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Influence of Root Canal Size and Curvature on Insertion Depth of Three Different Endodontic Irrigation Needles

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Abstract: The aim of this study was to evaluate the influence of root canal size and curvature on the insertion depth of three different endodontic irrigation needles. Four root canals with curvatures ranging from 0° to 69.72° were first enlarged to size .04/25. The insertion depths of a standard open-ended irrigation needle (SI), a single side-vented needle (SV), and a TruNatomy irrigation needle (TN) were then measured repeatedly in the chosen root canals and recorded as distances short of the working length. In curved canals, the SI and SV were tested with and without pre-bending. After enlargement to a greater taper (.06/25), these measurements were repeated. For a descriptive analysis, means and standard deviations were computed, and comparison was performed using the Wilcoxon test and formulated using a Monte-Carlo approximation with the level of significance set to 5%. Due to its flexible material, the best overall results in terms of insertion depth close to the working length were observed for the TN. The SI and SV could be inserted deeper in straight root canals and after enlargement to a greater taper ($p < 0.05$). In curved root canals, pre-bending of the SI and SV resulted in statistically significantly higher insertion depths ($p < 0.05$). In conclusion, cannula material properties, preparation size, and insertion depth mainly depend on each other. In curved root canals, a more flexible cannula like the TN should be favored to achieve better insertion depths. If using stainless-steel cannulas, they should be pre-bent to facilitate an insertion closer to the working length.

Keywords: endodontic irrigation needle; insertion depth; open-ended needle; side-vented needle; TruNatomy irrigation needle

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1. Introduction

Removing all microorganisms from the root canal is a crucial step during endodontic therapy, as they are proven to be the main cause of persistent endodontic infections and treatment failures [1–4]. Due to the complexity of root canal systems, this is unfortunately not as easy as it sounds. Mechanical instrumentation, which is part of a chemo-mechanical disinfection protocol, often leaves untouched areas that may be covered with bacteria and/or remnants of infected or necrotic pulp tissue [5–7]. Although greater enlargement may reduce the percentage of untouched areas, it is recommended that the final preparation size is only large enough in the apical portion to optimize disinfection and at the same time not too large to prevent errors such as ledges, perforations or weakening of the root [7,8]. Whereas in the past, final root canal enlargement sizes were generally greater, nowadays, minimally invasive techniques are recommended to save the tooth structure [9,10]. With this approach, minimal enlargement is considered a means of providing access to the apical anatomy for the irrigants, which are then expected to accomplish most of the disinfection [11].

To understand how mechanical enlargement size affects chemical disinfection, it is necessary to look at certain influencing factors. In general, the efficacy of endodontic irrigants depends on factors that can be categorized into two groups. Group one contains solution-associated factors such as the solution type, percentage, temperature, and volume [11–15]. Group two consists of different application factors such as the needle type, diameter, insertion depth, pressure, and agitation method [15–20]. Fluid dynamic studies have shown that, regardless of any additional agitation method, effective fluid exchange is limited to just a few millimeters apically from the end of the cannula [16,17]. Consequently, the insertion depth of the cannula is of major importance for sufficient chemical disinfection, especially if minimal enlargement sizes are chosen.

In clinical practice, various means of delivery are used for root canal irrigation, ranging from traditional standard open-ended irrigation needles (SIs) to closed-ended/side-vented needles (SVs) and the more recently introduced TruNatomy irrigation needle (TN). Rather than being made from stainless steel like the others, the TN is made from a more flexible and softer polypropylene. Whereas cannulas made of stainless steel must be pre-bent to follow the root canal curvature, the TN can more easily adapt to such anatomies. The aim of this study was to investigate whether root canal taper, curvature and irrigation needle type (SI, SV, or TN) have an influence on the insertion depth. The null hypothesis states that the insertion depth of different cannulas with the same tip size is solely dependent on root canal diameter.

2. Materials and Methods

With regard to tooth selection for the ex vivo setup, the aim was to find four root canals with small initial diameters (<ISO 15) and different curvatures ranging from straight to severe. The small initial diameter is important to achieve a defined geometry during subsequent enlargement. Teeth with previous endodontic treatments, metal restorations, resorptions, incomplete apex formations, and multiple visible foramina were excluded. All teeth available for selection were extracted in a private dental practice for periodontal reasons, and the consent of patients was obtained. A high-definition CBCT scan of three teeth that met the aforementioned criteria was initially performed to ensure that there were no calcifications, pulp stones or abrupt canal deviations that could represent a natural anatomical obstacle to the insertion of the cannula. A mesio-buccal and disto-buccal canal in a first maxillary molar, a mesio-buccal canal in a first mandibular molar, and a buccal canal in a maxillary first premolar were selected to repeatedly measure insertion depths of three different cannula types in the following experiments.

