

SPECTROPHOTOMETRIC DETERMINATION OF IRRIGANT EXTRUSION  
USING PASSIVE ULTRASONIC IRRIGATION, ENDOACTIVATOR OR  
CONVENTIONAL IRRIGATION

A THESIS  
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## **DEDICATION**

In memory to my grandfather, Juan de Dios Verhook Hidalgo. For giving me through his love and advice, the courage and incentive to keep working on this project and throughout this residency. Until January 31<sup>st</sup> 2013 you inspired me with your voice, now and for the rest of my life I keep your voice in my heart.

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## INTRODUCTION

The goal of chemo-mechanical preparation in endodontics is to remove microorganisms, remaining pulp tissue, and dentin debris from the root canal system. Sodium hypochlorite (NaOCl) is the irrigant most often used due to its antimicrobial activity and tissue dissolution ability. In many cases, instrumentation does not completely debride the canal wall as portions of the root canal system may not be accessible by hand or rotary instruments(1). Debris accumulation may also interfere with the primary objectives of root canal treatment.

Root canal irrigation using conventional syringe irrigation is limited and primarily depends on the depth and placement of the irrigation cannula. The efficiency of irrigation is thought to be increased by activating the solution with an ultrasonic or sonic device (2). Irrigation of the root canal system includes a risk of extrusion of the irrigant into the periapical region; in the case of irrigation with NaOCl, this can be associated with pain, swelling, and tissue damage (3).

There are several reports about the complications of irrigation with NaOCl during root canal therapy. Most of the complications are the result of accidental extrusion of the solution from the apical foramen, accessory canals or perforations into the periapical area(4).

Most NaOCl accidents occur because of inaccurate working length determination, iatrogenic widening of the apical foramen, lateral perforation, or

wedging of the irrigating needle. If a perforation or an open apex does exist, special attention is needed to prevent a NaOCl accident (5).

Factors affecting irrigant extrusion have been reviewed(6). It was reported that extrusion on vital and non-vital teeth were linked either to needle wedging, perforation or over-instrumentation in accordance with earlier findings(5). Needle wedging was a technique-related factor and has been shown to increase irrigant pressure at the apical foramen when open-ended needles are used, while over-instrumentation and perforation were anatomy-related factors, leading to increased cross-sectional area of the pathways connecting the root canal to the surrounding tissues, and decreased resistance to irrigant extrusion. High irrigant flow rate was frequently reported as a cause of extrusion, and its avoidance was recommended to reduce the risk (5, 6).

Bone lesions may also contribute to irrigant extrusion by reducing the periapical tissue resistance to extrusion. Long-standing periapical lesions have also been associated with an increased possibility of external apical root resorption, resulting in an effect similar to over-instrumentation (7).

Extrusion accidents may be more probable in teeth with nonvital pulps and periapical lesions. A pathway with reduced tissue resistance towards soft tissues, oral cavity or maxillary sinus (i.e. cortical bone fenestration or perforation, sinus tract, direct communication with the maxillary sinus, perforation of the root canal above the alveolar crest) could be an additional factor leading to extrusion accidents (8).

Several new methods have been developed [passive ultrasonic irrigation (PUI) and passive subsonic irrigation (EndoActivator®)] to improve irrigation efficacy. However, safety of these new methods has yet to be evaluated.

Diverse study models have been used to detect irrigant extrusion. For instance, a radiopaque solution was used in 1977 by Salzgeber and Brilliant to observe apical extrusion of irrigant in patients with necrotic pulps (9). Another method used in 2009 by Desai and Himmel consisted in measuring the volume of the extruded liquid collected during irrigation(10). In 2010, Mitchell et al. presented a model using image analysis to evaluate apical irrigant extrusion on extracted teeth with a simulated periapical environment (11). More recently, Psimma et al. introduced a new method of quantifying the volume of extruded irrigant during root canal irrigation ex vivo in real time, using a point-conductivity probe by determining electrolyte concentration(12).

Mitchell et al. concluded that the frequency of apical extrusion of NaOCl was dependent on the type of root canal irrigation system and apical preparation size. The extent of extrusion depended on the irrigation system, with syringe and slotted-needle irrigation resulting in the greatest extent of extrusion (13).

## LITERATURE REVIEW

The impact of root canal irrigation has been identified as an important issue and this has been reflected in the development of new irrigation methods and an increasing number of scientific studies on this topic (14). Chemo-mechanical preparation of the root canal system aims to remove microorganisms (15), remaining pulp tissue, and dentin debris (16).

The root canal contains accessory canals, canal wall irregularities, and cavities. These anatomical structures are not accessible by hand or rotary instruments in many cases (17). The instruments used in root canals produce dentin debris that might be pressed into existing irregularities. Dentin debris is composed of dentin chips, bacteria, and necrotic pulpal tissue. Debris accumulation is a side effect of root canal instrumentation, and it may interfere with the primary objectives of root canal treatment. Complete removal of debris is essential to allowing direct contact of the irrigant solution with the root canal wall into dentin tubules to assist with disinfection (18).

Chemomechanical preparation of the root canal is an important step in disinfecting and preparing root canals. The effectiveness of irrigation depends on both mechanical flushing and chemical action. By using syringe irrigation, the ability to flush the root canal is limited and primarily depends on the depth and placement of the irrigation cannula (19). The efficiency of irrigation is thought to be increased by activating the solution with an ultrasonic or hydrodynamic device (14).

## **METHODS OF IRRIGATION**

### **Syringe Irrigation**

Irrigation with syringes has been a standard method of irrigant delivery before the advent of passive ultrasonic activation (20). This technique, which involves dispensing an irrigant into a canal through needles of different sizes, is still widely accepted by both general practitioners and endodontists. Needles are designed to dispense the irrigant through their most distal end or laterally through side-vented channels (21). Manual irrigation with a side-ported needle (Max-I-Probe; Dentsply International, York, PA) using positive pressure within 2–3 mm of working length is the most commonly used endodontic irrigation system. Instances of expressing irrigants into periapical tissues and causing significant tissue damage and postoperative pain have been reported with the use of positive pressure (22).

