Effect of Apical Size and Taper on Volume of Irrigant Delivered at Working Length with Apical Negative Pressure at Different Root Curvatures

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Abstract

Introduction: The purpose of this investigation was to determine the effect that apical preparation size and preparation taper have on the volume of irrigant delivered at the working length for different canal curvatures using apical negative pressure irrigation. **Methods:** One hundred fifty-five human teeth (55 maxillary canines and 100 mandibular molars) were used in this study. Root canals were prepared with rotary instruments to a size 35.04 and separated into 3 experimental groups according to their degree of curvature: group A (n = 50) included canal curvatures ranging from 0° to 10°, group B (n = 50) from 11° to 30°, and group C (n = 50) from 31° to 65°. Samples of each curvature group were further randomized to experimental subgroups according to the apical size and taper as follow: 35.06, 40.04, 40.06, 45.04, and 45.06. The apical third was irrigated using a microcannula and the volume of NaOCl suctioned at the working length under negative pressure was measured over a period of 30 seconds using a fluid recovery trap. Positive controls consisted of measuring the maximum volume of 5.25% NaOCl capable of being suctioned by the microcannula from an open glass vial over 30 seconds. Negative control was the volume of irrigant aspirated by the microcannula with a preparation size of 25.04 over 30 seconds. **Results:** The volume of irrigant was significantly greater when the apical preparation size increased from 35.06 to 40.04. As the apical preparation taper increased further from 40.04 to 40.06, the volume of irrigant significantly improved in group B, but it was not significant in group A. Apical preparation sizes greater than 40.06 did not show an increase of the volume of irrigant aspirated. **Conclusions:** The degree of root canal curvature decreased the volume of irrigant at the working length for a given apical size and taper. An apical preparation of 40.06 significantly increased the volume and exchange of irrigant at the working length regardless of curvature. *(J Endod 2013;39:119–124)*

Key Words

Apical enlargement, curvature, EndoVac, irrigation, volume, working length

Effective disinfection of the root canal system remains one of the main clinical and microbiological challenges to overcome when striving to improve the outcome of endodontic therapy. Different factors make this goal difficult and unpredictable. Among them are the physical limitation of irrigating within a closed system (1–4), anatomic variations and complexities (5, 6), curved canals, and bacterial aggregation in biofilms (7). Even though mechanical instrumentation is an important step in shaping root canals to allow cleaning and disinfection (8, 9), it produces debris that remains packed in anatomic complexities, oval extensions, and isthmuses (10), thus creating a reservoir for bacteria and fungi.

Innovative new irrigation techniques and systems have been examined in the endodontic literature over the past few years. These new delivery systems and fluid-activation technologies have shown a substantial improvement in root canal disinfection (11–13), mainly by enhancing irrigation at the apical level (14, 15). The volume of irrigant solution seems to play a role in the disinfection process (16). Studies have found that the volume of irrigant has an even greater effect on cleaning than the delivery system or the type of activation used (17, 18).

Apical negative pressure (ANP) irrigation (EndoVac; SybronEndo, Orange, CA) has shown promising results in disinfection (19) and debris and smear layer removal while using a closed-canal system (20). These results are obtained with straight (21) and curved canals (22).

When using positive-pressure irrigation, irrigant penetration, volume, and exchange are questionable (23–25). Root canal anatomy and curvatures will create further mechanical (needle penetration) and physical limitations (closed-canal system) that will be directly correlated to the debridement and disinfection of the root canal system (26, 27), especially in the apical third (28).

A previous study measured the volume of irrigant recovered by ANP at the working length using straight root canals (29). However, the effect of root canal curvature on the efficacy of this system remains unclear. The purpose of this investigation was to determine the effect that apical preparation size and preparation taper have on the volume of irrigant aspirated by the microcannula of EndoVac at the working length for different canal curvatures using ANP irrigation.

