

# Apical Pressure and Extent of Irrigant Flow beyond the Needle Tip during Positive-pressure Irrigation in an *In Vitro* Root Canal Model

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## Abstract

**Introduction:** This study aimed to measure the pressure generated during positive-pressure irrigation at the periapex of an *in vitro* tooth model using a novel method of measurement, investigating the effect of flow rate and needle design. Apical pressure was correlated with the extent of dye clearance from the end of a needle tip in a plastic root canal model with similar dimensions. **Methods:** The mesiobuccal canal of a mandibular molar was instrumented to #35/06 and placed into a chamber coupled to a pressure transducer. Irrigation was performed using a digital peristaltic pump using flow rates from 1–15 mL/min with irrigation needles of different sizes and designs. A plastic root canal model instrumented to the same size filled with dye was used to measure the extent of dye clearance beyond the needle tip using the same irrigation conditions. **Results:** Positive-pressure irrigation revealed a flow rate–dependent increase in apical pressure ( $P < .05$ ). The apical pressure at high irrigation flow rates was several times higher than at low flow rates. Needle designs with safety features yielded statistically significant lower apical pressures than needles without safety features ( $P < .05$ ). There was no further increase in dye clearance from the end of the needle tip in a plastic root canal model at flow rates higher than 4 mL/min. **Conclusions:** If apical clearance of dye beyond the needle tip is a measure of irrigation effectiveness, then maximum effectiveness with safe apical pressures can be gained at specific flow rates using specific needle tip designs. The use of an irrigation flow rate of 4 mL/min was able to achieve maximum effectiveness in this study. (*J Endod* 2013;39:511–515)

## Key Words

Apical pressure, dye clearance, flow rate, irrigation, needle design

Root canal irrigation plays an important role in the debridement and disinfection of the root canal system and is an integral part of root canal preparation procedures (1–4). Past research in endodontic irrigation has scrutinized the conditions under which irrigants are able to reach the most apical portion of the root canal. Using radiography, Salzgeber and Brilliant (5) concluded that an apical preparation size of 0.3 mm was required for irrigant penetration into the apical third, whereas Ram (6) concluded that an apical size of 0.4 mm was required for this to occur. Further studies suggested that in order for irrigation to be effective, the needle was required to be placed close to the apical region, and a smaller-gauge needle was more effective than a large-gauge needle (7, 8). When the comparative safety of various irrigation methods was investigated, manual irrigation with a side-vented closed-end needle placed at 2 mm from the working length resulted in periapical extrusion of the irrigant (9). Current irrigation protocol recommendations suggest that clinicians should use a small-gauge needle with a side-vented or closed-end design with the needle placed in the apical third (10) or even 1 mm from the working length (11). There is no recommendation for a safe and effective flow rate for endodontic irrigation, and apical extrusion of irrigants is an ongoing concern during positive-pressure irrigation.

Recently, 3-dimensional computational fluid dynamics (CFD) has been used to simulate irrigant flow in a root canal model and evaluate parameters such as apical pressure because of the force exerted by irrigant flow (12, 13). To our knowledge, these simulated studies represent the first numeric estimation of apical pressure during irrigation. Results are difficult to compare in this respect from 1 study to another because different software algorithms and parameters such as irrigation flow rate, apical size, and the taper of simulated models were used. One CFD study reports an apical pressure of 1707 Pa (12.8 mm Hg) at 3 mm from the apex for a beveled needle, whereas a side-vented closed-end needle resulted in 529 Pa (3.9 mm Hg) at 3 mm from the apex using an irrigation flow rate of 6 mL/min in a model with an apical size of 0.4 mm and a 6% taper (14). A different CFD study using several root canal model sizes and different irrigation flow rates reported a range of apical pressures differing from the aforementioned study by several orders of magnitude (15). CFD modeling also is able to generate streamlines, providing a visual representation of irrigant flow. One CFD study identified the limit of irrigant replacement beyond the needle tip as 1–1.5 mm regardless of the range of flow rates used (12). Another study compared the flow patterns generated in an *in vitro* root canal irrigation model with the streamlines in an equivalent CFD model, with both models showing good agreement (14).