### **Sonic- Subsonic Irrigation**

Kahn et al 1995, used a subsonic handpiece, Micromega 1500 (Medidenta Intl. Co., Woodside, NY) to instrument and irrigate canals. This handpiece energizes an endodontic file using sound waves causing the file to vibrate at ~8,000 vibrations/s (21). Several years later, the EndoActivator was designed to enhance hydrodynamic phenomena by means of the subsonic activation of a passive smooth polymer tip, which is inserted into the root canal full of irrigating solution (23).

## Passive Sonic Irrigation

A sonic system operates between 1-8 kHz. Compressed air is forced through a driver to produce oscillations and is converted into mechanical vibration. These vibrations are in the audible frequency range. Some examples of sonic devices would be Sonic Air and Megasonic 1400 by Medidenta.

According to the manufacturer, the EndoActivator (Advanced Endodontics, Santa Barbara CA) uses sonic energy to irrigate root canal systems. This system has two components: a handpiece and the activator tips (Yellow 15/02, Red 25/04, Blue 35/04). The battery-operated handpiece activates from 2,000–10,000 cycles/min, which translates to 0.3 kHz – 0.166 kHz which is in the subsonic range. The manufacturer recommends using this device after completion of cleaning and shaping and irrigation of the canal with a manual syringe and an endodontic irrigation needle. Placing irrigant into the canal and chamber, passively fitting tips which are activated at 10,000 cycles/min for 30–60 seconds are the steps to follow (24).

Sonic activation has been shown to be an effective method to remove the oral biofilm and enhance root canal disinfection (25). It has been reported that sonic irrigation is capable of producing clean canals (26, 27). On the other hand, the performance of sonic agitation appears to be less effective compared with ultrasonic activation of irrigant solutions (26). This may be attributed to the different acoustic streaming velocity and frequency. However, other studies found no difference between the two systems (27). In contrast, according to Desai and Himel 2009,

EndoActivator had a minimal, although statistically insignificant, amount of irrigant extruded out of the apex when delivering irrigant into the pulp chamber and placing the tip into the canal and initiating the sonic energy of the EndoActivator .(10)

The results obtained by Merino et al. suggest that even in curved canals, passive ultrasonic irrigation is more effective in activating the irrigant at working length than sonic irrigation (28).

### Passive Ultrasonic Irrigation

Richman was the first to describe the use of ultrasonics for cleaning the root canal. Ultrasonic devices operate between 25-40 kHz transforming electrical and electromagnetic energy into mechanical energy (29).

Two types of ultrasonic irrigation have been described in the literature: one where irrigation is combined with simultaneous ultrasonic instrumentation (UI) and another without simultaneous instrumentation, so called passive ultrasonic irrigation (PUI) (30). Passive ultrasonic irrigation is defined as the activation of rinsing solution in the root canal using an ultrasonic file without continuous flow (31). The energy is transmitted by means of ultrasonic waves and can induce acoustic streaming, defined as a steady current in a fluid driven by the absorption of high amplitude acoustic oscillations. Ahmad, Roy & Kamarudin described the action of acoustic streaming created by ultrasonic (32).

Cavitation was thought to be a process by which bubbles formed from the action of the file which then become unstable, collapse, and induce an implosion causing shock, shear and vacuum. Nevertheless, Ahmad, Pitt Ford & Crum

demonstrated that acoustic streaming was the mechanism of action of ultrasonics (33).

Martin and Cunningham along with other authors assessed the efficacy of ultrasonics (34). According to Paragliola et al., some of the agitation techniques, such as passive ultrasonic irrigation (PUI), may help the irrigating solution reach the apical third by activating the NaOCl after the cleaning and shaping procedure (35).

In combination with NaOCl, passive ultrasonic irrigation has been shown to be more effective than conventional hand irrigation in removing dentin debris from the root canal irregularities in the root canal system (14).

#### Apical negative pressure (EndoVac):

The EndoVac apical negative pressure irrigation system (Discus Dental, Smart Endodontics, Culver City, CA) has 3 components: Micro cannula (MICRO), the Macro cannula (MACRO), and the Master Delivery Tip (MDT). The MDT simultaneously delivers and evacuates the irrigant. The Macro cannula is used to suction irrigant from the chamber to the coronal and middle segments of the canal. The Micro cannula contains 12 microscopic holes and is capable of evacuating debris to full working length. A constant flow of fresh irrigant is being delivered by negative pressure to working length (2). According to Nielsen and Baumgartner, the volume of irrigant delivered by the EndoVac system was significantly higher than the volume delivered by conventional syringe needle irrigation during the same time period (36).

Desai and Himel, concluded that EndoVac was significantly better for root canal debridement at the apical termination than positive pressure needle irrigation. EndoVac did not extrude irrigant after deep intracanal delivery and suctioning the irrigant from the chamber to full working length (10).

### Open Apex and Apical Anomalies

There is considerable controversy concerning the exact termination point for root canal therapy procedures (37). Clinical determination of apical canal morphology is difficult at best. The existence of an apical constriction may be more conceptual than actual. Dummer et al. determined that a traditional single apical constriction was present less than half the time (38). Frequently, the apical root canal is tapered or parallel or contained multiple constrictions. Other authors have suggested that an apical constriction is usually not present, particularly when there is apical root resorption and periradicular pathology (39, 40). Studies on canal morphology have shown that root canals are rarely conical or straight, and have lateral canals, apical deltas, fins, webs, and transverse anastomoses that are part of the inherent variation in root canal morphology (41).