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Materials and Methods

A flowchart of the methodology is presented in Figure 1. One hundred fifty-five human teeth (55 maxillary canines and 100 mandibular molars) were used in this study. All teeth were stored in sterile saline and examined under a dental operating microscope (OPMI Pico Mora Dental Microscope; Carl Zeiss, Oberkochen, Germany). Teeth presenting with cracks, resorption, immature apices, root caries, previous root canal treatment, and double curvature were excluded from the study. The presence of 2 separate canals in the mesial roots of mandibular molars was verified by taking mesiodistal angled radiographs. Only the mesiobuccal canals from the mesial roots of mandibular molars were included in the study. For maxillary canines, radiographs were performed in the mesiodistal direction to confirm the presence of a single canal. After access opening was completed, patency was obtained using a 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until the tip of the file was visible at the apical foramen. The canal length was determined, and the working length was established by subtracting 1.0 mm. The root lengths were standardized to 18 mm by decoronation of the tooth perpendicular to the long axis using a high-speed, water-cooled diamond disc. A Gates Glidden #2 bur (Dentsply Maillefer) was used, limiting its instrumentation to 6 mm to provide the coronal enlargement followed by a glide path established to a size #20 K-file. A coronal reservoir made of wax (Hygienic; Colténe/Whaledent AG, Altstätten, Switzerland) was created to resemble the pulp chamber and retain the irrigant solution. Furthermore, in order to resemble the clinical challenges, a closed system was created by coating each root with soft modeling wax (Hygienic). During this procedure, an ISO #20 K-file was introduced into the canal to the working length in order to prevent the penetration of wax into the canal space.

Root canal instrumentation was performed using the ProFile rotary system (Dentsply Maillefer) with a crown-down technique until a file size #25.04 reached the working length. EndoVac's Master Delivery Tip (MDT) (SybronEndo) and the corresponding macrocannula were used to aspirate the irrigant using 1.5 mL 5.25% NaOCl between each instrument according to the sequence and group assignment. In order to standardize this phase, a rubber stop was placed 9 mm from the tip of the macrocannula. Every effort was made to keep the canals filled with irrigant at all times.

Five maxillary canines were randomly selected to serve as the negative controls. The remaining 150 samples were instrumented up to size 35.04 using the ProFile rotary system and separated into 3 experimental groups according to their degree of curvature as described by Pruett et al (30). Briefly, radiographs were taken using a digital sensor RVG 6000 (Kodak Dental Systems, Atlanta, GA) with samples placed on a turntable in order to accurately determine the x-ray beam angulation. A #15 K-file was placed in the root canal and securely attached to the