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Presently, little is known about the range of apical pressures that can be generated by different irrigation flow rates and different needle tip designs. Previous studies on the effect of flow rate on the extent of irrigant exchange in a root canal have not systematically studied a clinically relevant range of irrigation flow rates. Together, there is limited evidence for the recommendation of a safe yet effective irrigation flow rate during root canal treatment. The aim of this study was to measure the pressure generated at the periapex and the extent of dye clearance from the end of a needle tip during positive-pressure irrigation, investigating the effect of flow rate and needle design.

**Materials and Methods**

**Dye Clearance Measurement**

A straight plastic root canal model with a closed apex (Dentsply Tulsa Dental, Tulsa, OK) was prepared to apical size 35 (0.35 mm) with a 6% taper (ProFile, Dentsply Tulsa Dental). A small, plastic cup-like reservoir for the irrigant was affixed to the top of the plastic block using an epoxy resin to act as a coronal chamber for the plastic root canal. After instrumentation and careful removal of any plastic debris within the prepared canal, crystal violet dye (BD Diagnostic Systems, Sparks, MD) was used to fill the canal without air bubbles. The needles were attached by a Luer lock connection to 3-stop color-coded Tygon ST tubing (Ismatec, Wertheim-Mondfeld, Germany). A digital peristaltic pump (Reglo Digital MS-2/8, Ismatec) was used to deliver the irrigant at precise flow rates. The peristaltic pump was calibrated once at the start of the study with each irrigation needle to ensure accurate flow rate by measuring the weight of water delivered through the pump in a specified period of time and the range of reproducible flow rates determined for each needle type. The needles were calibrated again with each set of irrigating conditions to ensure fidelity. A microscope (Global Surgical, St Louis, MO) with a camcorder device (1080p, HDR-XR520V; Sony, Tokyo, Japan) was used to record each irrigation sequence.

The plastic block was irrigated at 5 and 3 mm from the working length and, when possible without binding of the irrigation needle, 1 mm from the working length. The canal was irrigated for a minimum of 15 seconds at each flow rate and needle depth placement using positive irrigation pressure. Each irrigation sequence was repeated in triplicate. A still image at the 10-second time point from each video was imported into ImageJ software (National Institute of Health, Bethesda, MD) for measurement of the length of dye cleared from the end of the irrigation needle; this was referred to as dye clearance. The numeric data were imported into a spreadsheet, and statistical analysis was performed.

