SUMMARY OF ENDOACTIVATOR RESEARCH
FROM DRS. PIERRE MACHTOU, CLIFF RUDDLE & BOB SHARP

I.   Disinfection

For many years, our team has been extensively involved in investigating how to significantly improve existing endodontic disinfection methods. Clinically, disinfection protocols should encourage debridement, the removal of the smear layer, and the disruption of biofilms. Logically, well-shaped canals potentially facilitate 3-D cleaning, filling root canal systems, and predictable success. Importantly, the technology selected to promote disinfection should be easy-to-use clinically, safe, and cost effective.

II.   EndoActivator

In an effort to clinically improve endodontic outcomes, the EndoActivator was developed. This technology provides an easy-to-use, safe, and affordable method to enhance disinfection. Virtually any dentist who places emphasis on shaping canals can efficiently integrate the EndoActivator into clinical use.

III.   Validation

Before initiating scientific research to determine the validity of the EndoActivator, five (5) internationally recognized professors, well-known for their research and publications in the field of endodontic disinfection, developed a protocol that when followed would serve to validate and standardize ALL EndoActivator studies and, hence, results. The 5 different department chairmen who developed and approved the protocol and methodologies of the Caron Study (see below) were Lumley (Birmingham), Gulabivala (Eastman), Lambrechts (Catholic University of Leuven), Machtou (Paris VII), and Sirtes (Geneva).

IV.   Research

The following research has shown the EndoActivator produces significantly cleaner canals compared to the controls and the commonly employed methods utilized by well-trained international dentists and endodontists alike. Some of the following studies have already been accepted for publication in peer-reviewed journals.

- *Caron G: Cleaning efficiency of the apical millimeters of curved canals using three different modalities of irrigant activation: an SEM Study; Master Thesis Part 1, Paris 7 University (Paris, France), 2006.*
  First study ever evaluating disinfection in highly curved mesial canals of mandibular molar roots. Debridement and smear layer removal was evaluated with SEM at 500 microns, 1,000 microns, and 2,000 microns. The EndoActivator produced statistically significantly cleaner canals compared to the controls and two other methods, including Rinse Endo *(Figures 1-3)*.
  * See Abstract in ATTACHMENT A *

- *Caron G: Cleaning efficiency of the apical millimeters of curved canals using three different modalities of irrigation activation: an SEM Study, Master Thesis Part 2, Paris 7 University (Paris, France), 2006.*
  The EndoActivator was shown, again, to produce statistically significantly cleaner canals as compared to the controls and RinsEndo. Study emphasis was on the apical one-third. Importantly, the second study in conjunction with the first study, provided a sufficient sample size for statistical analysis and scientific validation *(Figures 1-3)*.
  * See Abstract in ATTACHMENT A *

- *Akveld NAE, Hiep STP: The efficacy of sonic irrigation (EndoActivator) and type of irrigant on removing artificially placed dentine debris from the apical root canal, Academic Centre for Dentistry Amsterdam (Amsterdam, the Netherlands) in association with Department of Endodontology of University of La Sapienza (Rome, Italy), 2007.*
  Passive sonic irrigation produced statistically significantly cleaner canals. "The EndoActivator is a valuable instrument in endodontic treatment because of its superior removal of dentine debris compared to irrigant only". The EndoActivator was considered a low risk device, and no damage or breakage was reported.
  * See Abstract in ATTACHMENT B *

- *Chye TL: Effectiveness of the EndoActivator on smear layer and debris removal at the apical 1/3 of curved root canals: an SEM Study, Master Thesis, National University Hospital (Singapore), 2008.*
  Compare the efficacy of the EndoActivator to passive ultrasonic irrigation using EDTA on smear layer and debris removal at the apical portions of curved root canals. "Within the limitations of this study, a one-minute use of the EndoActivator with 17% EDTA was as efficient as ultrasonics in removing debris in the apical regions of the curved root canals".
  * See Abstract in ATTACHMENT C *

- *Kanter V, Weldon E: Ultrasonic vs. Sonic Endodontic Systems, Master Thesis, University of Florida, Department of Endodontics (Gainesville, FL, USA), 2009.*

  EndoActivator was statistically significantly better than Ultrasonics and the control group in removing loose debris 3mm from the radiographic apex. Additionally, the EndoActivator was statistically significantly better than the ultrasonic group in opening dentinal tubules 3mm from the radiographic apex. Finally, the EndoActivator provided better obturation of lateral and accessory canals (P<0.01) *(Figures 4-5)*.

- *Kuttler S: Associate Professor of Endodontics, Nova SE University (Fort Lauderdale, FL, USA), April 2009.*

  Showed the efficacy of the EndoActivator, including the elimination of the smear layer and open dentinal tubules, in curved mesial canals in mandibular molar teeth *(Figure 6)*.

V. **<u>Ongoing Studies</u>**

- *Lumley PJ: Birmingham Dental Hospital (Birmingham, England, UK)*

- *Gulabivala K: UCL-Eastman Dental Institute (London, England, UK)*
  A preliminary study showed that the EndoActivator enhanced biofilm disruption. Based on the promising results from the preliminary study, a formal study is now underway.

- *Lambrechts P: Catholic University of Leuven (Leuven, Belgium)*
  Currently conducting a long-term, 4-year clinical study. Through personal communication, Prof. Lambrechts reports that "the EndoActivator is a promising adjunct to reach a higher standard of cleaning". See also his published article in the December 2006 issue of the *Endo Tribune*.

- *Sirtes G: University of Geneva (Geneva, Switzerland)*

- *Zehnder M: University of Zurich (Zurich, Switzerland)*

- *Harhash AI: Loma Linda University (Loma Linda, CA, USA)*
  Currently studying the effect of the EndoActivator to reduce clinical soak times and produce negative cultures in canals flooded with MTAD.

- *Haapasalo M: UBC (Vancouver, BC, Canada)*
  Currently studying disinfection utilizing a new irrigant in conjunction with the EndoActivator. Through personal communication, Dr. Haapasalo reports that "…the results look good for it (EndoActivator)." Pending Publication in the *JOE*.

VI. **<u>Discussion</u>**
Our group recognizes and fully appreciates the importance of developing then following a precise research protocol. Differences in reported outcomes may be explained by the clinical techniques utilized, the protocols followed, and the scientific method used to analyze results. We are completely confident that our results can be collaborated by anyone utilizing the protocols developed by the group of well-respected research professors.

VII. **<u>Common Sense Factor</u>**
From a common sense or practical standpoint, hundreds of EndoActivator users routinely report that the solution inside the pulp chamber typically turns from clear to cloudy when using this device in well-shaped canals and in accordance with the Directions for Use. This frequent observation provides immediate clinical evidence and represents debris that would have otherwise been left inside the root canal space. Cleaned root canal systems provide an opening for 3-D obturation and long-term success *(**Figures 7-9**)*.

VIII. Published Papers

- de Gregorio C, Estevez R, Cisneros R, Heilborn C, Cohenca N: Effect of EDTA, sonic, and ultrasonic activation on the penetration of sodium hypochlorite into simulated lateral canals: an in vitro study, *J Endod* 35:6, pp. 891-895, 2009.
  * See ATTACHMENT D *

- Desai P, Himel V: Comparative safety of various intracanal irrigation systems, *J Endod* 35:4, pp. 545-549, 2009.
  * See ATTACHMENT E *

- Gu L, Kim JR, Ling J, Choi KK, Pashley DH, Tay FR: Review of contemporary irrigant agitation techniques and devices, *J Endod* 35:6, pp. 791-804, 2009.
  * See ATTACHMENT F *

- "Highly Rated Products--Evaluators Reports and Clinical Tips: EndoActivator", *Gordon J. Christensen CLINICIANS REPORT* 2:6, pp. 1&4, 2009.
  * See ATTACHMENT G *

Look for upcoming publications showing the efficacy of the EndoActivator for adapting and removing calcium hydroxide, moving MTA around root curvatures into root defects, and removing residual obturation materials in the retreatment situation. For further information, feel free to contact:

- Cliff Ruddle: ruddlec@aol.com
- Bob Sharp   sharpendo@sacendo.com
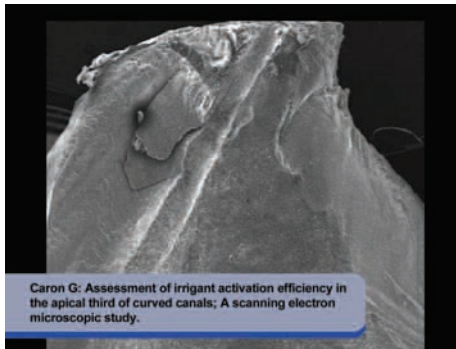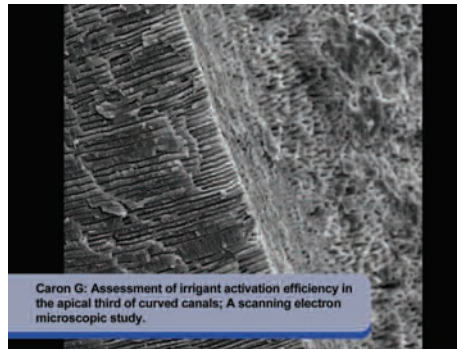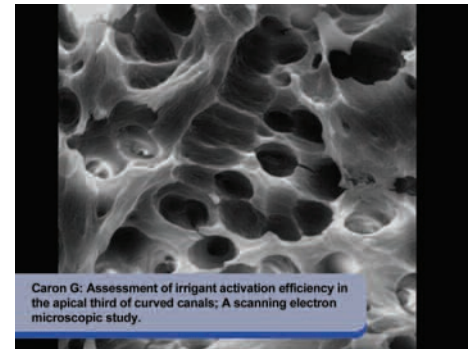- Pierre Machtou   pmach2@wanadoo.fr

Caron G: Assessment of irrigant activation efficiency in the apical third of curved canals; A scanning electron microscopic study.