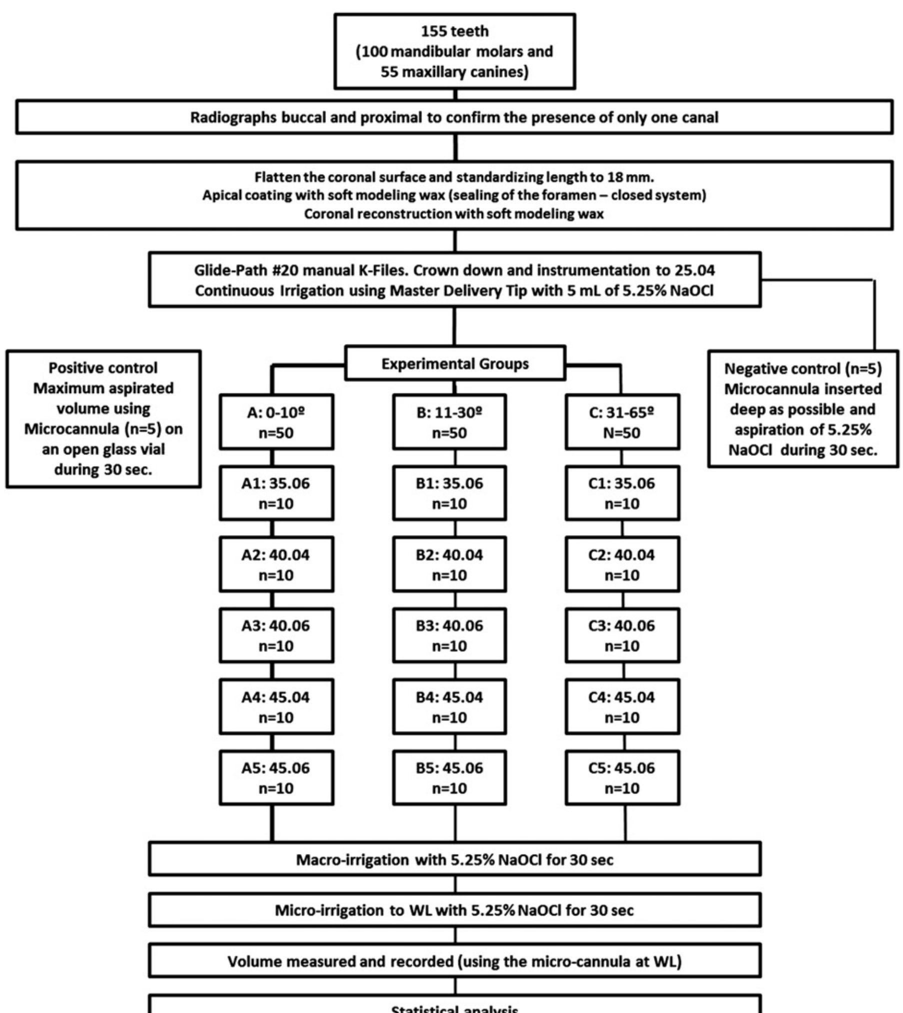

Figure 1. A flowchart of the methodology.

coronal portion with wax on the mesial wall. After a series of radiographs were taken from different angles, a radiograph of each sample showing the K-file appearing straight was obtained, and the x-ray beam angulation was recorded using a turntable where the specimens were mounted. The turntable was then rotated 90° to reveal the maximum curvature of the root canal (31).

The radiographic images obtained showing the angle of maximum curvature were processed by using Photoshop CS 5 (Adobe Systems, Inc, San Jose, CA), and the degree and the radius of root canal curvatures were calculated (Fig. 2*A–C1*). Teeth included in this study had a radius between 3 and 5 mm. Three groups were established: group A (n = 50) included canal curvatures ranging from 0° to 10°, group B (n = 50) from 11° to 30°, and group C (n = 50) from 31° to 65°.

Samples of each curvature group were further randomized into experimental subgroups according to the following apical size and taper: 35.06, 40.04, 40.06, 45.04, and 45.06. Apical patency was confirmed throughout the preparation of the samples by placing an ISO #10 K-file to the apical terminus without disrupting the apical wax seal. In addition, each sample was gauged apically using a nontapered instrument (Lightspeed LSX, SybronEndo) in order to ensure that apical preparation remained the same as established for the assigned group.

The first phase of the ANP final irrigation consisted of delivering 5.25% NaOCl to the pulp chamber with the MDT while the irrigant was aspirated using the macrocannula at the middle third for 30 seconds. To stabilize the samples and standardize the technique, roots were mounted on a platform as shown in Figure 3*A*. A stand kept the microcannula in a fixed position after being inserted to the working length (Fig. 3*B*), and a novel device kept the fluid recovery trap in a vertical position to allow recording of the irrigant volume. This device, consisting of a syringe attached to the aspirating tube, allowed the collection of the fluid aspirated by the microcannula as described in a previous study (29).

A vacuometer (MVA6181; Mityvac, St Louis, MO) was used to calibrate the pressure of the suction line at 4.42 in Hg. The pressure was constantly recorded and maintained during all experimental procedures.

The canals were irrigated using the microcannula, and the volume of NaOCl suctioned at the working length under negative pressure was measured over a period of 30 seconds using the fluid recovery trap. Upon completion of the microirrigation, the microcannulas were inspected under an operating dental microscope, and a range of 1–5 out of the 12 microholes were determined blocked. In order to allow the maximum efficacy and to follow the manufacturer's recommendations, a new microcannula was used to irrigate each sample.

Positive controls consisted of measuring the maximum volume of 5.25% NaOCl capable of being suctioned by the EndoVac microcannula from an open glass vial over 30 seconds and repeating this 5 times. Because the apical size of the microcannula was 0.32 mm, the negative control was the volume of irrigant aspirated in 5 straight teeth with a preparation size of 25.04 over 30 seconds. With the microcannula wedged into the canal without reaching the working length, the space between the cannula and the canal walls was eliminated, thus preventing continuous flow of the irrigant to the microholes.