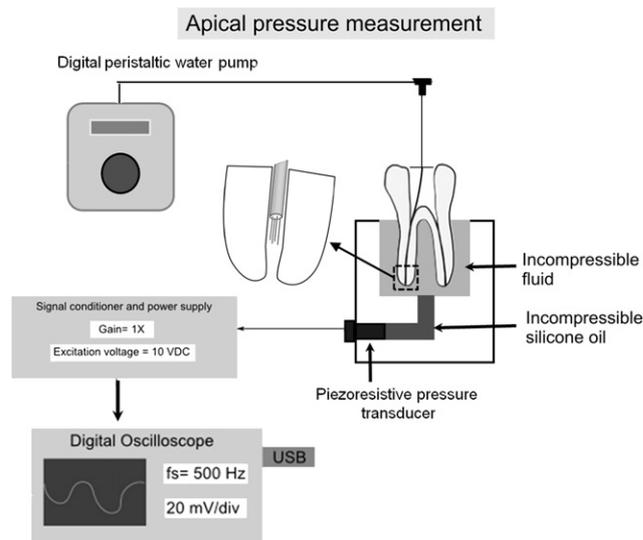
**Apical Pressure Measurement**

An extracted human mandibular molar with 2 separate mesial canals with independent apical foramina was chosen. The tooth was accessed, and size 08 K-files were placed in the mesiobuccal and mesiolingual canals to confirm separate canal systems by radiographic examination and cone-beam computed tomography scanning with a 0.076-mm isotropic voxel size. The mesiobuccal canal of this mandibular molar was prepared to apical size 35 (0.35 mm) with a 6% taper (ProFile) 1 mm short of the length at which an 08 K-file was seen under magnification at the apical foramen. The size of the apical foramen was adjusted to a 0.2-mm diameter. The mesiolingual canal was uninstrumented. Irrigation with approximately 10 mL 3% sodium hypochlorite was used during instrumentation. Using a thin layer of nail varnish, the main mesiolingual and distal apical foramina were sealed in order to eliminate any effect of the presence of other foramina on apical pressure measurements. The mesiobuccal apical foramen remained patent. The

tooth was placed into an air-tight custom fixture coupled to a piezoresistive pressure transducer (8519B-5; Endevco, San Juan Capistrano, CA). Incompressible silicone oil was used to separate the transducer from water to prevent degradation of the transducer (Fig. 1). Pressure generated at the root apex during irrigation is transferred through the incompressible fluid media to the pressure transducer. The setup allowed for measuring pressures between  $-258$  mm Hg and  $+258$  mm Hg. Signals were transferred to an oscilloscope (BK Precision, Yorba Linda, CA) via a strain-gauge signal conditioner (Vishay, Shelton, CT), which was also used to excite the pressure transducer. The oscilloscope sampled at 250 Hz (Fig. 1). The voltage readings were converted into pressure readings using a conversion equation specific to the setup, which was verified during calibration. Calibration was performed by inserting the tooth into the pressure acquisition setup and internally pressured using compressed air. The pressure applied in the tooth was adjusted using a pressure regulator. Pressure increments of 1 pound per square inch gauge (psig) starting from 0 psig (0 mm Hg) up to 5 psig (258 mm Hg) were selected, and the corresponding voltage outputs were acquired. A linear fit of the pressure to voltage data resulted in the conversion equation. The coefficient of determination value of the voltage-to-pressure linear fit was  $R^2 = 0.9993$ , which confirmed that the pressure transducer was used within its linear response range. Irrigation was delivered as described in the previous section. The mesiobuccal canal of the extracted mandibular molar was irrigated at 5 and 3 mm from the working length and, when possible without binding, 1 mm from the working length. The canal was irrigated for a minimum of 10 seconds at each flow rate and needle depth placement using positive irrigation pressure. Each irrigation sequence was repeated in triplicate. The data from the oscilloscope were analyzed, and statistical analysis was performed.

**Irrigation Needles**

Four irrigation needles were used: a 25-gauge blunt open-ended needle with a flexible polyimide tubing tip (FlexiGlide; Vista Dental Products, Racine, WI), a 30-gauge blunt open-ended needle with a flexible polyimide tubing tip (FlexiGlide), a 30-gauge side-vented closed-ended needle (ProRinse, Dentsply Tulsa Dental), and a 27-gauge slotted



**Figure 1.** An experimental design for pressure measurement at the apical foramen. Different needle tip designs, flow rates, and distance from the apical foramen were used in the measurements.

open-ended needle (Monoject 471 Endodontic Irrigation Needle; Covidien, Mansfield, MA).