Figure 1

Caron G: Assessment of irrigant activation efficiency in the apical third of curved canals; A scanning electron microscopic study.

Figure 2

Caron G: Assessment of irrigant activation efficiency in the apical third of curved canals; A scanning electron microscopic study.

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Assessment of irrigant activation efficiency in the apical third of curved canals:
a scanning electron microscopic study

G. Caron[1], K. Nham[2], F. Bronnec[1] & P. Machtou[1]

[1] Department of Endodontics and Restorative Dentistry, Garanciere School of Dentistry, University of Paris 7, Paris, France; [2] Department of Surface Physico-Chemistry, UMR7045, ENSCP, Paris, France

Running title:
Assessment of irrigant activation efficiency in the apical third of curved canals: a scanning electron microscopic study

Correspondence: Dr. Gregory Caron, 5 rue Garanciere 75006 Paris, France
(e-mail: greg.hypomoclion@gmail.com)

Aim: To investigate, via SEM observations, three activation devices for root canal irrigants after root canal preparation and assess the importance of this final step before obturation

Methodology: Sixty-eight curved canals from freshly extracted mandibular molars used for this study were divided into 3 groups with four control teeth. All teeth were prepared with Protaper Universal® rotary files and appropriate irrigation. Each test group was then flushed with 1 ml of EDTA (17%) and 3 ml of sodium hypochlorite (3%). In group 1, both irrigants were activated with the gutta-percha master cone. In group 2, activation was achieved with RinsEndo®. In group 3, each irrigant was activated with a recent device: the Endoactivator®. All teeth were split with a novel approach to allow visualization of every third of the canal, particularly the apical third. The samples were prepared for SEM observation to assess the root canal cleanliness involving assessment of smear layer removal. Scoring was done in blinded fashion by two calibrated observers according to a five-score scale.

Results: Each apical third sample showed very high levels of cleanliness ($\leq$ score 3). Sonic activation was significantly more effective than automated-dynamic irrigation (p=0.006), but there was no significant difference between sonic activation and manual-dynamic activation (p=0.177). Automated-dynamic irrigation was less effective in removing smear layer than manual-dynamic activation, but the difference was not significant (p=0.85).

Conclusion: The findings of this study indicate that activation devices (especially sonic activation and manual-dynamic activation) may bring real benefits in terms of root canal cleanliness in comparison with no final irrigation regimen. Final activation of irrigants after mechanical preparation seems to be a major step in the debridement of root canal systems before three-dimensional obturation.

Keywords: irrigation, activation, RinsEndo®, Endoactivator®, smear layer.

The efficacy of sonic irrigation (EndoActivator) and type of irrigant on removing artificially placed dentine debris from the apical root canal

N.A.E. Akveld, S.T.P. Hiep
Department of Cariology Endodontology Pedodontology, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, the Netherlands
In association with department of endodontology of University La Sapienza, Rome, Italy

Abstract

N.A.E. Akveld, S.T.P. Hiep The efficacy of sonic irrigation (EndoActivator) and type of irrigant of the file on removing artificially placed dentine debris from the apical root canal.

Aim To determine the influence of sonic irrigation and type of irrigant on removal of artificially placed dentine debris from the apical root canals during passive sonic irrigation.

Method Fifteen extracted mandibular premolars with one root canal were selected. The root canals were prepared till size 30, taper 06 using rotary System GT instruments (Densply Maillefer, Ballaigues, Switzerland). Each root was split longitudinally, forming two halves. A groove was cut in the canal wall 2-6 mm from the apex. Each groove was filled with dentine debris mixed with 5,5% NaOCl or water, and the premolar was reassembled by joining the two halves of the teeth by sticky wax. All canals were sonically irrigated using a nylon tip (EndoActivator) which was passively placed in the canal until the apical foramen or until the tip got stocked in the canal.

In all groups fifteen selected teeth were used (n=15). In group 1 the canals were sonically irrigated with 6,0 ml 5,5% NaOCl. The small sized nylon tip was used for the passive sonically irrigation. In group 2 the canals were sonically irrigated with 6,0 ml 5,5% NaOCl for 1 min. using the medium sized nylon tip. Group 3 and 4 were treated the same respectively, except for the fact that water was used as irrigant instead of 5,5% NaOCl.

Group 5 was irrigated with 6,0 ml of water for 60s with a 27 gauge syringe. No passive sonically irrigation has been used in this group. Before and after irrigation, images of the grooves were captured and stored. The quantity of dentine debris in the grooves was evaluated. The differences in debris score between the experimental groups were analysed with Mann-Whitney test, Kruskal-Wallis test and Wilcoxon Signed Ranks test. The level of significance was set at $\alpha = 0{,}05$.

Results

The difference between all groups and the control group was significant. ($P < 0.05$ Mann-Whitney test).

No significant difference in using different sized tips has been found in statistic analyses between group 1 and 2 ($P = 0.06$) and group 3 and 4 ($P = 0.059$) using the Kruskal-Wallis test. Also no significant differences in using different irrigants have been found in statistic analyses between group 2 and 4 using a medium tip ($P = 0.101$ Kruskal-Wallis test). But significant difference in using different irrigants has been found between group 1 and 3 using a small tip ($P = 0.029$ Kruskal-Wallis test).

Conclusion

Passive sonic irrigation is more effective in removal of dentine debris from artificial standardizes grooves than syringe delivery of water only. Using different irrigants, water or NaOCl, gives conflicting results on the effect of dentine debridement. The usage of different sized tips gives no significant difference in debridement.

Keywords: passive sonic irrigation, natural teeth, NaOCl, water, dentine debris removal

ABSTRACT

Aim:

The aim of this study was to compare, under the scanning electron microscope (SEM), the efficacy of the EndoActivator to passive ultrasonic irrigation (PUI), using ethylenediaminetetraacetic acid (EDTA), on smear layer and debris removal at the apical portions of curved root canals.

Methodology:

Forty-five extracted maxillary teeth with curved root canals were randomly distributed into 3 test groups. All teeth were prepared using ProFile rotary instruments and subjected to different final irrigation regimes; group A, 17% EDTA without sonics or ultrasonics; group B, 17% EDTA with sonics (EndoActivator); and group C, 17% EDTA with ultrasonics. The teeth were split in half, sectioned longitudinally and prepared for viewing under a scanning electron microscope (SEM). Samples were examined under SEM and scored for debris and smear layer removal.

Results:

At the 2 mm level from the apical foramen, specimens from Group B and C scored significantly better than Group A for debris removal ($p < 0.05$). There was no significant difference in terms of smear score for all 3 groups at the 2 mm and 6 mm level.

Conclusions:

Within the limitations of this study, a one-minute use of the EndoActivator with 17% EDTA was as efficient as ultrasonics in removing debris in the apical regions of the curved root canals. A one minute application of EDTA in curved root canals is not effective in the removal of smear layer, even when the EndoActivator or ultrasonics was used.