Differences of volume aspirated at the working length for each group (apical size and taper) were compared with the Friedman test. When the Friedman test showed significant differences, comparisons between subgroups were analyzed using the Wilcoxon signed rank test. Differences in the volume aspirated among the 3 degrees of curvatures within the same apical size preparation were analyzed with the Kruskall-Wallis test. When this test led to significant results, the Mann-Whitney U test was applied to analyze the specific sample pairs (SPSS 15 for Windows; SPSS Inc, Chicago, IL). A P value $\leq$.05 was considered significant.

Results

The positive control showed that the maximum volume capable to be aspirated by the EndoVac microcannula was 0.8 mL/30 s under 4.42 in Hg negative pressure. The negative control resulted in an aspirated volume of up to 0.20 mL/30 s.

Significant differences in the volume of irrigant aspirated were found within the 3 groups when shaped to different apical preparations ($P < .001$).This volume was significantly greater when the apical preparation size increased from 35.06 to 40.04 (group A, P = .005; group B, P = .007; and group C, P = .007; Table 1). As the apical preparation taper increased further from 40.04 to 40.06, the volume of irrigant significantly improved in groups B (P = .02) and C (P = .02), but it was not significant in group A (P = .07). Apical preparation sizes greater than 40.06 did not show an increase of the volume of irrigant

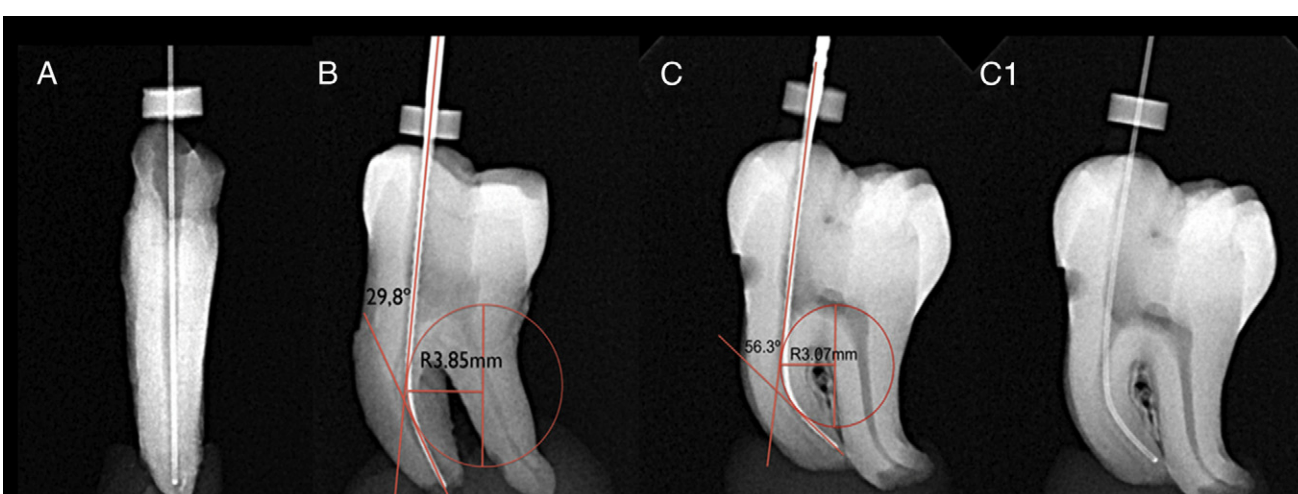

Figure 2. (*A–C*) Representative images of each group (by curvature) and (*C1*) the image of a specimen in group C (31°–65°) with the microcannula inserted to the working length.