The main pathways for extrusion of irrigants are the apical foramen and iatrogenic perforations. Perforating resorptive defects of the root could also present portals of exit for an irrigant and be a cause for concern in the treatment of traumatized teeth (4). Mjör et al. found tremendous variation in the morphology of the apical root including numerous accessory canals, areas of resorption and

repaired resorption. They clearly represent special challenges during root canal therapy and their presence cannot be ascertained clinically or radiographically (42).

### Sodium Hypochlorite

The most common endodontic irrigant for many years has been sodium hypochlorite (NaOCl). Its first reported use in modern medicine was in 1915, when Dakin recommended a 0.5% solution of NaOCl for debridement of infected wounds. Since then, NaOCl has become a popular and effective intracanal irrigant. It is an inexpensive, readily available, and easily used chemical that usually rates well in research (5).

Sodium hypochlorite is an alkaline irrigant with a pH of approximately 11–12. It oxidizes and hydrolyzes proteins and causes hemolysis of red blood cells. It has been demonstrated to be an effective agent against a broad spectrum of bacteria and to dissolve vital as well as necrotic tissue (43).

A variety of NaOCl concentrations ranging from 0.5% to 5.25% have been advocated, as well as a variety of temperatures. The longer the solution can remain in contact with tissue, the higher the temperature of the solution, and the higher the concentration, the greater the ability of NaOCl to dissolve the tissue (3). According to Hand et al., 5.25% NaOCl is significantly more effective than 2.5% or 1.0% in dissolving necrotic tissue (44).

In an in vitro study using bovine muscle to evaluate variables in the tissue dissolution effect of NaOCl, Stojicic et al., found that there was a positive linear relationship between tissue dissolution and the concentration of NaOCl. The effect

of agitation on tissue dissolution was greater than that of temperature; continuous agitation resulted in the fastest tissue dissolution. Also, hypochlorite with added surface active agent had the lowest contact angle on dentin and was most effective in tissue dissolution in all experimental situations (45).

### Sodium Hypochlorite Accidents

The most commonly used irrigating solution during root canal therapy is NaOCl and if used injudiciously, it can be extremely destructive to host cellular tissues. Irrigation with NaOCl must be done with care not to inject the solution past the apical foramen into the periradicular tissues (46). Inadvertent injection of sodium hypochlorite beyond the apical foramen may occur in teeth with wide apical foramina and when the apical constriction has been destroyed during root canal preparation or by resorption. Additionally, extreme pressure during irrigation or binding of the irrigation needle tip in the root canal with no release for the irrigant to leave the root canal coronally may result in contact of large volumes of the irrigant with the apical tissues. If this occurs, the excellent tissue-dissolving capability of sodium hypochlorite will lead to tissue necrosis. A similar situation may occur following iatrogenic perforation of the root, and in cases of horizontal root fracture or perforating resorption (4).

The caustic effects of NaOCl in such an incident are manifested with severe pain, periapical bleeding, and almost immediate swelling. Slow irrigation, light pressure, and use of a non-binding needle will help to prevent such an occurrence (47).

## Methods to Detect Sodium Hypochlorite Extrusion

Various methods have been used to evaluate apical extrusion of irrigants. In 1977, Salzgeber and Brilliant observed apical extrusion of irrigants in patients with necrotic pulps by using a polyiodide compound; a radiopaque solution used extensively in medical radiology to delineate organs, organ systems, and spaces (9).

In 1987, Fairbourn and Montgomery developed a model to collect extruded debris. Roots of mandibular premolars were forced through a hole in a #1 rubber stopper. Aluminum crowns suspended beneath the roots, served as a collecting container for extruded debris (48). In 1991, Myers and Montgomery used Fairbourn and Montgomery's model to collect extruded debris adding a collection vial to the design (49).

More recently, Desai and Himel evaluated in vitro the apical extrusion of irrigant from various irrigation devices by measuring the volume of the extruded liquid collected during irrigation. Teeth were mounted and sealed via composite and wax to a removable cap, perforated, and sealed with a pressure equalization cannula. This cap unit could be assembled and disassembled from apical extrusion collection vials (10).

Mitchell et al. developed an in vitro model that measures extrusion of irrigants from the root canals of instrumented extracted teeth into a simulated periapical environment. The teeth were rigidly fixed and secured to a modified flat-sided clear plastic container (SKS Industries, Watervliet, NY) with dimensions of 4.5cm x 4cm x 4cm using self-curing resin (Lang Dental, Wheeling, IL) and

embedded in 0.2% agarose gel (ph =7.3-7.4) containing 1 mL 0.1% m-cresol purple, which changes color at a pH of 9.0 in a gel mixed with a pH sensitive dye. After root canal irrigation with 6% NaOCl, observations of color change in the gel beyond the root apex indicated extrusion of NaOCl into the gel. Standardized digital photographs were taken 20 minutes after the first irrigant was used. Photographs were analyzed by using Adobe Photoshop 7 (Adobe, San Jose, CA) to determine the amount of extrusion expressed as percent of total pixels (11).

In 2011, Mitchell et al. based their experimental model on that of a previous study (11), with modifications to include quantification of the extent of extrusion (13).

Finally, Psimma et al. in 2013, introduced a new method of quantifying the volume of extruded irrigant during root canal irrigation ex vivo in real time, using a point-conductivity probe by determining electrolyte concentration (12).

### Spectrophotometric Determination of pH

A spectrophotometer is a photometer that can measure intensity as a function of the light source wavelength. Important features of spectrophotometers are spectral bandwidth and linear range of absorption or reflectance measurement. A spectrophotometer is commonly used for the measurement of transmittance or reflectance of solutions, transparent or opaque solids, such as polished glass, or gases. However they can also be designed to measure the diffusivity on any of the listed light ranges that usually cover around 200nm - 2500nm using different controls and calibrations. Ultimately, a spectrophotometer is able to determine,

depending on the control or calibration, what substances are present and exactly how much are in a target through calculations of observed wavelengths (50).