Effect of EDTA, Sonic, and Ultrasonic Activation on the Penetration of Sodium Hypochlorite into Simulated Lateral Canals: An *In Vitro* Study

Cesar de Gregorio, DDS, MS,* Roberto Estevez, DDS,* Rafael Cisneros, DDS,* Carlos Heilborn, DDS,†‡ and Nestor Cohenca, DDS‡

Abstract

Introduction: The purpose of this study was to evaluate the penetration of 5.25% sodium hypochlorite alone or in combination with 17% EDTA in simulated lateral canals using sonic and ultrasonic activation. **Methods:** Four hundred and eighty simulated lateral canals were created in 80 single rooted cleared teeth by inserting 06 K-files at 2, 4.5 and 6 mm of working length. Samples were mounted on clear silicon to simulate the presence of surrounding periodontal tissues and its effects on fluid dynamics and then randomly assigned to four experimental groups: 1 ($n = 20$) 5.25% NaOCl + sonic activation; 2 ($n = 20$) 5.25% NaOCl + ultrasonic activation; 3 ($n = 20$) 5.25% NaOCl + 17% EDTA + sonic activation and 4 ($n = 20$) 5.25% NaOCl + 17% EDTA + ultrasonic activation. Sonic activation was delivered using the Endoactivator® inserted 2 mm short of working length and activated for 1 minute. Ultrasonic activation was performed with a stainless steel ultrasonic file inserted 2 mm short of working length and passively activated for 3 cycles of 20 seconds each. Samples were evaluated by direct observation of the images recorded under the operating microscope and by radiographic evaluation after irrigation with a contrast solution. **Results:** Sonic and ultrasonic activation resulted in a better irrigation of the lateral canals at 4.5 and 2 mm from working length compared to traditional needle irrigation alone. Traditional needle irrigation alone demonstrated significantly less penetration of irrigant into the lateral canals and was limited to the level of penetration of the needle. **Conclusion:** The addition of EDTA did not result in better penetration of irrigants into the lateral canals. (*J Endod 2009;35:891–895*)

Key Words

Passive ultrasonic irrigation, root canal irrigation, sonic irrigation

Recognizing the predominant role of microorganisms in producing pulpal and periapical pathosis, endodontic treatment is aimed at the elimination of microorganisms from the root canal system (1–4). Sjogren et al (5) showed that endodontic success was directly related to the presence of negative bacterial culture before root canal filling. Despite all efforts to achieve a root canal system free of bacteria, to date it is evident that bacteria can still survive in areas that are not accessible to current cleaning and shaping procedures. Thus, research should be oriented to improve cleaning and disinfection of root canals.

Mechanical instrumentation is the establishment of a specific cavity form that permits instruments and irrigants easy access into the canal space creating a tapered shape in order to obtain optimal final irrigation and obturation (6). Irrigation acts as a flush to remove organic and inorganic debris as well as a bactericidal agent, tissue solvent and lubricant. Byström et al established that mechanical instrumentation of the root canal followed by saline irrigation alone leaves bacteria in the canal system and the supporting actions of disinfectants such as sodium hypochlorite (NaOCl) are still necessary (7, 8).

The tissue-dissolving properties of NaOCl have been well documented; however, its ability to remove smear layer has not been showed to be effective (9). Therefore, NaOCl has been used in association with EDTA, which acts on the inorganic debris formed in instrumented root canals (10, 11). The removal of the smear layer facilitates the diffusion of the chemical substances, irrigants, and medications delivered to the root canal system, thus allowing a more predictable disinfection and seal of the canal system (12, 13).

Other factors may also play a role on the efficacy of root canal irrigation (14–17). Chow (18) showed that the efficacy of apical irrigation is directly related to the depth of insertion of the needle, which in some cases presents a challenge to the clinician. The apical third of the root canal system is particularly difficult to clean because of the complicated anatomy, apical deltas, narrow isthmus, and lateral canals (19, 20). Some studies have reported a clear correlation between lateral canals obturation and healing of periapical lesions (21, 22). However, in order to fill lateral canals, these should be thoroughly cleaned (23).

The effective delivery of irrigants to the apical third can be enhanced by using ultrasonic and sonic devices (24–31) as well as apical negative-pressure irrigation (32, 33). Activation with sonic devices generates mechanical oscillation, mainly at the tip of the file, with frequency ranging from 1 to 6 KHz. Ultrasonic activation combines acoustic waves with the chemical action of the irrigant and generates a microstreaming along the file and secondary acoustic streaming with frequency ranging from 45 and 40 KHz (34). This microstreaming moves the solution against the root canal surfaces, enhancing mechanical cleansing of the canal walls and bacterial destruction.
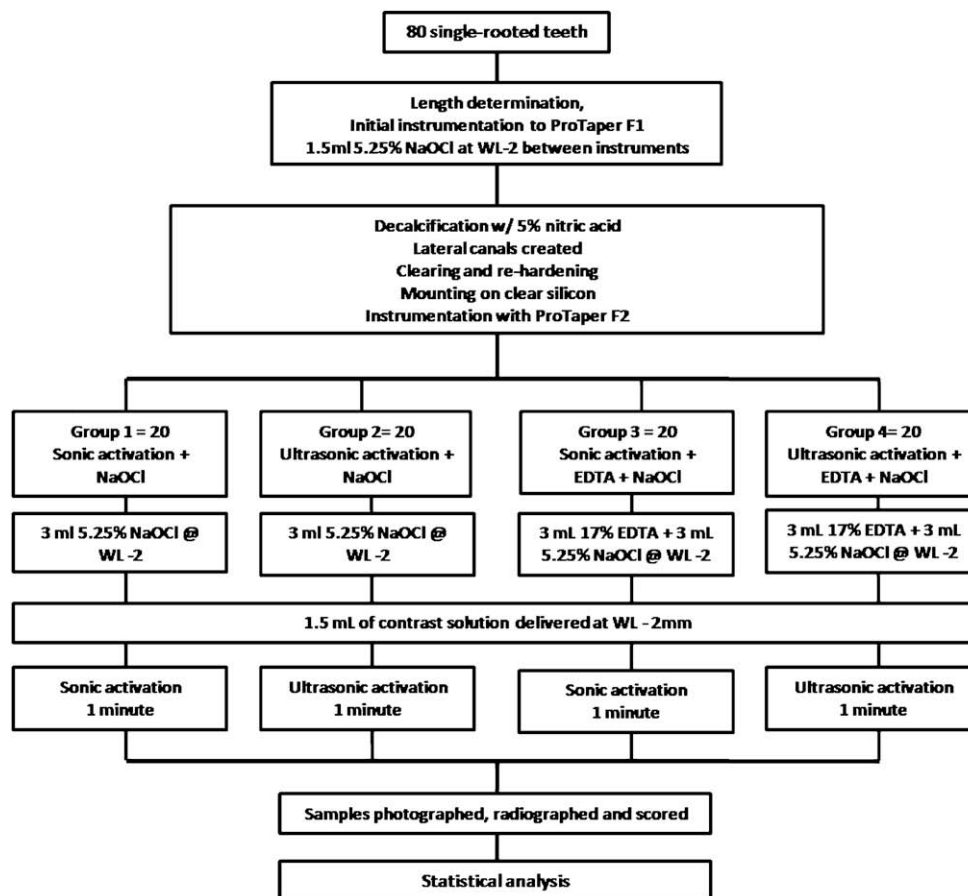
Basic Research—Technology

Figure 1. Flowchart of methodology.

Previous studies showed that sonic or ultrasonic activation may allow a better removal of pulpal tissue remnants and debris from isthmuses and fins (24, 28). The purpose of this study was to evaluate the penetration of 5.25% sodium hypochlorite alone or in combination with 17% EDTA in simulated lateral canals using sonic and ultrasonic activation.

Materials and Methods

Eighty single rooted teeth were used in this study (Fig. 1). Teeth were kept for 2 hours in 4% NaOCl, and any visible calculus was removed ultrasonically. The presence of a single canal was verified radiographically by taking three angulated films and by direct exploration under the dental-operating microscope (OPMI Pico Dental Microscope; Carl Zeiss, Oberkochen, Germany). All experimental procedures were performed by the same operator. Patency of the root canals was obtained using a 10 K-file (Maillefer, Ballaigues, Switzerland), and root length was standardized to 16 mm. The initial root canal shaping was performed to a working length of 15 mm using Protaper Universal rotary files (Maillefer) up to F1 corresponding to a 20/.07 size/taper. During this instrumentation, 1.5 mL of 5.25% NaOCl was delivered between each instrument using a 27-gauge side port Monojet needle (Sherwood Davis & Geck, St Louis, MO).

Upon completion of the shaping procedures, teeth were cleared using the modified technique described by Venturi et al (35). Clearing techniques of dental tissues were first described by Robertson et al (36, 37) and implied the decalcification in acids followed by immersion in oil with a high refractive index such as methyl salicylate. Briefly, teeth were submerged in 5% nitric acid for 36 hours, and the solution was

renewed every 8 hours. Once decalcified, samples were cleared with tap water for 3 minutes, and lateral canals were created inserting 06 K-files at 2, 4.5, and 6 mm of the working length on the buccal and lingual walls perpendicularly to the external surface (38). Samples were then dehydrated in ascending grades of ethyl alcohol (60%, 80%, and 96.6%) for 14 hours. File handles were removed to avoid dissolution and samples submerged in 99.9% methyl salicylate for clearing and rehardening of dental tissues. A total of 480 simulated lateral canals were created, six in each tooth, with two lateral canals at each of the three working lengths.

Samples were mounted on a supporting device containing clear silicon to simulate the presence of surrounding periodontal tissues and its effects on the dynamics of irrigation solution. Root canal shaping was then completed to the working length using a Protaper F2 rotary file corresponding to a 25/.08 size/taper. This final shaping was aimed to create a clinically relevant shape/size preparation as well as a smear layer. Samples were then randomly assigned to four experimental groups: (1) group 1 ($n = 20$): 5.25% NaOCl + sonic activation, (2) group 2 ($n = 20$): 5.25% NaOCl + ultrasonic activation, (3) group 3 ($n = 20$): 5.25% NaOCl + 17% EDTA + sonic activation, and (4) group 4 ($n = 20$): 5.25% NaOCl + 17% EDTA + ultrasonic activation.