2.1. Sample Preparation

After preparing a straight-line access, patency of the chosen root canals was checked using a #10 k-file (VDW, Munich, Germany). An apical gauging was performed to check whether the planned instrumentation sizing (.04/25 and .06/25) was appropriate. Sodium hypochlorite (NaOCl) was used in a 5% solution during all shaping procedures. Two-thirds of the root canal length—predetermined by CBCT—was then enlarged using a size .04/25 VDW.ROTATE instrument (VDW, Munich, Germany). After coronal enlargement, the actual root canal length was determined by advancing a #10 K-file into the root canal until its tip was visible at the apical foramen under a microscope. The rubber stop was adjusted to the adjacent cusp (coronal reference), and instrument length was measured using an endodontic measuring block, rounded to the nearest 0.5 mm. The final working length (WL) was chosen to be 1 mm shorter than the measured actual root canal length. In the next step, root canals were enlarged up to size .04/25, and insertion depths of three different irrigation needles were tested (n = 10). Afterwards, further enlargement was performed up to a greater taper (VDW.ROTATE .06/25, VDW, Munich, Germany), and insertion depth measurements were repeated.

A second CBCT scan was performed after final enlargement to determine the curvature of the root canals by applying the method described by Schneider [21]. DICOM data were imported into the program SICAT Endo (SICAT, Bonn, Germany), and the chosen root canals were marked using so-called EndoLines between the adjacent cusp and the apical foramen (Figure 1). The determined curvatures ranged between 0° and 69.72° and are presented in Tables 1 and 2.