Yamazaki et al. reported a system involving acetic acid (HOAc) vs ammonia (NH<sub>3</sub>) as primary standards, and bromocresol green (BCG) and thymol blue (TB) as indicators. Highly accurate pH estimations are conveniently made by evaluation of the spectra of an acid- base indicator suitable for the pH range of interest if the pK<sub>a</sub> is accurately known (51).

## **HYPOTHESES AND SPECIFIC AIMS**

Since irrigation is a key factor to a successful root canal treatment, the purpose of this study was to examine the safety of different irrigation devices.

This research project addressed the following hypotheses:

1. The method of irrigation affects the amount of irrigant extrusion.
2. Irrigant extrusion decreases in teeth with curved roots when compared to straight roots.

## **MATERIALS AND METHODS**

The research protocol used in this study was exempted from approval by the Institutional Review Board of the University of Minnesota. One hundred fourteen extracted single-rooted teeth were collected from the Oral Surgery and Periodontal clinics at the University of Minnesota School of Dentistry and the VA Hospital in Minneapolis. Teeth were stored in 0.2% sodium azide after extraction.

Root canal curvatures were measured according to the Schneider's method to classify roots as curved or straight (52). For the curved group, root curvature had to be greater than 20 degrees for inclusion. Teeth were decoronated to leave 15 mm of root length to standardized samples. A #10 FlexoFile (Dentsply, Maillefer, Johnson City, TN) was placed in teeth for both groups until just visible at the apex to determine patency and 1 mm was subtracted to establish working length. Fifty four straight roots (n=18/group) and sixty curved roots (n=20/group)] were selected for the study groups.

For root canal preparation, rotary instrumentation was performed using the ProTaper system (Dentsply, Maillefer, Johnson City, TN) in a crown-down fashion to the working length up to an apical file size #40, 0.04 taper while irrigating with 1ml of 5.25% NaOCl between files using conventional syringe irrigation.

After cleaning and shaping was completed, teeth from the straight and curved group were divided into 3 groups for final irrigation: 1) Conventional Irrigation, 2) PUI, 3) EndoActivator. Roots were coated with nail polish and sealed

in a microcentrifuge tube using silicone impression material, to collect any extruded NaOCl. Roots were then irrigated via PUI, EndoActivator®, or conventional irrigation. Creosol purple (3-4 fold dilution; 170  $\mu$ l; pH =7) was then added to each unknown sample of extruded irrigant. The samples were then vortexed and 170  $\mu$ l of each sample was pipetted into a 96-well plate. For a standard curve, 170  $\mu$ l of indicator with known amounts of NaOCl (0 – 30  $\mu$ l) were used and the 96-well plate read by a spectrophotometer (Biotek/ Synergy HT).

Micromolar ( $\mu$ M) concentrations were determined for quantification of NaOCl used for standards. Log of  $\mu$ M concentration calculated and plotted to the respective absorbance values to produce the standard curve. The standard curve was created using linear regression, which was then used to determine unknown concentrations of NaOCl in extrusion samples.

A diagrammatic representation of our methods is shown in Figure 1. The different irrigation groups and the method of detection for NaOCl extrusion using creosol purple indicator and the spectrophotometer are displayed.