Irrigation Protocols

During the initial instrumentation and shaping, 1.5 mL of 5.25% NaOCl was delivered between each file using a 27-gauge side port needle, 2 mm short of the working length. Upon completion of instrumentation with F2, all groups were irrigated with 3 mL of 5.25% NaOCl. Groups 3 and 4 received an additional 3 mL of 17% EDTA irrigation with

a 27-gauge side port needle. A final irrigation was performed in all experimental groups using 1.5 mL of NaOCl (mixed with contrast material) at 2 mm short of the working length. Overall, all experimental groups received 9 mL of 5.25% NaOCl, whereas groups 3 and 4 received an additional 3 mL of EDTA. The rate of delivery was standardized at 3 mL/min, and the side port was oriented mesially.

Contrast Solution

A contrast solution containing 50% of 5.25% NaOCl, 40% of 76% Pielograf (Justesa Imagem do Brasil, Rio de Janeiro, Brazil), and 10% Kuraray caries detector solution (Kuraray Medical Inc, Okayama, Japan) was prepared and delivered to the prepared root canals (39, 40). Using a 27-gauge side port needle, a total volume of 1.5 mL contrast solution was delivered 2 mm short of the working length without wedging.

Sonic and Ultrasonic Activation

Before sonic activation, the contrast solution was delivered to all samples by positive-pressure irrigation at 2 mm from the working length, and irrigant penetration was recorded and scored. Then, sonic activation was delivered using the Endoactivator (Advanced Endodontics, Santa Barbara, CA) set at 10,000 cycles per minute with a blue 35/.04 tip, inserted 2 mm short of the working length and activated for 1 minute. This protocol was applied for groups 1 and 3.

Ultrasonic activation was performed with a stainless steel ultrasonic file ISO 10 (Satelec Acteon Group, Merignac Cedex, France) mounted on a Suprasson P5 Booster ultrasonic unit (Satelec Acteon Group). The file was inserted 2 mm short of the working length and passively activated using a power setting of 3, according to manufacturer 's recommendations. The file was passively inserted into the canal without any filing motion. This procedure was performed in three cycles of 20 seconds each for a total activation time of 1 minute. Each file was used for up to 10 teeth and examined between samples under the stereomicroscope. This protocol was applied for groups 2 and 4. All procedures were recorded under the dental-operating microscope.

Evaluation Criteria

The samples were assessed by direct observation of the images recorded under the dental operating microscope and by radiographic evaluation of the samples after irrigation with the contrast solution (Fig. 1). Samples in groups 1 and 3 were assessed by direct observation both before and after activation and served as the control. The orientation of all samples in relation with the recording microscope was standardized to reproduce the same image in all groups.

Samples were scored based on the penetration of the contrast solution into the simulated lateral canals. Irrigant penetration was measured by the number of lateral canals (range, 0-2) in which the contrast solution penetrated at least 50% of the total length. The outcome was assessed in each tooth at each of the three working lengths (2, 4.5, and 6 mm).

Statistical Methods

The Wilcoxon signed-rank test was used to test for differences between outcomes measured before and after activation among groups 1 and 3. The Wilcoxon test was also used to test for differences between the measurements made on the same tooth using the direct observation method and the radiographic observation method. The Mann-Whitney U test was used to test for differences between the independent samples defined by the randomization groups.

Results

The mean number of lateral canals successfully penetrated by the irrigant is displayed in Table 1. At the 6-mm level, effective irrigation was obtained evidenced by the high level of irrigant penetration (Fig. 2). Results are consistent within the two evaluation methods. Sonic and ultrasonic activation resulted in a better irrigation of the lateral canals at 4.5 and 2 mm from working length compared with traditional needle irrigation alone, although the difference was not statistically significant at 6 mm from working length (Figs. 2 and 3). No significant differences were found between sonic and ultrasonic activation (Table 1). The addition of EDTA did not result in better irrigant penetration (Fig. 3). Traditional needle irrigation alone showed significantly less penetration of the irrigant into the lateral canals and was limited to the level of penetration of the needle (Figs. 2A and 3).

When comparing the two methods of observation, radiographic evaluation evidenced less penetration of irrigant into the lateral canals compared with the direct observation method. The difference was statistically significant ($p < 0.05$) at each working length in each of the four

TABLE 1. Mean Number of Lateral Canals Successfully Penetrated by the Irrigant

Group	N	6 mm Mean (SD)	4.5 mm Mean (SD)	2 mm Mean (SD)
Direct observation method				
1: Sonic, NaOCl	20	1.83 (0.37)	1.20 (0.75)	1.00 (0.84)
2: Ultrasonic, NaOCl	20	1.60 (0.75)	1.43 (0.67)	0.60 (0.77)
p value		0.66	0.37	0.16
3: Sonic, NaOCl + EDTA	20	2.00 (0.00)	1.00 (0.86)	1.05 (0.76)
4: Ultrasonic, NaOCl + EDTA	20	1.62 (0.48)	1.50 (0.71)	1.00 (0.79)
p value		0.01	0.08	0.84
Sonic activation (groups 1 and 3)	40	1.91 (0.27)	1.10 (0.80)	1.03 (0.79)
Ultrasonic activation (groups 2 and 4)	40	1.61 (0.63)	1.46 (0.68)	0.80 (0.80)
p value		0.01	0.04	0.21
Radiographic observation method				
1: Sonic, NaOCl	20	0.75 (0.91)	0.45 (0.63)	0.10 (0.31)
2: Ultrasonic, NaOCl	20	0.55 (0.89)	0.45 (0.60)	0.05 (0.22)
p value		0.50	1.00	0.80
3: Sonic, NaOCl + EDTA	20	0.80 (0.89)	0.30 (0.47)	0.15 (0.37)
4: Ultrasonic, NaOCl + EDTA	20	0.55 (0.60)	0.30 (0.44)	0.00 (0.00)
p value		0.51	0.93	0.43
Sonic activation (groups 1 and 3)	40	0.78 (0.89)	0.38 (0.55)	0.12 (0.33)
Ultrasonic activation (groups 2 and 4)	40	0.55 (0.75)	0.37 (0.53)	0.03 (0.16)
p value		0.29	0.93	0.09

EDTA, ethylenediamine tetraacetic acid; NaOCl, sodium hypochlorite; SD, standard deviation.
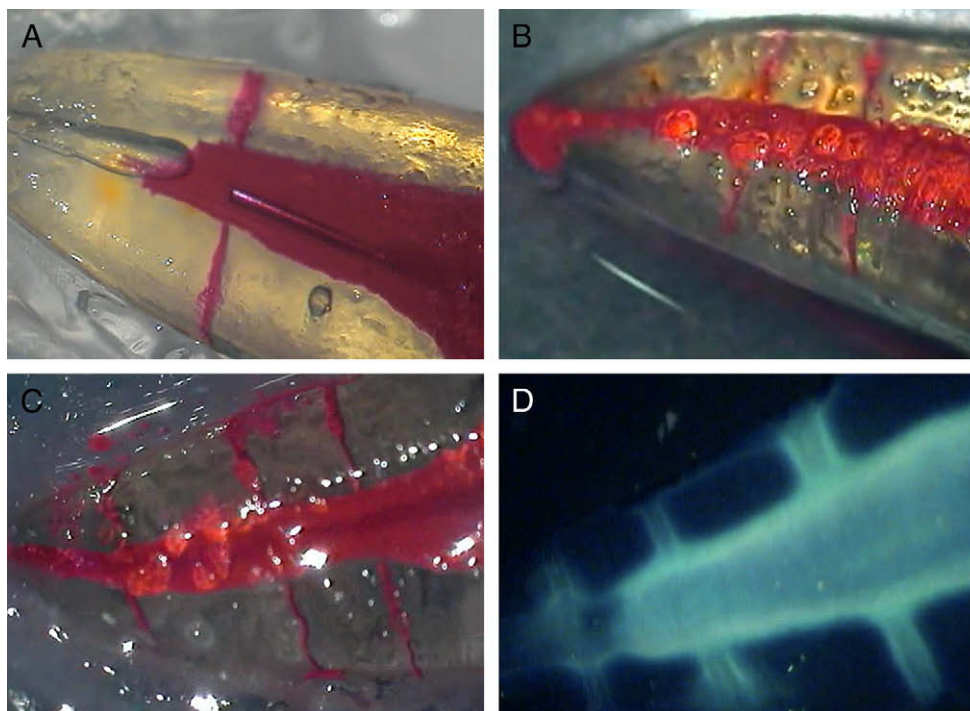
Basic Research—Technology

Figure 2. Irrigant penetration demonstrated by direct observation of cleared samples and radiographic contrast. A) The formation of a vapor lock and limited irrigant penetration is demonstrated when using needle only. B–C) Irrigant penetration after sonic and ultrasonic activation of cleared samples and D) radiographic contrast.

study groups. This may imply that even if the irrigant penetrated into the lateral canals, it could not be detected radiographically.