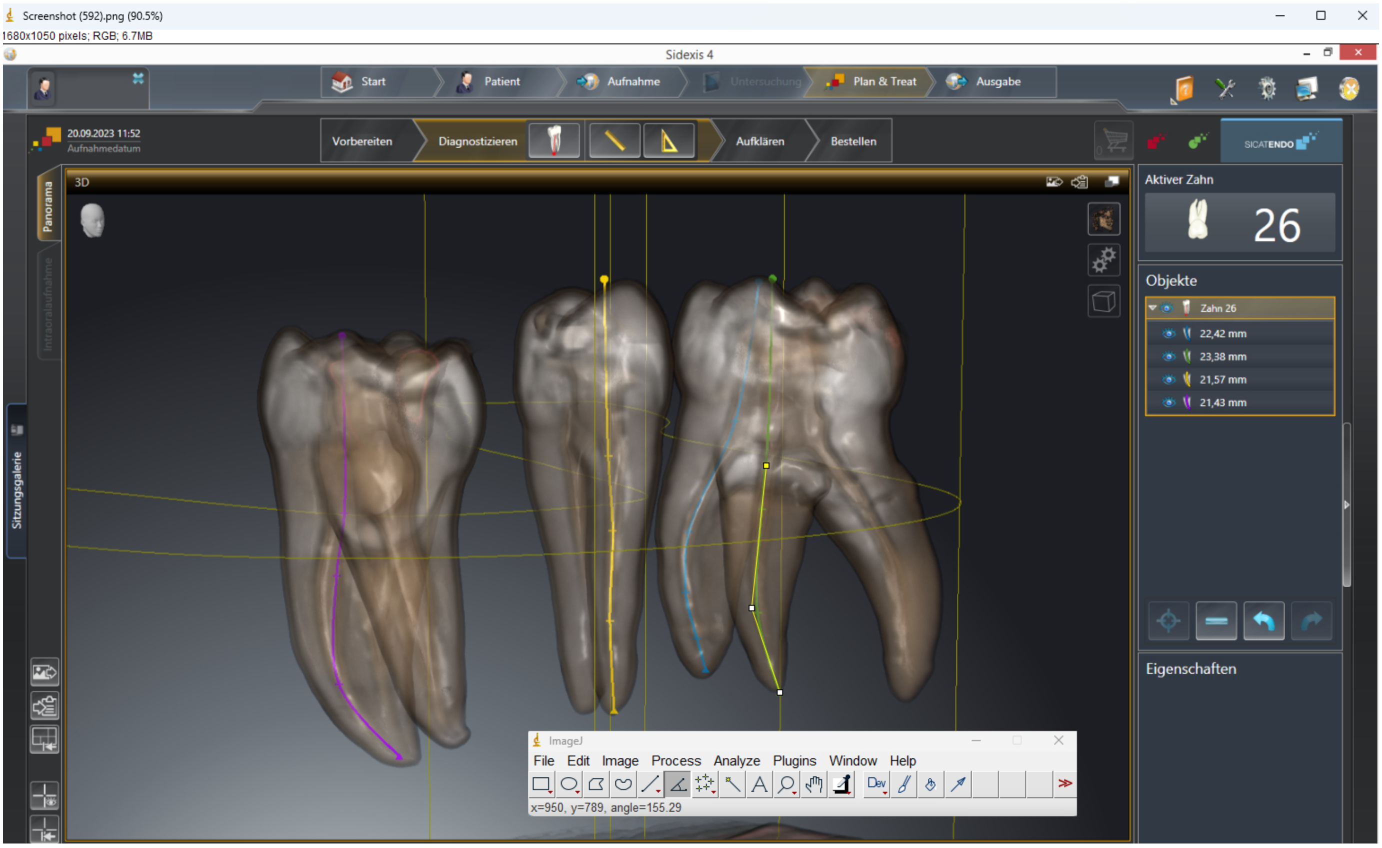

Figure 1. Example of how the program SICAT Endo (SICAT, Bonn, Germany) was applied. So-called EndoLines were used to mark root canals between the adjacent cusp and the apical foramen to predetermine the WL. This step was necessary to ensure that none of the chosen canals exceeded the maximum length of the chosen cannulas. Curvature was measured by aligning the root canal three-dimensionally, so that the largest possible curvature was visible. A screenshot was taken and opened with ImageJ, version 1.50d, and the inclination (in this case 155.29°) was subtracted from 180°, resulting in a root canal curvature of 24.71°.

Table 1. Mean differences and standard deviations between the working length and irrigation needle insertion depth in root canals with different curvatures enlarged up to size .04/25. Negative values indicate the distance in millimeters by which the tip of the irrigation needle was shorter than the working length. In the curved root canal, the insertion depth for the SI and SV was measured straight and after pre-bending. Due to material properties, no pre-bending was performed for the TN. Measurements with the SI, SV (straight and pre-bent) and TN were repeated 10 times in each of the four differently curved root canals.

Curvature	Standard Irrigation Needle (SI)		Side-Vented Needle (SV)		TruNatomy Irrigation Needle (TN)
	Straight n = 40	Pre-Bent n = 30	Straight n = 40	Pre-Bent n = 30	n = 40
0°	−1.85 ± 0.18		−1.87 ± 0.24		−2.20 ± 0.25
24.7°	−4.36 ± 0.11	−4.75 ± 0.62	−4.43 ± 0.10	−3.50 ± 0.65	−3.02 ± 0.14
46°	−4.77 ± 0.39	−3.96 ± 0.22	−4.75 ± 0.10	−3.66 ± 0.30	−2.72 ± 0.28
69.7°	−5.46 ± 0.34	−4.16 ± 0.22	−5.65 ± 0.12	−3.28 ± 1.69	−1.64 ± 0.19

Table 2. Mean differences and standard deviations between the working length and irrigation needle insertion depth in root canals with different curvatures enlarged up to size .06/25. Negative values indicate the distance in millimeters by which the tip of the irrigation needle was shorter than the working length. In curved root canals, the insertion depth for the SI and SV was measured straight and after pre-bending. Due to material properties, no pre-bending was performed for the TN. Measurements with the SI, SV (straight and pre-bent) and TN were repeated 10 times in each of the four differently curved root canals.

Curvature	Standard Irrigation Needle (SI)		Side-Vented Needle (SV)		TruNatomy Irrigation Needle (TN)
	Straight n = 40	Pre-Bent n = 30	Straight n = 40	Pre-Bent n = 30	n = 40
0°	−0.51 ± 0.12		−0.85 ± 0.04		−1.18 ± 0.20
24.7°	−2.96 ± 0.51	−1.84 ± 0.48	−2.07 ± 0.12	−2.33 ± 0.31	−2.39 ± 0.45
46°	−3.28 ± 0.35	−1.90 ± 0.20	−3.45 ± 0.13	−1.67 ± 0.55	−0.44 ± 0.14
69.7°	−4.67 ± 0.18	−2.96 ± 0.15	−4.90 ± 0.14	−3.02 ± 0.27	−0.79 ± 0.06

2.2. Insertion Depth Evaluation

All irrigation needles (SI, SV, and TN) were inserted into the root canal until the first slight resistance. No further pressure was applied to move the cannulas deeper. In the curved root canals, the less flexible stainless-steel cannulas (SI and SV) were evaluated with and without pre-bending. The pre-bending was performed in such a manner that the curvature of the cannula was comparable to the curvature of the specific root canal where it was inserted. Because of their different material properties, TNs were not pre-bent. All cannula placements were performed by an endodontic specialist.