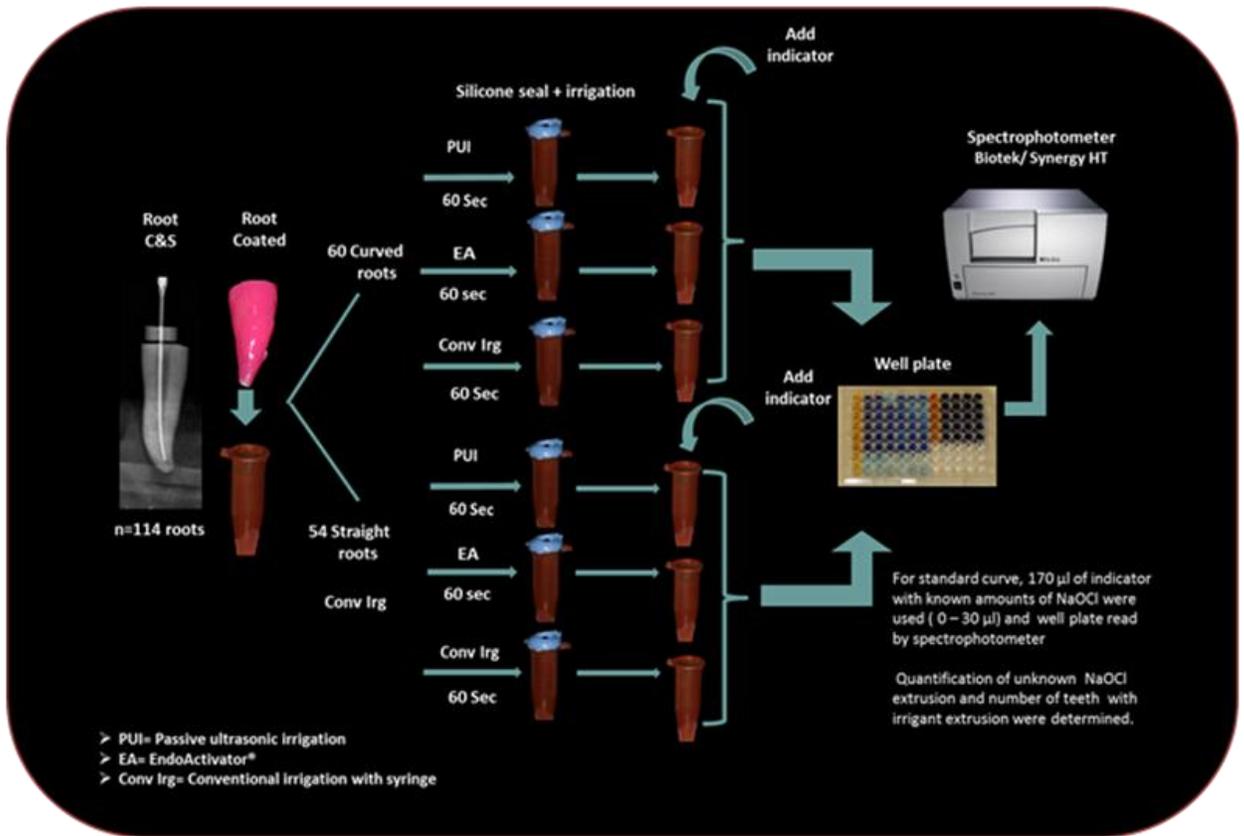


Figure 1. Material and methods sequence

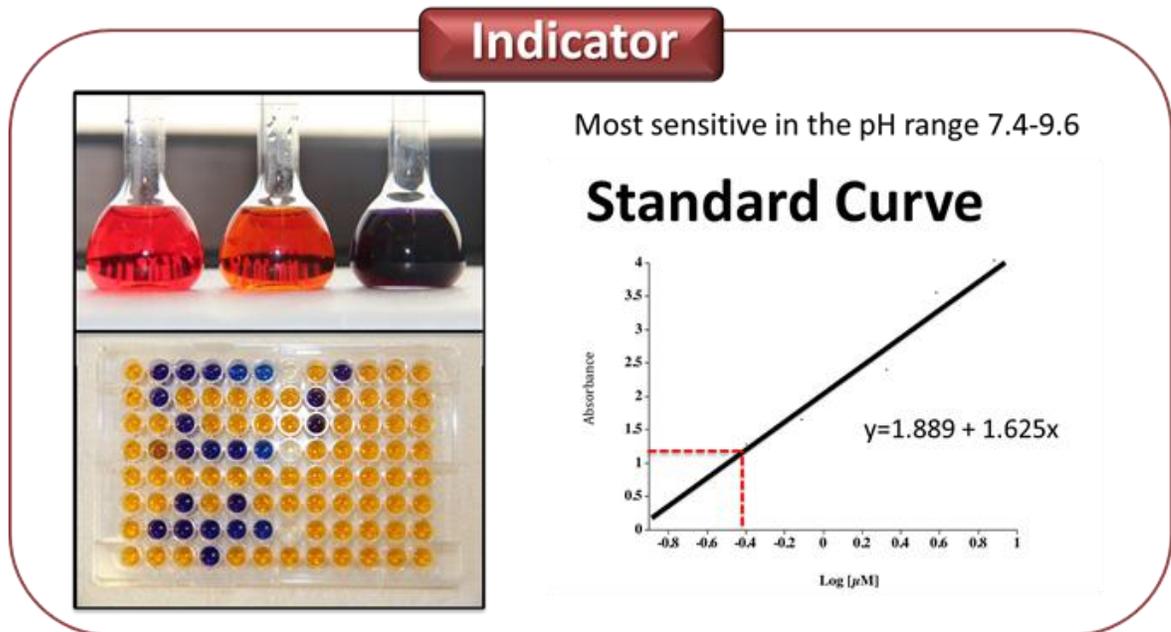
## **STATISCAL ANALYSIS**

Amounts of NaOCl extrusion between straight and curved roots and between irrigation techniques were compared using Fisher's exact tests. Similar comparisons were made between irrigation techniques within straight and curved roots. The total extrusion volumes by group (type of root and irrigation technique) were displayed graphically (p-values less than 0.05 were considered statistically significant. SAS V9.3 (SAS Institute Inc., Cary, NC) was used for the analyses.

## RESULTS

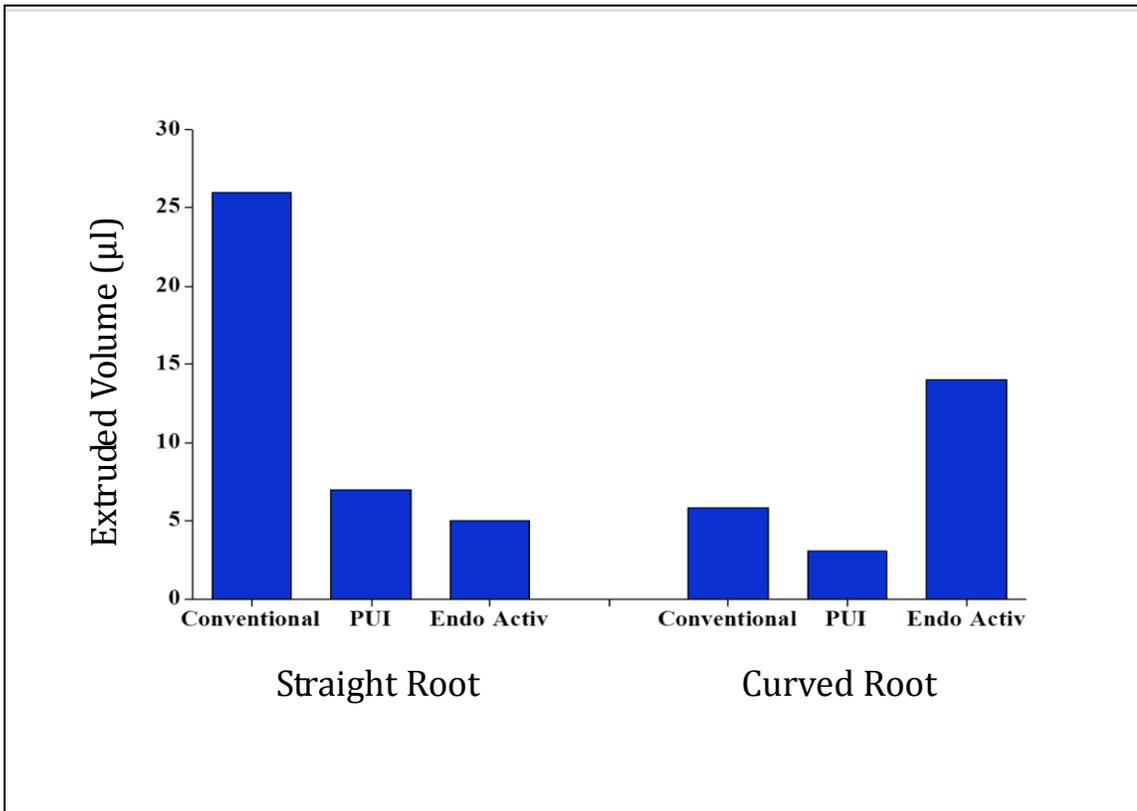
The number of teeth with irrigant extrusion was determined and the amount of NaOCl extrusion in each experimental sample quantified (using the standard curve of known amounts of NaOCl). Even a minute amount of NaOCl (0.5  $\mu$ l) could be easily detected by a color change. For small volumes (< 30  $\mu$ l), the color would intensify with increasing amounts of NaOCl, while large volumes could be measured conventionally. A 96 well plate and the results of standard curve are shown in Figure 2.