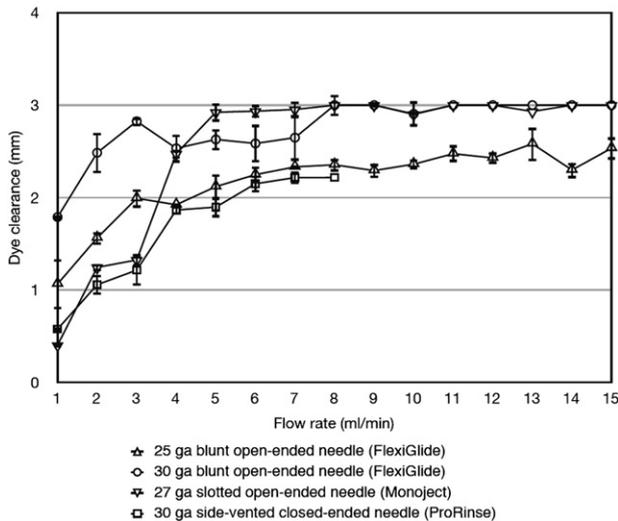
**Statistical Analysis**

Two-way analysis of variance (ANOVA) was used to determine the presence of any interaction between flow rate and needle design on the clearance of dye and apical pressure when comparing all or a selection of needle designs. Two-way ANOVA also was used to determine the presence of any interaction between flow rate and the depth of needle placement on the clearance of dye and apical pressure when examining 1 needle design at a time. If the interaction from any 2-way ANOVA analysis was statistically significant, a post hoc Bonferroni test was used. Subsequent 2-way ANOVA analyses were performed on subgroups of the dataset in order to investigate conditions for interaction. The level of statistical significance for the 2-way ANOVA and post hoc Bonferroni analysis was set at  $\alpha = 0.05$ .

**Results**

When measuring the clearance of dye beyond the end of the needle tip at 3 mm from the working length, all 4 needles used showed a flow rate–dependent increase in the length of dye cleared during irrigation that plateaued at flow rates beyond 4 mL/min (Fig. 2). Two-way ANOVA revealed significant interaction ( $P < .05$ ), and Bonferroni post hoc tests showed that the 30-gauge blunt open-ended (FlexiGlide) needle and the 27-gauge slotted open-ended (Monoject) needle cleared significantly more dye than the 25-gauge blunt open-ended needle (FlexiGlide) ( $P < .05$ ) and the 30-gauge side-vented closed-ended (ProRinse) needle. However, at flow rates beyond 4 mL/min, all of the needles cleared between 2 and 3 mm of dye from the end of the needle tip (Fig. 2).

Two-way ANOVA for data in the flow rate range of 1–4 mL/min showed a significant interaction ( $P < .05$ ), with needle design comprising 61.51% of the total variance and flow rate comprising 29.24% of the total variance. Two-way ANOVA for data in the flow rate range of 4–8 mL/min showed a significant interaction ( $P < .05$ ), with needle design comprising 91.85% of the total variance and flow rate comprising 3.84% of the total variance. Flow rate was not a significant source of variation in the flow rate range from 4 to 8 mL/min ( $P < .05$ ).



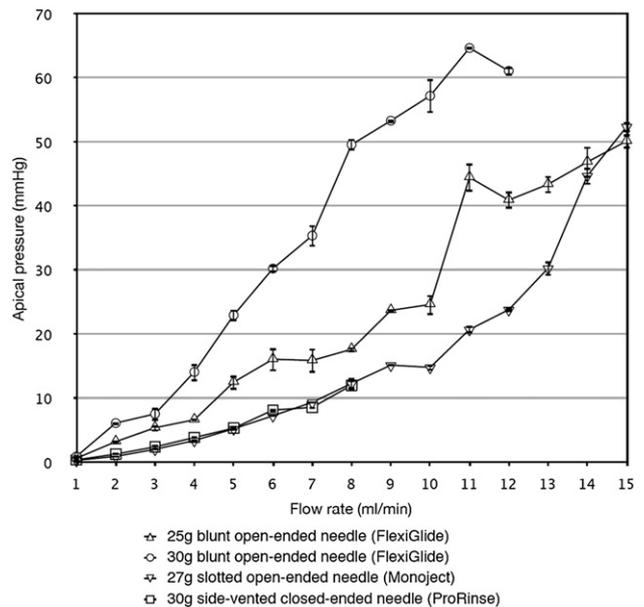
**Figure 2.** Dye clearance during positive-pressure irrigation at 3 mm from the apex. The bars show standard deviation.