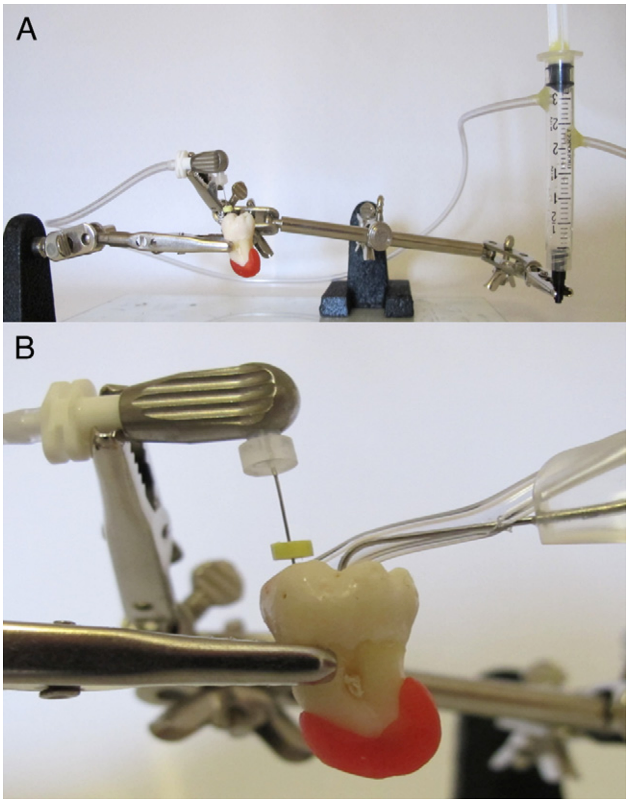

Figure 3. A custom-made platform developed for the study. (*A*) The fluid recovery trap placed vertically to allow adequate records. (*B*) The microcannula held with tweezers to standardize the process.

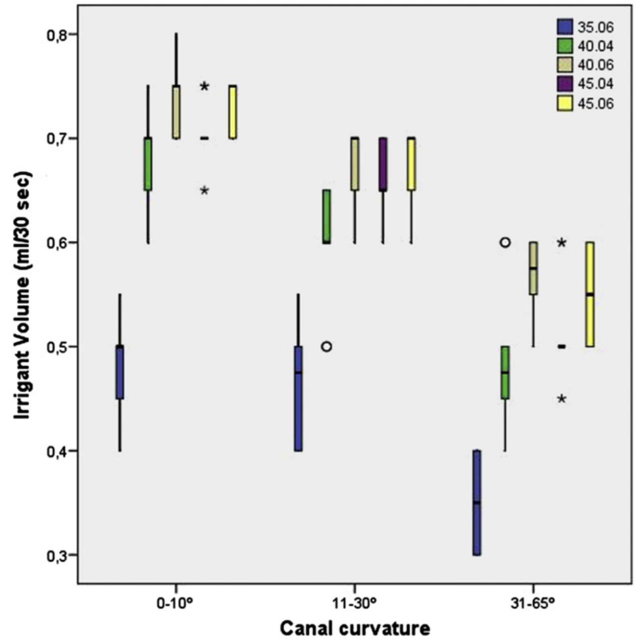

Figure 4. A diagram showing the results for each instrumentation according to canal curvature.

aspirated. Furthermore, the irrigant volume was greater in apical preparation size 40.06 than 45.04 in all groups although this finding was only statistically significant in group C (P = .03).

In regards to the influence of the curvature on the volume of irrigant recovered at the working length for the same apical preparation when comparing the 3 groups, significant differences were found in all apical sizes (P < .001). Specifically, no significant differences were found between groups A (0°–10°) and B (11°–30°) when the apical preparation size was 35.06 (P = .28). However, we found a significantly larger volume of irrigant in group A group when the apical preparation sizes were 40.04 (P = .003), 40.06 (P = .003), 45.04 (P = .01), and 45.06 (P = .002). The volume of irrigant was significantly larger when the degree of curvature decreased from group C (31°–65°) to group B (11°–30°) in all of the apical preparation sizes assessed in the present study (35.06, P = .001; 40.04, P = .003; 40.06, P < .001; 45.04, P < .001; and 45.06, P < .001; Fig 4).