For the majority of the teeth (approximately 70%) in the study, there was little, if any NaOCl extrusion with any of the three methods used or in straight or curved roots (approximately 70%). There was some NaOCl extrusion seen in a small number of cases (about 15 %) with minimal extrusion (<1  $\mu$ l) of. The approximate 15% remaining did have moderate NaOCL extrusion (1-10  $\mu$ l), suggesting the need to be mindful that NaOCl extrusion is possible, especially with apical anomalies such as seen with resorption or large patency files used through the apical foramen.



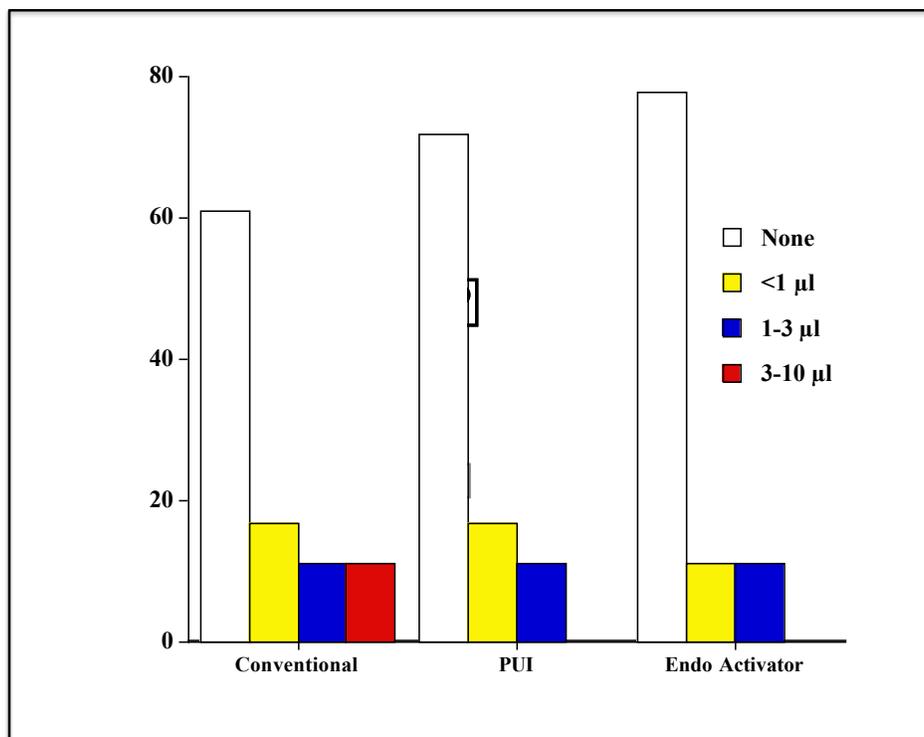
**Figure 2. Standard curve graphic, creosol purple indicator in the pH range 7.4-9.6 and well plate display with extrusion samples for standard curve. Line formula derived using linear regression from data points using input from known concentration with corresponding absorbance values from spectrophotometer for each known concentration. Log [ ] was used to form a straight line to more easily determine unknown values using standard curve.**

On Figure 3 we can appreciate the total extruded volume for straight and curved roots after using conventional irrigation, PUI or EndoActivator on their respective groups. Particularly on the straight roots group, conventional irrigation was the technique where we saw the most NaOCl extrusion. In the curved roots group, the greatest NaOCl was seen with irrigation using the EndoActivator.



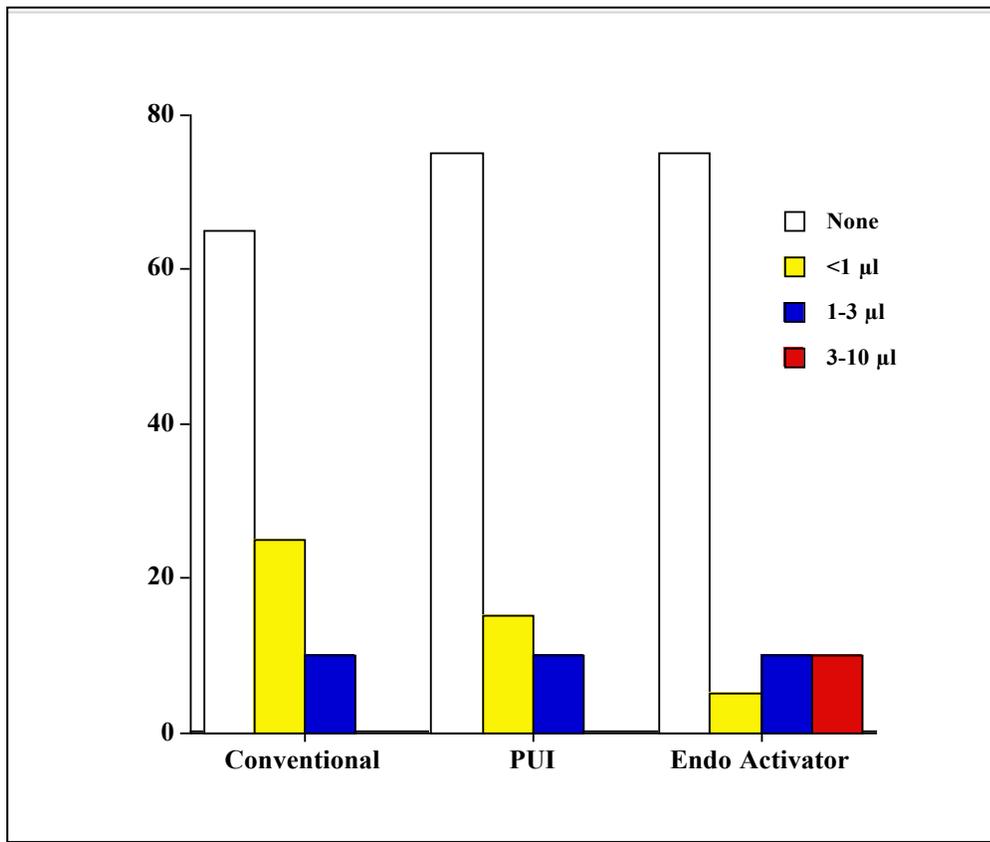
**Figure 3. Extrusion Volumes by Group**

