apical pressure to deliver irrigation solutions can result in effective irrigation inside the root canal system [29–37].

Many studies have shown the effectiveness of gutta-percha points in assisting the penetration of the irrigant into the canal. In the present study, the most effective penetration of the irrigant was observed in the manual activation group (MA). It was found that there is a highly significant difference between the manual activation group (MA) and passive irrigation (CN) with needle. Dhaimy et al. [38] demonstrated a significant difference between manual activation with gutta cone and passive irrigation. This is in accordance with our results.

De Gregorio et al. [9] demonstrated that irrigation with a negative apical pressure was the most effective in terms of canal penetration, while passive ultrasonic (PUI) activation was superior in terms of canal infiltration. However, nowadays, many studies have shown that the ultrasonic activation technique is more effective than the traditional technique in achieving optimal disinfection and the elimination of dentin remnants and pulp tissue from the canal system, starting with Sabins et al. [39], who showed a significant difference between the ultrasonic activation technique and the passive conventional technique.

Our study also aligns with the results of the research by Susila et al., who concluded that mechanical active irrigation improved debridement and canal/isthmus cleanliness, as well as improving delivery of irrigants up to the full working length [40], and with those of Abu Hasna et al. [41], who concluded that passive ultrasonic irrigation is typically more effective in dissolving organic tissue than the traditionally used syringe and needle irrigation.

Limitations of the current study include the absence of vital or necrotic tissues, as well as the typical circumstances of simulation inside the oral cavity; this is in addition to the limitations of syringe irrigation, which can be attributed to the weak mechanical flushing, inaccessibility due to irregularities of the canal walls, and the inability of irrigant delivery beyond 1mm from the tip of the needle in most of the samples. As a further recommendation, it is suggested that the study be performed inside a patient's mouth with more generalized in vivo conditions that could be applied inside the oral cavity.

## 5. Conclusions

Within the limitations, and based on the results of the present study, it can be concluded that the degree of irrigant effectiveness and deeper penetration was found to be significantly higher and achieve a maximum level when using an apically fitted gutta-percha cone together with manual agitation (MA), rather than with the side-vented endodontic needle (EN). In addition, using a conventional needle (CN) seems to have the least efficiency and penetration depth inside the root canal system.

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**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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