Discussion

Classic techniques for the *in vitro* evaluation of root anatomy and irrigant distribution include injection of an opaque material (India ink or gutta-percha) followed by clearing of the hard tissues (41–44). To the best of our knowledge, this is the first study that used artificially created lateral canals and cleared teeth to evaluate efficacy of irrigant

Figure 3. Graph showing the mean number of lateral canals successfully penetrated by the irrigant before and after sonic activation. *Traditional needle irrigation alone.

penetration. In addition, we also performed a radiographic evaluation in an attempt to show which method is more sensitive and reliable. Perhaps, radiographic evaluation evidenced less penetration of irrigant into the lateral canals because of the fact that the concentration of contrast material was not enough to be detected radiographically.

The ability of the irrigant to penetrate into areas not instrumented by mechanical instrumentation is critical for debridement and disinfection of the root canal system. Previous studies have shown that sonic and ultrasonic irrigation, for as little as 30 seconds, resulted in significantly cleaner canals than hand filing alone (45–46). Efficient penetration and distribution of the irrigant solutions in uninstrumented areas, represented by the artificially created lateral canals, correlates directly with previous studies that evaluated the efficacy of passive ultrasonic activation of irrigants for debridement, disinfection, and smear layer removal (28–30, 47, 48).

The limitations of positive-pressure irrigation alone, particularly at the apical third, might be related to the presence of gasses in the apical region forming a vapor lock into which further fluid penetration is difficult (Fig. 2*A*). This finding has been recently confirmed by the results obtained by Boutsioukis et al (49) in a computational fluid dynamics study. When using positive-pressure irrigation only, irrigant replacement was limited to 1 to 1.5 mm apical to the needle tip for all flow rates tested. Despite the fact that sonic and ultrasonic activation has different mechanism of action, which results in different frequencies and intensities, this activation resulted in more efficient irrigant replacement at the apical third, breaking the vapor lock and moving the solutions apically and laterally.

In conclusion, sonic and ultrasonic activation resulted in a better irrigation of the lateral canals at 4.5 and 2 mm from the working length. Traditional needle irrigation alone showed significantly less penetration of the irrigant into the lateral canals and was limited to the level of penetration of the needle. The addition of EDTA did not result in better

penetration of irrigants into the lateral canals. Further research is warranted to assess the effect of sonic and ultrasonic activation of irrigants on debridement, disinfection, and smear layer removal.

References

1. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18:269–96.
2. Kakehashi S, Stanley H, Fitzgerald R. The effect of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Pathol 1965;25:340–9.
3. Moller AJR, Fabricius L, Dahlen G, et al. Influence on periapical tissues of indigenous oral bacteria and necrotic pulp tissue in monkeys. Scand J Dent Res 1981;89:475–84.
4. Love RM, Jenkinson HF. Invasion of dentinal tubules by oral bacteria. Crit Rev Oral Biol Med 2002;13:171–83.
5. Sjogren U, Figdor D, Persson S, et al. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. J Endod 1997;30:297–306.
6. West JD, Roane JB. Cleaning and shaping the root canal system. In: Cohen S, Bruns RC eds. Pathways of the pulp. 7th ed. St. Louis, MO: CV Mosby Company; 1998:203–57.
7. Bystrom A, Sundqvist G. Bacteriologic evaluation of the efficiency of mechanical root canal instrumentation in endodontic therapy. Scand J Dent Res 1981;89:321–8.
8. Bystrom A, Sundqvist G. The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy. Int Endod J 1985;18:35–40.
9. Sen BH, Wesselink PR, Türkün M. The smear layer: a phenomenon in root canal therapy. Int Endod J 1995;28:141–8.
10. Teixeira CS, Felippe MC, Felippe WT. The effect of application time of EDTA and NaOCl on intracanal smear layer removal: an SEM analysis. Int Endod J 2005;38:285–90.
11. da Silva LA, Sanguino AC, Rocha CT, Leonardo MR, Silva RA. Scanning electron microscopic preliminary study of the efficacy of SmearClear and EDTA for smear layer removal after root canal instrumentation in permanent teeth. J Endod 2008;34:1541–4.
12. Orstavik D, Haapasalo M. Disinfection by endodontic irrigants and dressings of experimentally infected dentinal tubules. Endod Dent Traumatol 1990;6:142–9.
13. Jeon IS, Spänberg ISW, Yoon TC, et al. Smear layer production by three rotary reamers with different cutting blade design in straight root canals: a scanning electron microscopic study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:601–7.
14. Baumgartner JC, Cuenin PR. Efficacy of several concentrations of sodium hypochlorite for root canal irrigation. J Endod 1992;18:605–12.
15. Siqueira JF Jr, Rocas IN, Favieri A, et al. Chemomechanical reduction of the bacterial population in the root canal after instrumentation and irrigation with 1%, 2.5%, and 5.25% sodium hypochlorite. J Endod 2000;26:331–4.
16. Cunningham WT, Balekjian AY. Effect of temperature on collagen-dissolving ability of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol 1980;49:175–7.
17. Cunningham WT, Joseph SW. Effect of temperature on the bactericidal action of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol 1980;50:569–71.
18. Chow TW. Mechanical effectiveness of root canal irrigation. J Endod 1983;9:475–9.
19. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg 1984;58:589–99.
20. Pineda F, Kuttler Y. Mesiodistal and buccolingual roentgenographic investigation of 7,275 root canals. Oral Surg 1972;33:101–10.
21. Seltzer S, Bender IB, Ziontz M. The interrelationship of pulp and periodontal disease. Oral Surg Oral Med Oral Pathol 1963;16:1474–90.
22. Seltzer S, Bender IB, Smith J, et al. Endodontic failures-an analysis based on clinical, roentgenographic, and histologic findings. I. Oral Surg Oral Med Oral Pathol 1967;23:500–16.
23. Weine FS. The enigma of the lateral canal. Dent Clin North Am 1984;28:833–52.
24. Goodman A, Reader A, Beck M, et al. An in vitro comparison of the efficacy of the step-back technique versus a step-back/ultrasonic technique in human mandibular molars. J Endod 1985;11:249–56.
25. Cameron JA. The use of 4 per cent sodium hypochlorite, with or without ultrasound, in cleansing of uninstrumented immature root canals; SEM study. Australian Dent J 1987;32:204–13.
26. Metzler R, Montgomery S. The effectiveness of ultrasonics and calcium hydroxide for the debridement of human mandibular molars. J Endod 1989;15:373–8.
27. Cheung GSP, Stock CJR. In vitro cleaning ability of root canal irrigant with and without endosonics. Int Endod J 1993;26:334–43.
28. Lee S-J, Wu M-K, Wesselink PR. The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls. Int Endod J 2004;37:672–8.
29. Gutarts R, Nusstein J, Reader A, et al. In vivo debridement efficacy of ultrasonic irrigation following hand rotary instrumentation in human mandibular molars. J Endod 2005;31:166–70.
30. Van der Sluis L, Wu M, Wesselink P. The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from human root canals prepared using instruments of varying taper. Int Endod J 2005;38:764–8.
31. Passarinho-Neto JG, Marchesan MA, Ferreira RB, et al. In vitro evaluation of endodontic debris removal as obtained by rotary instrumentation coupled with ultrasonic irrigation. Aust Endod J 2006;32:123–8.
32. Nielsen BA, Craig Baumgartner J. Comparison of the Endovac System to needle irrigation of root canals. J Endod 2007;33:611–5.
33. Hockett JL, Dommisch JK, Johnson JD, et al. Antimicrobial efficacy of two irrigation techniques in tapered and nontapered canal preparations: an in vitro study. J Endod 2008;34:1374–7.
34. Ahmad M, Pitt Ford T. Ultrasonic debridement of root canals: acoustic streaming and its possible role. J Endod 1987;13:490–9.
35. Venturi M, Breschi I, Prati M, et al. A preliminary analysis of the morphology of lateral canals alter root canal filling using a tooth-clearing technique. Int Endod J 2003;36:54–63.
36. Robertson D, Leeb IJ, McKee M, et al. A clearing technique for the study of root canal systems. J Endod 1980;6:421–4.
37. Robertson DC, Leeb IJ. The evaluation of a transparent tooth model system for the evaluation of endodontically filled teeth. J Endod 1982;8:317–21.
38. Venturi M, Di Lenarda R, Prati C, et al. An in vitro model to investigate filling of lateral canals. J Endod 2005;31:877–81.
39. Kahn FH, Rosenberg PA, Gliksberg J. An in vitro evaluation of the irrigating characteristics of ultrasonic and subsonic handpieces and irrigating needles and probes. J Endod 1995;21:277–80.
40. Salzgeber RM, Brilliant JD. An in vivo evaluation of the penetration of an irrigating solution in root canals. J Endod 1977;3:394–8.
41. Miyashita M, Kasahara E, Yasuda E, et al. Root canal system of the mandibular incisor. J Endod 1997;23:479–84.
42. Karagoz-Kucukay I. Root canal ramifications in mandibular incisors and efficacy of low-temperature injection thermoplasticized gutta-percha filling. J Endod 1994;20:236–40.
43. Pujar M, Bhagwat SV. Determination of the morphological irregularities in the middle and apical 1/3rd region of the root canal system of permanent maxillary incisors. Indian J Dent Res 2002;13:96–8.
44. Kasahara E, Yasuda E, Yamamoto A, et al. Root canal system of the maxillary central incisor. J Endod 1990;16:158–61.
45. Jensen SA, Walker TL, Hutter JW, et al. Comparison of the cleaning efficacy of passive sonic activation and passive ultrasonic activation after hand instrumentation in molar root canals. J Endod 1999;25:735–8.
46. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003;29:674–8.
47. Guerisoli DM, Marchesan MA, Walmsley AD, et al. Evaluation of smear layer removal by EDTAC and sodium hypochlorite with ultrasonic agitation. Int Endod J 2002;25:418–21.
48. Spoleti P, Siragusa M, Spoleti MJ. Bacteriological evaluation of passive ultrasonic activation. J Endod 2003;29:12–4.
49. Boutsioukis C, Lambrianidis T, Kastrinakis E. Irrigant flow within a prepared root canal using various flow rates: a computational fluid dynamics study. Int Endod J 2009;42:144–55.