Figure 4 shows the percent of teeth with and without NaOCl extrusion in teeth with straight roots. Particularly on the PUI group, one specimen had to be replaced after 41µ of NaOCl was extruded due to an apical anomaly (see figure 6 and 7).



**Figure 4. Percent of teeth with/without NaOCl extrusion on straight roots. One tooth in the PUI group was excluded as it had NaOCl extrusion of 41 µl due to a missed apical anomaly and this tooth was replaced (data from this tooth not included).**

Figure 5 shows the percent of teeth with and without NaOCl extrusion in teeth with curved roots. Overall, most teeth did not show any irrigant extrusion (65-75%), but 25-35% of teeth did show some irrigant extrusion. This NaOCl extrusion was seen with each of the irrigation techniques. The EndoActivator group had the greatest extrusion amounts (3 to 10µ) of irrigant.



**Figure 5. Percent of teeth with/without NaOCl extrusion on curved roots**

Data for the irrigant extrusion amounts and percentages of teeth with extrusion are shown below in Tables 1-4. There is not a statistically significant association between extrusion and type of root or technique.

**Table 1. Comparing Extrusion Amounts between Straight Roots and Curved Roots**

<b>n (%)</b>	<b>Straight N=52</b>	<b>Curved N=60</b>
<b>None</b>	36 (69)	43 (72)
<b>&lt; 1</b>	8 (15)	9 (15)
<b>1-3</b>	6 (12)	6 (10)
<b>3-10</b>	2 (4)	2 (3)

Fisher's exact test p-value = 1.0000

**Table 2. Comparing % of all teeth with Extrusion between Irrigation Techniques**

<b>n (%)</b>	<b>Conventional N=36</b>	<b>PUI N=38</b>	<b>Endo Activ N=38</b>
<b>None</b>	22 (61)	28 (74)	29 (76)
<b>&lt; 1</b>	8 (22)	6 (16)	3 (8)
<b>1-3</b>	4 (11)	4 (11)	4 (11)
<b>3-10</b>	2 (6)	0	2 (5)

Fisher's exact test p-value = 0.4819

There is not a statistically significant association between extrusion and technique.

**Table 3. Comparing % of teeth with Extrusion between Irrigation Techniques in Straight Roots**

<b>n (%)</b>	<b>Conventional N=18</b>	<b>PUI N=18</b>	<b>Endo Activ N=18</b>
<b>None</b>	11(61.1)	13 (72)	14 (78)
<b>&lt; 1</b>	3 (16.7)	3 (17)	2 (11)
<b>1-3</b>	2 (11.1)	2 (11)	2 (11)
<b>3-10</b>	2 (11.1)	0	0

Fisher's exact test p-value = 0.6857

There is not a statistically significant association between extrusion and technique in straight roots.

**Table 4. Comparing Extrusion between Irrigation Techniques in Curved Roots**

<b>n (%)</b>	<b>Conventional N=20</b>	<b>PUI N=20</b>	<b>Endo Activ N=20</b>
<b>None</b>	13 (65)	15 (75)	15 (75)
<b>&lt; 1</b>	5 (25)	3 (15)	1 (5)
<b>1-3</b>	2 (10)	2 (10)	2 (10)
<b>3-10</b>	0	0	2 (10)

Fisher's exact test p-value = 0.4466

There is not a statistically significant association between extrusion and technique in curved roots.

## DISCUSSION

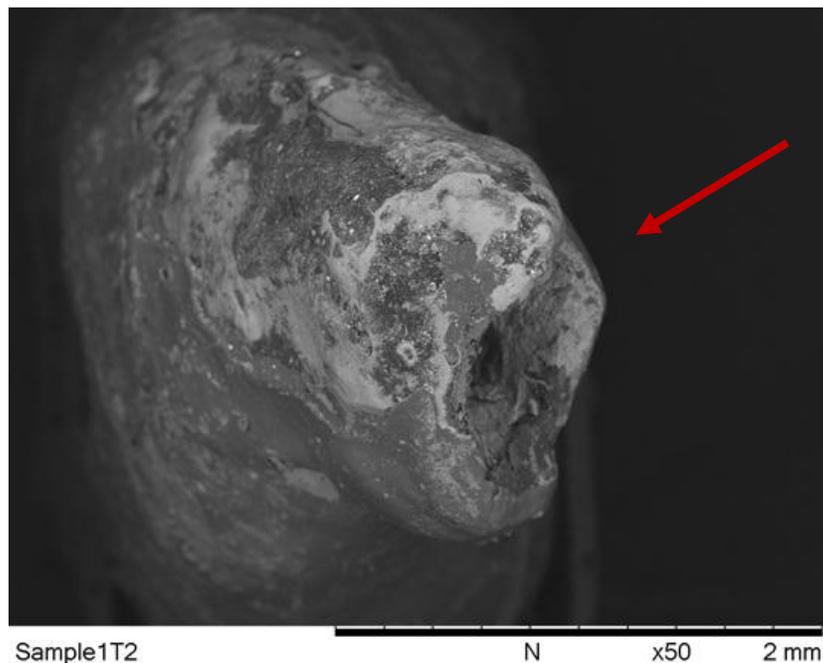
Various methods have been used to evaluate apical extrusion of irrigants in vitro; however none of them involved the use of a spectrophotometer as a model. This study evaluated irrigant extrusion during passive ultrasonic irrigation (PUI), subsonic irrigation (EndoActivator®), or conventional syringe irrigation. A novel in vitro spectrophotometric model was developed to detect apical extrusion of NaOCl from instrumented teeth using creosol-purple as indicator. An indicator similar to this was also used by two recent studies(11, 13). Creosol –purple changes color depending upon the pH, and it is most sensitive in the pH range 7.4 - 9.6.