All needles showed an increase in apical pressure as the flow rate increased during positive-pressure irrigation (Figs. 3 and 4). When the needles were placed at 3 mm from the working length, the apical pressures ranged from 0.34 mm Hg (45.32 Pa) to 52.43 mm Hg (6690.09 Pa) (Fig. 3). Two-way ANOVA showed a significant interaction ( $P < .05$ ), with needle design comprising 34.25% of the total variance and flow rate comprising 44.98% of the total variance. Post hoc Bonferroni analysis showed that the mean apical pressures generated by the use of the 25-gauge and 30-gauge blunt open-ended (FlexiGlide) needles were significantly higher than those produced by all other needles ( $P < .05$ ).

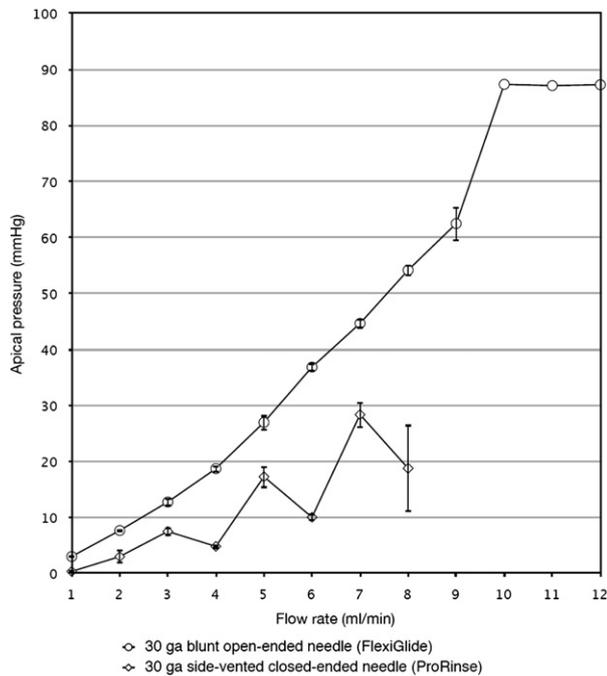
When the needles were placed at 1 mm from the apex (Fig. 4), only 2 needles could be placed at this level in the root canal without binding of the needle tip. These needles included the 30-gauge blunt open-ended (FlexiGlide) needle and the 30-gauge side-vented closed-ended (ProRinse) needle. The apical pressures ranged from 0.38 mm Hg (50.66 Pa) to 87.26 mm Hg (11,633.71 Pa) (Fig. 4). A significant interaction ( $P < .05$ ) was shown, with needle design comprising 21.33% of the total variance and flow rate comprising 65.16% of the total variance. Post hoc Bonferroni analysis showed statistically significant differences ( $P < .05$ ) between the apical pressures generated by these needles. The needle that generated the highest apical pressures was the 30-gauge blunt open-ended needle (Fig. 4). When the 30-gauge side-vented closed-ended needle was placed at 1 mm from the working length, the apical pressure was unpredictable and oscillated between low and moderate apical pressures (Fig. 4).

**Discussion**

This study describes the first attempt to measure apical pressure during root canal irrigation using an *in vitro* human tooth model. This novel method is reproducible and represents a direct approach to validating CFD estimations of apical pressure during irrigation; there is potential to use this method to assess the safety of current and new irrigating conditions and techniques. The parallel setup of the measurement of apical pressure and dye clearance using similar root canal



**Figure 3.** Apical pressure during positive-pressure irrigation at 3 mm from the apex. The bars show standard deviation.



**Figure 4.** Apical pressure during positive-pressure irrigation at 1 mm from the apex. The bars show standard deviation.

models allows the comparison of these 2 variables, representing a measure of safety and effectiveness.