Comparative Safety of Various Intracanal Irrigation Systems

Pranav Desai, BDS, DDS, and Van Himel, DDS

Abstract

The objective of this project was to evaluate the safety of various intracanal irrigation systems by measuring the apical extrusion of irrigant. Twenty-two single canal, extracted mature teeth were instrumented and secured through the lid of a scintillation vial to collect apically extruded irrigant. A precision syringe pump delivered controlled amounts of irrigant at a constant flow. The irrigation systems used were EndoVac Micro and Macro Cannula, EndoActivator, manual irrigation with Max-I-Probe needle, Ultrasonic Needle Irrigation, and Rinsendo. Results were analyzed by using one-way analysis of variance with Scheffé test ($P < .05$). The EndoVac Micro and Macro cannulae groups did not extrude irrigant, and there was no statistically significant difference between these 2 groups and the EndoActivator group. Within the groups that produced extrusion, EndoActivator extruded statistically significantly less irrigant than Manual, Ultrasonic, and Reinsendo groups. There was no statistically significant difference among Manual, Ultrasonic, and Rinsendo groups. This study showed that the EndoVac did not extrude irrigant after deep intracanal delivery and suctioning the irrigant from the chamber to full working length. 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. Manual, Ultrasonic, and Rinsendo groups had significantly greater amount of extrusion compared with EndoVac and EndoActivator. *(J Endod 2009;35:545–549)*

Key Words

EndoActivator, EndoVac, RinsEndo, safety, ultrasonic needle

From the Department of Endodontics and Operative Dentistry, University of Tennessee Health Science Center, College of Dentistry, Memphis, Tennessee.

Address requests for reprints to Dr Pranav Desai, Department of Endodontics and Operative Dentistry, University of Tennessee, College of Dentistry, 875 Union Ave, Memphis, TN 38163. E-mail address: pdesai@utmem.edu.

Chemomechanical debridement is an important part of endodontic treatment. Elimination of pulpal tissue, microbiota and their by-products, and organic and inorganic debris removal by using instruments and intracanal irrigants are objectives of this important phase of treatment. Sodium hypochlorite along with ethylenediaminetetraacetic acid is able to achieve the goal of chemical debridement (1, 2). Sodium hypochlorite carries risk of extrusion into periapical tissues causing inflammation, ecchymoses, hematoma, and sometimes even necrosis and paresthesia (3–5). Accordingly, any root canal irrigation delivery system that reduces the risk of sodium hypochlorite extrusion into the periapical tissues would greatly benefit patient care.

In vitro studies have demonstrated that when root canals are instrumented and irrigated with patent apical terminations, extrusion of irrigants beyond the apical constriction is routine (6–9). Accordingly, the premise of this study was to create the worst case scenario for testing the potential of each device to extrude endodontic irrigants: a tooth with a patent apical foramen, not covered by either bone or membrane, and terminating in an atmospheric neutral environment.

The specific aim of this *in vitro* study was to compare the relative safety of various intracanal irrigation systems. The volume of irrigant that extruded beyond the minor diameter of the apical foramen was measured. The device 's safety was then directly correlated to the amount of extruded irrigant. Five irrigation delivery and/or activation systems with different irrigation principles were included in this study.

The EndoVac apical negative pressure irrigation system (Discus Dental, Smart Endodontics, Culver City, CA) has 3 components: Micro cannula (MICRO) (test group 1) (Fig. 1B), the Macro cannula (MACRO) (test group 2) (Fig. 1A), and the Master Delivery Tip (MDT) (Fig. 1C-3). The MDT simultaneously delivers and evacuates the irrigant (Fig. 2). 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. Nielsen and Baumgartner (10) concluded that EndoVac was significantly better for root canal debridement at the apical termination than positive pressure needle irrigation.

The EndoActivator) (Advanced Endodontics, Santa Barbara CA) (test group 3) (Fig. 1D-1) uses sonic energy to irrigate root canal systems. This system has 2 components, a handpiece and activator tips (Yellow 15/02, Red 25/04, Blue 35/04). The battery-operated handpiece activates from 2,000–10,000 cycles/min. 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 (11). On placing irrigant into the canal and chamber, passively fitting tips are activated at 10,000 cycles/min for 30–60 seconds. It has been reported that sonic irrigation is capable of producing clean canals (12, 13).

Manual irrigation with a side-ported needle (Max-I-Probe; Dentsply International, York, PA) (MAX) by using positive pressure (test group 4) (Fig. 1C-2) 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 (3–5).

A unique Ultrasonic Needle system (UN) capable of delivering and agitating the irrigant simultaneously was used in this study (test group 5) (Fig. 1C-1). It has been observed that the needle can produce cavitations with high ultrasonic output in shaped canals by removing pulpal tissues and debris better than hand and rotary instrumentation alone from canals and isthmi (14).

Rinsendo (RE) (Air Techniques Inc, New York, NY) (test group 6) irrigates the canal by using pressure-suction technology. Its components are a handpiece, a cannula with a 7-mm-long exit aperture, and a syringe carrying irrigant (Fig. 1D-2). The
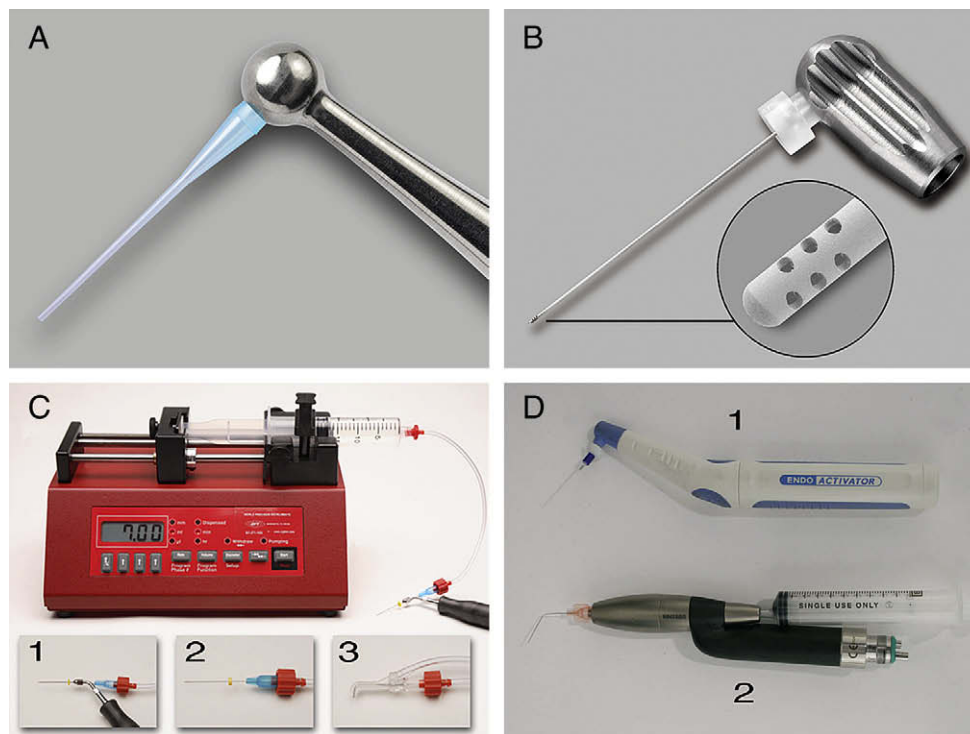
Basic Research—Technology

Figure 1. (*A*) The EndoVac plastic Macro and (*B*) stainless steel Micro cannulae are shown inserted in their respective titanium components. The Micro 's tip (enlargement) terminates with array of twelve 100-μm holes (only 6 are visible) extending between an area 0.2–0.7 mm from the spherical end of the cannula. (*C*) PSP at top was used to deliver irrigant through (*C-1*) the ultrasonic needle, (*C-2*) the Max-I-Probe, and (*C-3*) the EndoVac 's MDT. (*D1*) The battery-operated EndoActivator is shown with a plastic activation tip inserted. (*D2*) The Rinsendo is shown fully assembled; it delivers irrigant via internal pneumatic pressure.

handpiece is powered by dental air compressor and has irrigation speed of 6.2 mL/min. Research has shown promising results in cleaning the root canal system. Periapical extrusion of irrigant has also been reported (15).