According to previous studies PUI was more effective in straight canals than in curved canals (28). In contrast with these findings, the present study did not find a statistically significant association between extrusion and the type of root when comparing straight and curved roots.

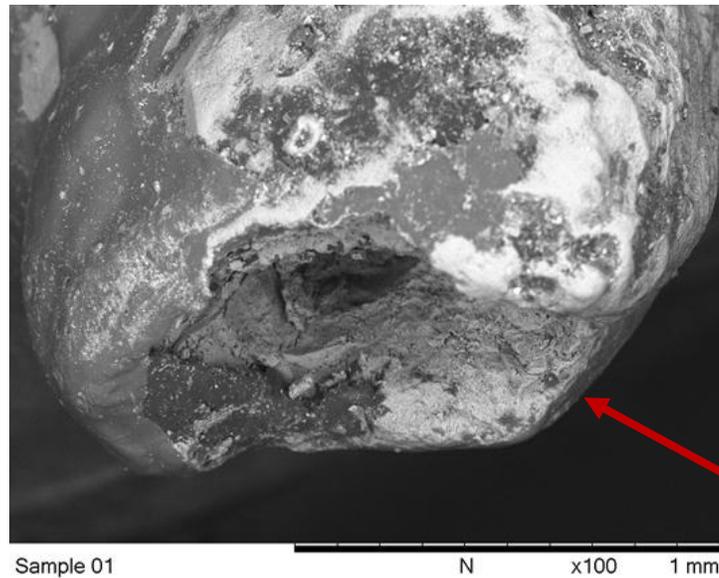
In a 2011 study, Mitchel et al. demonstrated that apical preparation size and the method of activation and delivery of NaOCl into the apical one-third play a role in the amount of extrusion into the apical tissues. The methods of activation that were evaluated included EndoActivator (EA), EndoVac (EV), Rispi-Sonic/MicroMega 1500 (MM), passive ultrasonic irrigation (PUI), and syringe irrigation (13). As a counterpoint, our results showed no statistically significant association between extrusion and technique when irrigation was performed using passive ultrasonic irrigation (PUI), subsonic irrigation (EndoActivator®), or conventional syringe irrigation. Although our results were not statistically significant, our conventional

syringe irrigation group showed more extrusion than the other techniques used, with the exception of one sample from the PUI/straight group that extruded 41 $\mu$ l and was replaced for another sample. This excessive extrusion was attributed to an apical anomaly that was confirmed after SEM analysis of the root.

These findings correlate with Mitchell et al. results that showed syringe and needle irrigation resulted in greater frequency and extent of extrusion than activated devices (13). In addition, results of studies done by Lambrianidis et al. or Myers and Montgomery noted that irrigation with positive pressure resulted in periapical extrusion (49, 53).



**Figure 6. SEM x 50 analysis of the root that was replaced from the PUI/straight group**



**Figure 7. SEM x 100 analysis of the root that was replaced from the PUI/straight group**

Besides the presence of any apical anomaly, the lack of resistance to apical flow by the surrounding structure could be another factor that might contribute with irrigant extrusion. Our model did not include the simulation of periapical tissues since we were trying to test potential irrigant extrusion on extreme conditions.

It is understood that in clinical situations several factors might decrease the extent to which these systems extrude solutions. Periapical tissues and bone provide resistance to apical extrusion as well as non-patent canals (10).

Some recent studies have indicated that the use of EndoActivator facilitates irrigant penetration and mechanical cleansing compared with needle irrigation, with no increase in the risk of irrigant extrusion through the apex (10, 54). On the other hand, findings by Merino et al. suggest that even in curved canals, passive

ultrasonic irrigation was more effective in activating the irrigant at working length than the EndoActivator. A possible explanation for these results could be related to the lower intensity of 166 Hz generated by EndoActivator compared with 30 KHz generated by the PUI (180 times more) (28). As mentioned previously, the results of the present study were not statistically significant but minute amounts of extrusion occurred with each technique in some teeth used in the two root forms (straight, curved) evaluated. The findings of this study are in agreement with the results of Desai et al. where samples irrigated with the Endoactivator extruded a very small volume of irrigant, although statistically insignificant. The protocol for their study was also designed to maximize the possibility of irrigant extrusion through an unrestricted, yet normal apex (10).

## CONCLUSIONS

The spectrophotometric method used in this study is extremely sensitive and can detect <1  $\mu$ l of NaOCl extrusion, while providing quantification of irrigant levels extruded.

Use of the PUI or EndoActivator® tip to within 1 mm of the working length appears to be safe, yet apical anomalies may allow NaOCl extrusion.

Use of NaOCl has been cautioned in cases of an open apex, perforation resorption, and vertical root fractures; but apical anatomy should also be considered, especially if patency files are used, which may affect foramen anatomy.

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