A camera mounted on a tripod was then used to take a digital picture of the needle, where the chosen reference point was visible. To determine the actual insertion depth, the distance between the reference point (adjacent cusp of the tooth) and the upper end of the cannula was measured using the open-source software ImageJ (Figure 2). Afterwards, the result was subtracted from the total cannula length. This step was first repeated ten times for every needle with all root canals at size .04/25, and then again after further enlargement to size .06/25.

2.3. Statistical Analysis

For a descriptive analysis, means and standard deviations were computed. After checking data for normal distribution, comparison was performed using the Wilcoxon test and formulated using a Monte-Carlo approximation with the level of significance set to 5%. All calculations were performed with the statistical software SPSS Version 29.0 (IBM, Armonk, NY, USA).

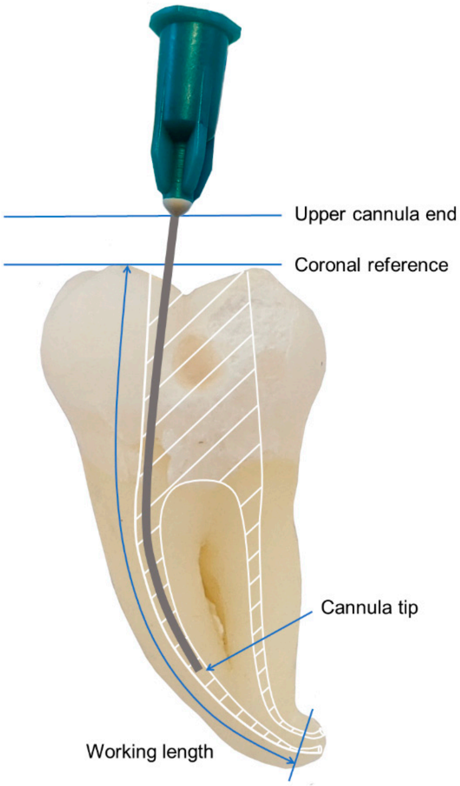

Figure 2. To determine the actual insertion depth, the distance between the coronal reference (adjacent cusp of the tooth) and the upper end of the cannula was measured using the open-source software ImageJ. This result was then subtracted from the total cannula length to calculate the distance by which the cannula tip was shorter than the WL.

3. Results

Results of the descriptive analysis are shown in Tables 1 and 2. The SI and SV could be inserted statistically significantly deeper if the root canal was straight and had a greater taper ($p < 0.05$). On average, all cannula tips were 3.5 mm short of the WL in canals enlarged up so size .04/25, and only 2.15 mm if root canals were enlarged to a .06 taper. Considering the average values independently of the respective root canal, pre-bending the SI and SV could significantly improve the insertion depth in curved root canals ($p < 0.05$). Best overall results in terms of insertion depth were observed for the TN.

4. Discussion

Several studies have been published over decades describing different phenomena regarding irrigation needle insertion depth. Zhou et al. [22], for example, evaluated fluid dynamics and observed an influence on velocity and wall shear stress depending on the needle depth and canal curvature. Boutsioukis et al. [16] also used fluid dynamics to compare different cannula types. They observed that a side-vented needle achieved sufficient irrigant replacement only if it was placed at least 1 mm short of the WL. The open-ended needle was able to achieve complete replacement even up to 2 mm. The maximum shear stress decreased as needles moved away from the WL. Perez et al. [19] evaluated the influence of insertion depth on the removal of hard-tissue debris using micro-computed tomographic imaging and observed a significant improvement when the needle was inserted 1 mm short of the WL. Although the irrigation efficacy may be increased by deeper cannula placement, this carries an increased risk of debris and irrigant extrusion [23–25]. Consequently, placing irrigation needles up to the WL is not the solution. It seems to be more important to have a balance between root canal enlargement, needle diameter and insertion depth. To date, very few studies have directly compared how deep a cannula of a specified size can be placed into root canals with different geometries. While deep placement and a more sufficient irrigation protocol might be easily achieved in a large straight root canal, it would be more difficult after minimally invasive apical enlargement of curved canals. Considering the selected size of 30 gauge, which corresponds to a diameter of 0.3 mm, and an apical enlargement of size 25, the needles should come close to the WL, but none of the chosen cannulas should be able to fully reach the WL. If the taper is also considered, then the cannula's insertion depth could theoretically range between 1 mm (.06/25) and 1.5 (.04/25) short of the WL.