Materials and Methods

Twenty-two single-rooted, extracted maxillary central and lateral incisors with mature apices were selected. The same 22 teeth were used in all 6 groups to avoid variables of different canal anatomy and apical diameter. A consistent and known volume of irrigant was delivered to each pulp canal, and all apical extrusion was trapped in a collection vial similar to that of Brown et al (8). The percent difference between the extruded and delivered irrigant was calculated and analyzed.

Canal Preparation

After conventional access preparation, canals were shaped by using a crown-down technique with Endo Sequence, rotary nickel titanium instruments (Brasseler USA Dental Instrumentation, Savannah, GA) to a master apical file (MAF) size of #50/04. MAF is defined as the largest file that binds slightly at correct working length after straight-line access. Once the teeth were shaped to MAF, a micro capillary tip (Ultradent Products Inc, South Jordan, UT) was used to deliver 6.0% sodium hypochlorite through the prepared root canal space, until no visual evidence of intracanal organic tissue was found.

Test Units and Irrigant Control

The test units were prepared in the following manner (Fig. 3). The prepared teeth were mounted through a hole in the mating lid (Fig. 3*A-1*) of a removable 20-mL collection vial (Research Product Interna-

tional Corp, Mt Prospect, IL) (Fig. 3*A-4*) next to an atmospheric equalization 18-gauge needle (Ultradent Products Inc) (Fig. 3*A-3*). Both the tooth and the 18-gauge needle were secured and sealed to the lid by using light-cure composite resins (Esthet-X, Dentsply Caulk; Dentsply International, Milford, DE) and yellow sticky wax (Kerr Lab, Sybron Dental, Orange, CA) (Fig. 3*A-2*). The collection vial was dried and weighed on a digital scale (Sauter; August Sauter of America, New York, NY) and then securely screwed into the tooth/needle/lid assembly (8).

In all tests, irrigation was accomplished with room temperature tap water delivered to the pulp canal according to manufacturer 's instruction. To maintain irrigation consistency, a programmable precision syringe pump (PSP) (Fig. 1*C*) (Alladin, AL 1000; World Precision Instruments, Inc, Sarasota, FL) was used to deliver between 3.48 and 3.53 mL at the precise rate of 7.0 mL/min, except for the Rinsendo, because it contains its own pneumatic pump and irrigation syringe. A custom-made Fluid Recovery Trap (FRT) (Fig. 3*A-5*) collected coronally expressed irrigant in group 3 (Fig. 3*C*) or the irrigant flow through the Micro and Macro cannulae in groups 1 and 2 (Fig. 3*A*).

Testing Procedure

Group 1: Micro Cannula, EndoVac. The MDT was attached to the PSP to deliver irrigant into the pulp chamber (Fig. 3*A-6*). The micro cannula was attached to FRT (Fig. 3*A-8*), placed at full working length, and used according to manufacturer 's instructions.

Group 2: Macro Cannula, EndoVac. The Macro cannula was used as described in group 1. Its apical advancement ended wherever the intracanal diameter prevented its further apical extension.

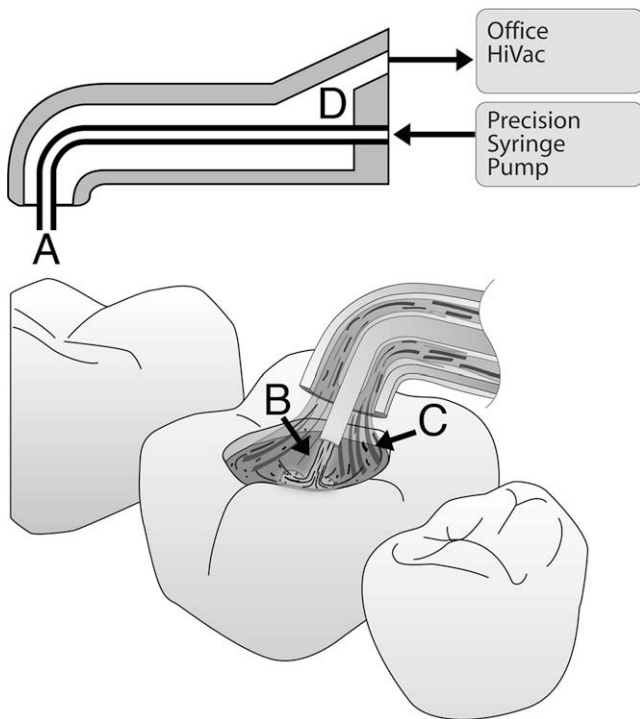**Group 3: EndoActivator.** The PSP was attached to irrigation needle that delivered irrigant into the pulp chamber (Fig. 3*C*). The

was performed because the specific gravity of water at 25°C (77°F) is 1.00 at the second decimal place, reflecting the limit of the PSP's display. The percentage of extrusion in each test was calculated (Apical irrigant extrusion/Total irrigant delivered) and recorded. Results were analyzed by using one-way analysis of variance with Scheffé test ($P < .05$).

Results

At the end of the experiment 22 teeth were left. Four teeth were eliminated because of cracked roots resulting from desiccation.

The apical negative pressure group 1 (EndoVac Micro Cannula) and group 2 (EndoVac Macro Cannula) were the only ones that did not extrude irrigating solution into the collection vial (Fig. 4). There was no statistically significant difference between groups 1, 2, and 3 (EndoVac Micro, EndoVac Macro, EndoActivator). Group 3 extruded statistically significantly less irrigant compared with group 4 (Max-I-Probe Needle), group 5 (Ultrasonic needle), and group 6 (Rinsendo). There was no statistically significant difference among groups 4, 5, and 6. Group 6 extruded highest irrigant followed by groups 5, 4, and 3 (Fig. 5).

Discussion

Results of this study broadly correlated with studies by Lambrianidis et al (6), Brown et al (8), Myers and Montgomery (9), and Roy and Laurence (16), which noted that irrigation with positive pressure resulted in periapical extrusion. This study also supports the result of Fukumoto et al (17) that negative pressure irrigation technique reduced periapical extrusion.

EndoVac Micro and Macro cannulae did not extrude irrigant through the apex. Because nothing was extruded, the amount of irrigant circulating through the Macro and Micro cannulae could be questioned. To address this concern, it was decided to collect the irrigants circulating through these components by using the FRT. Data from the FRT demonstrated that 82%–99% of the irrigant circulated through the Macro cannula, whereas 51%–54% circulated through the Micro cannula. The MDT was responsible for suctioning the coronal overflow (Fig. 3A-7) (Fig. 2).

Although Endoactivator extruded irrigant, the volume was very small, and the clinical significance is not known. However, the manufacturer's instructions at the time of research did not suggest the use of manual irrigation before using Endoactivator. In a recent publication by Ruddle (11), he suggested the use of intracanal irrigation before using EndoActivator. To relate these results to the manufacturer's instructions, groups 3 and 4 could be added together and then compared with the other groups. This would potentially make the differences between the EndoActivator and the EndoVac even greater.

The protocol for this study was designed to maximize the possibility of irrigant extrusion through an unrestricted, yet normal apex. 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. If quantities of periapical extrusion occurred clinically such as reported in this article, greater adverse treatment reactions associated with full-strength sodium hypochlorite would most likely occur. The model used most likely correlates, by design, to a canal that is open to atmospheric pressure, such as occurs when the apex of a tooth is extruding into the maxillary sinus with no apical covering or restriction (18, 19).

Because the basic goal of successful endodontic therapy is to eradicate microorganisms and other intracanal debris from the root canal system, the clinician must be able to deliver antimicrobial and tissue solvent solutions in predictable volumes safely to full working

Figure 2. The EndoVac's MDT delivers irrigant from its stainless steel tip (*A*) into an access opening (*B*) and concurrently aspirates the excess (*C*) via its evacuation hood (*D*), thus ensuring a brimful access opening necessary for successful apical negative pressure irrigation. Because the MDT delivers more irrigant than is actually drawn through the Macro and Micro cannulae, it was necessary to measure the actual volume flow via an FRT (Fig. 3*A*). Fig. 3*A* shows the MDT as an abstract schematic without the detail shown here.