TABLE 1. The Mean Volume of Irrigant Aspirated (mL/30 s) in Each Group at Each Apical Preparation

Apical preparation	Mean (SD) Group A (0°–10°)	Group B (11°–30°)	Group C (31°–65°)
35.06	0.49 (0.05)	0.46 (0.05)‡	0.35 (0.04)
40.04	0.69 (0.05)*†	0.60 (0.06)*‡	0.49 (0.07)*
40.06	0.74 (0.03)†	0.67 (0.04)*‡	0.57 (0.04)*
45.04	0.71 (0.03)†	0.66 (0.04)‡	0.52 (0.02)
45.06	0.73 (0.03)†	0.68 (0.04)‡	0.55 (0.05)

SD, standard deviation.

*A statistically greater volume of irrigant when apical preparations increase within curvatures.

†A statistically greater volume for the same apical preparation in group A than group B.

‡A statistically greater volume for the same apical preparation in group B than group C.

Discussion

The volume of irrigant delivered to the root canal system during the treatment of root canals is a key factor in debris removal and disinfection (17, 32). The volume of irrigant aspirated by the ANP system has previously been investigated by Desai and Himel (33), who reported their results as percentages based on whether the irrigant was aspirated by the MDT or microcannula, and by Brunson et al (29), who measured the volume delivered at the working length using straight root canals (29). Based on the results of the present study, the ideal apical preparation size and taper was 40.04, which resulted in a 44% increase in the volume of irrigant compared with 35.06. Taking into account that most treatments are rendered in roots with different degrees of curvature, the aim of the present study was to determine the effect of root curvature on the volume of irrigant at the working length. Furthermore, 0.00 taper Lightspeed LSX rotary files were used to ensure that the apical preparation remained the same as established for the assigned group and were not anatomically larger. Recently, Munoz and Camacho-Cuadra (22) evaluated irrigant penetration in curved canals while using ANP and obtained similar results to those reported in straight root canals (34, 35). However, the replenished irrigant volume by the ANP system in curved root canals remained unknown.

The negative pressure obtained by the hi-vac line equipment was measured at 4.42 in Hg in contrast to the 7.5 in Hg reported in a previous study (29). The difference in line pressure should be taken into consideration when using ANP and particularly when comparing results from different studies. Future studies should be aimed at evaluating the effect of the hi-vac suction line on the volume of irrigant replenished at the working length when using a microcannula. In the present study, we recorded the time that the fluid, free of air bubbles, takes to cover a given length of the suction tubing connected to the microcannula and found it to be 12.5 seconds per 15 cm of tubing.

In straight root canals (curvatures ranging from 0° to 10°), the results of the present study are in accordance with a previous study (29) and showed that an apical preparation of 40.04 is necessary to obtain a significantly larger volume, whereas sizes larger than 40.04 failed to show significant differences in volume at the working length. In root canals with moderate (11°–30°) and severe (31°–65°) curvatures, increasing the taper to 40.06 resulted in a significantly larger volume of irrigant. However, a further increase of the apical size to ISO 45 did not significantly increase the irrigant volume in any of the groups. In fact, the volume recorded with 45.04 was lower than the volume obtained with 40.06 in all 3 curvature groups although this finding was only statistically significant in group C.

Apical preparation sizes greater than ISO 45 were not included in the present study even though some studies advocate for larger apical enlargement to enhance bacterial control and more irrigation (36, 37). Recently, Elayouti et al (38) reported that increased apical enlargement of curved canals did not result in complete apical preparation, but it did lead to the unnecessary removal of dentin. Clinically, we should aim at maintaining an adequate balance among the preservation of the dental structures, the apical anatomy, and the need for apical disinfection especially in curved canals (39). When treating teeth with curved canals, clinicians should carefully decide the adequate apical preparation in order to achieve an effective and predictable irrigation without weakening the tooth structure (40). Bearing in mind the limitations of this *in vitro* study, we concluded the following:

1. The degree of root canal curvature decreased the volume of irrigant at the working length for a given apical size and taper.
2. An apical preparation of 40.06 significantly increased the volume and exchange of irrigant at the working length regardless of curvature.
3. Further studies should show whether an increase of irrigation time would achieve a comparable irrigant volume without the need to further enlarge root canal with moderate to severe curvatures.

Acknowledgments

The authors deny any conflicts of interest related to this study.

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