In a clinical setting, the tip of the cannula should never bind within the root canal, to prevent inadvertent irrigant extrusion. This risk increases in cases where open-ended needles are chosen [23]. Nonetheless, the maximum insertion depth in this current study was defined as the first depth where the cannula encountered resistance because, in our opinion, this depth allows a more validated comparison between the different needle types. Rodriguez et al. [26] used a similar set-up but compared the insertion depth of two different sized side-vented needles in various root canals. They observed that, regardless of the degree of canal curvature, sufficient placement up to the WL is not possible with a 25G cannula, even if the canal is enlarged to size .04/40. They recommended cannulas with smaller diameters, such as 30G, as chosen in the present study.

Even though the applied ex vivo setup has advantages regarding standardization, there are certain limitations as well. Because all cannulas were repeatedly inserted into the same root canals, it is possible that the SI, in particular, may have altered the root canal surface in the curved specimens due to their open-ended design. However, this mirrors clinical practice, where cannulas must be inserted into the canal several times. The round tip of the SV and the soft material of the TN make it nearly impossible to harm the dentin. Different deformation phenomena were observed for these two cannulas after insertion. Following a straight insertion into the curved canals, a more pronounced bend in the direction of the side opening or in the opposite direction was observed in the SV directly at the opening. The softer material of the TN led to deformations in both straight and curved canals when the tip encountered an irregular surface and continued to be pushed further until slight resistance. The tip may also have been partially compressed. This could explain the results observed in the present study, where the distance between the tip and WL was <1 mm. This outcome seems mathematically impossible when considering the diameters of the cannula and the root canal. Such observations for the TN occurred only in more curved canals after enlargement to size .06/25, which exceeds the .04 taper of the TN. The SI and SV, however, also exceeded the maximum insertion depth in the straight canals after enlargement. A possible explanation could be minor inaccuracies in maintaining the defined WL during the shaping procedure.

Although the optimal insertion depth for all needles was anticipated in relatively straight root canals enlarged to size .06/25, opposite results were observed for the TN. An inferior insertion depth may also be attributed to the material itself, where initial resistance might be perceived differently, compared to stainless steel cannulas, therefore possibly leading to an incorrect assessment of a perfect fit at a more coronal position. In a clinical setting, it should be borne in mind that the softer material poses a higher risk of unnoticed blockage or shorter placement due to different tactile feedback and increased susceptibility to deformation. Therefore, it should only be placed to a depth that is dependent upon the respective enlargement size using the clearly visible depth indications. No deformations were observed for the SI. The null hypothesis could be partially rejected, as insertion depth is not only dependent on root canal diameter but is also influenced by its curvature, the type and material properties of the cannula, and the insertion procedure (straight, pre-bent). The results of the present study illustrate the problems of syringe irrigation, especially in clinical situations, where root canals can only be enlarged minimally, for example, in cases with extremely complex anatomies or in roots with small diameters. Clinically, it cannot be assumed that a cannula fitting the final enlargement size could be inserted far enough to ensure adequate fluid exchange in the apical root canal area. Especially in curved root canals, more flexible cannulas such as the TN should be favored, or stainless-steel cannulas should be pre-bent to facilitate deeper placement of the tip. Another possibility is to choose cannulas that are even smaller than the final enlargement size. As syringe irrigation is not sufficient to achieve adequate disinfection of the root canal, additional agitation of the irrigants is recommended during each endodontic treatment [20,27,28].

While the observations made in this study are plausible, they are subject to biases and also limited due to a small sample size. As measurements were performed repeatedly by only one single operator, further studies are required to analyze operator-dependent factors and check whether repeated insertion of stainless-steel cannulas leads to defects on the outer root canal wall in curved canals. Moreover, studies with larger sample sizes are needed to reflect the anatomical variability of teeth (root canal morphology, diameter, curvature, and length) and draw definite causal conclusions.

5. Conclusions

Preparation size and insertion depth are mainly dependent upon each other and should be chosen carefully to enable sufficient disinfection, as well as to save tooth structure. In curved root canals, more flexible cannulas like the TN should be favored, or stainless-steel cannulas should be pre-bent to facilitate an insertion closer to the working length.

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