The measurement of the length of dye clearance beyond the end of the irrigating needle tips used in this study revealed that in the clinically relevant range of flow rates from 1 to 15 mL/min, there was no further increase of clearance of dye at irrigation flow rates beyond 4 mL/min for all needle tip designs and sizes used during positive-pressure irrigation. This was also shown by the use of 2-way ANOVA on a subset of the data group from the flow rate range of 4–8 mL/min, indicating that flow rate was not a significant source of the total variation in the data. The 2 needle tips that were able to clear the greatest length of dye during positive-pressure irrigation were a 30-gauge blunt open-ended needle tip and a 27-gauge slot-tipped needle. Although both of these needles are equally effective in irrigant replenishment in a canal, needles designed to vent the irrigant laterally instead of apically may allow for increased patient safety. It is important to consider that all of the needles used during positive-pressure irrigation cleared a length of dye within a 1-mm range of each other; should needles of varying sizes and designs have similar efficacy, then a clinician should choose a smaller needle size and a needle design that promotes lateral shunting of irrigant flow rather than directing irrigant flow directly toward the apex of the tooth. Thus, in choosing a needle design and size for root canal irrigation, a 27-gauge or 30-gauge safe needle design can allow replenishment of the irrigant as effectively as a 30-gauge blunt open-ended needle tip. A CFD study compared two 30-gauge needles of different design and found that a blunt open-ended needle tip design was able to fully replace irrigant in a canal when placed 2 mm from the working length, whereas a side-vented closed-ended needle tip needed to be placed at 1 mm from the working length in order to fully clear the irrigant to the apex (16). The current study also found similar trends with the same needles. The 30-gauge blunt open-ended needle was able to achieve almost 1 mm more dye clearance than the 30-gauge side-vented closed-ended needle tip, but irrigation efficacy needs to be

balanced with patient safety considerations, and the absolute length of irrigant replenishment cannot be the sole factor in choosing an irrigation needle tip.

The range of apical pressures generated during positive-pressure irrigation in the current study shows good agreement with the range of pressures calculated simulating irrigation at 6 mL/min using CFD analysis in a previous study (14). If the minimum and maximum apical pressure measurement calculated in this CFD study is converted into the pressure units used in the current study for a similar needle design and size, the apical pressure range is similar. The CFD study range would be 8–12 mm Hg in comparison to our range of 5–15 mm Hg. Differences in the range of apical pressures calculated by other CFD studies can be attributed to different experimental settings and different turbulence models (16). It is not known exactly what pressure requirements might result in a hypochlorite extrusion accident, but it is interesting to consider that capillary pressure in the human body is approximately 25 mm Hg in the capillary bed, 30–40 mm Hg in the arterial end of the capillaries, and 10–15 mm Hg on the venous end (17). Lymphatic capillary pressure, although often presenting with a range of values, is generally lower than 10 mm Hg (18). It is logical to assume that the periapical and pulp capillaries at the venous end are a possible entry site of irrigant into the tissues and that the apical pressure delivered by the irrigant should not exceed that of the capillaries. The data of the present study show that it is quite easy to exceed capillary pressure when the needle is close to the working length even at low flow rates. The “safe” needle design seems to confer an effective safety benefit. During positive-pressure irrigation, the 25-gauge and 30-gauge blunt open-ended needles and larger-sized needles with design elements allowing lateral shunting of the irrigant created significantly higher apical pressures than other safe needle designs in smaller sizes. This seems to support the overall effectiveness of the needle tips designed to enhance patient safety. However, clinicians must still be cautious. When the smaller needles were placed at 1 mm from the working length, both the blunt open-ended needle tip and the side-vented closed-ended needle tip created high and unpredictable apical pressures. It is not known whether this unpredictability in apical pressure when this particular needle is placed at 1 mm from the working length is a realistic representation of what might happen in a clinical scenario. It is possible that the unpredictable apical pressures could have been created by differences in positional placement of the needle. For instance, should the side-venting portion of the needle have been partially blocked by curvature in the root canal, this may have resulted in more apical shunting of the irrigant. It is also possible that slight differences in the depth of placement, such as a difference of 0.5 mm in the apical placement of the needle caused by the investigator, may have caused the unpredictable apical pressures.

The current study has limitations in its generalizability to all root canals because this study used a single apical preparation size and taper for the entire study. An apical preparation size of ISO 35 (0.35 mm) and a 6% taper was chosen because this represents a common preparation endpoint for many practitioners and enables the placement of certain needles very close to the apical foramen. It should also be noted that an extracted tooth model was used for apical pressure measurements, whereas a plastic root canal block was used for the dye clearance measurements. Thus, a comparison of results from these 2 experiments should be performed with some caution. It may be useful for a future study to use a cleared extracted tooth in similar dye clearance experiments. However, chemical treatment of the tooth for making it transparent may also alter the surface behavior of dentin and therefore impact the results. Sources of error include challenges in maintaining a system sealed against the leakage of air despite the use of adhesive

sealants to seal connections between irrigation needle tips and tubing. There is also an inherent ebbing that exists in the delivery of irrigant through a peristaltic pump. This was addressed by using a peristaltic pump with multiple rollers in an attempt to achieve a smooth flow of irrigant. The length and width of the vent in the various sizes of side-vented closed-ended needles will also necessarily vary because of differences in the size of the needle barrel.

Considering the results of the 2 parts of the current study together seems to be a step toward being able to provide a safe and effective guideline for the irrigation of root canals. During positive-pressure irrigation, small-gauge safety irrigation needles have been shown to be comparably effective to large- and small-gauge blunt open-ended irrigation needles in irrigant replenishment. When evaluating dye clearance beyond the end of the needle tip during positive-pressure irrigation, it was shown that at a flow rate of above 4 mL/min the dye clearance remained unchanged. A strong increase in apical pressure above irrigation flow rates of 4 mL/min was also shown with these needle tips. Therefore, in order to avoid high apical pressures and gain the maximum exchange of irrigant beyond the needle tip, one can use lower irrigation flow rates with small-gauge needles using a safety design without the concern of sacrificing irrigation effectiveness and poor replenishment of irrigant.

The findings of this study and other studies may help to guide researchers when designing future irrigation studies, especially with respect to the depth of needle placement to ensure the exchange of irrigant at the most apical portion and the influence of irrigation flow rate on the extent of irrigant exchange. These are but 2 factors that influence irrigation efficacy; supplementary methods of irrigation may contribute to address other factors. A recent study comparing a chlorhexidine rinse or passive ultrasonic irrigation with sodium hypochlorite as supplementary methods of irrigation showed no significant difference between the 2 methods and that neither method could predictably render the root canals free of bacteria (19). A separate study comparing conventional positive-pressure irrigation, passive ultrasonic irrigation, and continuous ultrasonic irrigation in their ability to remove contrast solution from simulated lateral canals of extracted teeth found that continuous ultrasonic irrigation significantly increased the penetration of irrigant into lateral canals (20). It is increasingly apparent that for irrigation to be fully effective, 1 approach might be the combined use of several different supplemental techniques.

Future studies using this novel method of apical pressure measurement should investigate the effect of apical preparation size and canal taper on apical pressure and irrigant replenishment. Other factors influencing apical pressure and irrigant replenishment such as anastomoses between canals and severe canal curvature should also be considered in future research.

In conclusion, all needle types included in the present study can allow safe and effective irrigation. However, there are important differences in apical pressure between the needles depending on the flow rate and the distance from the apical foramen, and it is important to be aware of these differences. Based on the results of this study, there is no

requirement to irrigate at a very high flow rate, and a gentle irrigation pressure yielding approximately 4 mL/min will achieve the maximum length of irrigant exchange. This will allow clinicians to feel more confident when irrigating in the apical third of the root canal.

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