EndoActivator tip (35/04) was placed within 2 mm of WL and activated while moving in an up and down motion for 30 seconds.

Group 4: Manual Syringe and Max-I-Probe Needle. The 30-gauge Max-I-Probe needle attached to the PSP was placed 2 mm short of working length without binding and moved in an up and down motion during irrigation (Fig. 3*B*).

Group 5: Ultrasonic Needle Irrigation. The Ultrasonic unit used was Spartan MTS, 115 V (Obtura Spartan USA, Fenton, MO). The 25-gauge diameter, experimental beveled ultrasonic needle (Becton Dickinson & Co, Franklin Lakes, NJ) measured 1.5 inches in length and was mounted at a 45-degree angle to the ultrasonic handpiece. The PSP was attached to the ultrasonic needle, which delivered the irrigant. The ultrasonic needle was placed short of the binding point and moved in an up and down motion during irrigation (14).

Group 6: Rinsendo. Its syringe was filled with 3.50 mL of irrigant and weighed before and after the experiment to confirm the volume of the irrigant in the syringe. Rinsendo was operated at 45-PSI pressure. The cannula was placed into the coronal third of the canal without binding and moved up and down during irrigation (Fig. 3*D*).

Data Collection and Analysis

The volume of irrigant delivered into each pulp canal via the PSP was recorded from the pump's digital display. After each test, the lid assembly was separated from the collection vial, weighing the collection vial again and subtracting the pre-test tare weight to calculate the apical extrusion. Because the experiment was conducted at room temperature with water as the irrigant, no conversion between the weight and volume
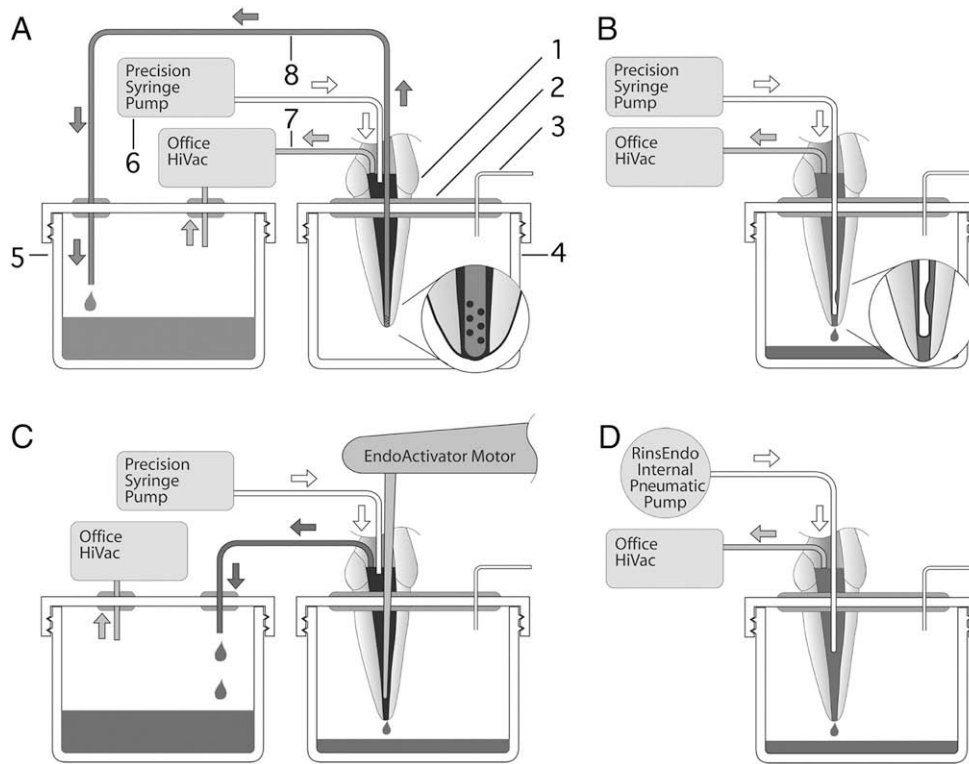
Figure 3. All tests used the same set of teeth (*A-1*), mounted and sealed via composite and wax (*A-2*) to a removable cap, perforated, and sealed with a pressure equalization cannula (*A-3*). This cap unit could be assembled and disassembled from apical extrusion collection vials (*A-4*). An FRT (*A-5*) was used in 2 test groups. Except for Rinsendo, all irrigant was delivered via a PSP (*A-6*). EndoVac 's (*A*) Macro and Micro (not shown) received irrigant at the access opening via the PSP, coronal excess was evacuated into the Hi-Vac (*A-7*), while the irrigant flowing through the Macro/Micro cannulae was trapped (*A-8*). (*B*) The Max-I-Probe and ultrasonic needles both received their irrigant from the PSP. (*C*) The EndoActivator received its irrigant at the access opening via the PSP, and coronal excess was trapped. (*D*) The Rinsendo delivered irrigant to its cannula via its internal pneumatic pump.

length. This goal seems to have been accomplished by using the Endo-Vac system in terms of safety (no apical extrusion) and volume (data from the FRT). Fear of a procedural error attributed to full-strength sodium hypochlorite extrusion might cause clinicians to use an inadequate flow of sodium hypochlorite at full working length (20), thus decreasing the efficacy of full-strength sodium hypochlorite at full working length. This observation is supported by a recent study testing positive and negative postoperative cultures (21) as well as studies examining intracanal debris and smear layer in the apical region (10, 17).

Figure 4. Percent apical irrigant extrusion by group. EA, EndoActivator.

Group Comparison		p Value
MICRO	MACRO	> 0.9999
MICRO	EA	0.9025
MICRO	MAX	< 0.0001*
MICRO	UN	< 0.0001*
MICRO	RE	< 0.0001*
MACRO	EA	0.8729
MACRO	MAX	< 0.0001*
MACRO	UN	< 0.0001*
MACRO	RE	< 0.0001*
EA	MAX	< 0.0001*
EA	UN	< 0.0001*
EA	RE	< 0.0001*
MAX	UN	0.6523
MAX	RE	0.0990
UN	RE	0.9014

Figure 5. Statistical group comparison with *P* value. EA, EndoActivator. *Statistical significance.

This study concluded that the EndoVac did not extrude irrigant after deep intracanal delivery and suctioning the irrigant from the chamber to full working length. EndoActivator had a minimal, although statistically insignificant, amount of irrigant extruded out of the apex when delivering irrigant into the pulp chamber, placing the tip into the canal, and initiating the sonic energy of the EndoActivator. Manual, Ultrasonic, and Rinsendo groups had significantly greater amounts of extrusion compared with EndoVac and EndoActivator groups.

References

1. Clegg MS, Vertucci FJ, Walker C, Belanger M, Britto LR. The effect of exposure to irrigant solutions on apical dentin biofilms in vitro. J Endod 2006;32:434–7.
2. Dunavant TR, Regan JD, Glickman GN, Solomon ES, Honeyman AL. Comparative evaluation of endodontic irrigants against Enterococcus faecalis biofilms. J Endod 2006;32:527–31.
3. Ehrich DG, Brian JD Jr, Walker WA. Sodium hypochlorite accident: inadvertent injection into the maxillary sinus. J Endod 1993;19:180.
4. Bowden JR, Ethunandan M, Brennan PA. Life-threatening airway obstruction secondary to hypochlorite extrusion during root canal treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:402–4.
5. Mehdipour O, Kleier DJ, Averbach RE. Anatomy of sodium hypochlorite accidents. Compend Contin Educ Dent 2007;28:544–6, 548,550.
6. Lambrianidis T, Tosounidou E, Tzoanopoulou M. The effect of maintaining apical patency on periapical extrusion. J Endod 2001;27:696–8.
7. Tinaz AC, Alacam T, Uzun O, Maden M, Kayaoglu G. The effect of disruption of apical constriction on periapical extrusion. J Endod 2005;31:533–5.
8. Brown DC, Moore BK, Brown CE Jr, Newton CW. An in vitro study of apical extrusion of sodium hypochlorite during endodontic canal preparation. J Endod 1995;21:587–91.
9. Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and Canal Master techniques. J Endod 1991;17:275–9.
10. Nielsen BA, Baumgartner J. Comparison of the EndoVac system to needle irrigation of root canals. J Endod 2007;33:611–5.
11. Ruddle C. Endodontic disinfection-tsunami irrigation. Endodontic Practice 2008;5: 8–17.
12. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003;29:674–8.
13. Jensen SA, Walker TL, Hutter JW, Nicoll BK. Comparison of the cleaning efficacy of passive sonic activation and passive ultrasonic activation after hand instrumentation in molar root canals. J Endod 1999;25:735–8.
14. Burleson A, Nusstein J, Reader A, Beck M. The in vivo evaluation of hand/rotary/ultrasound instrumentation in necrotic, human mandibular molars. J Endod 2007;33:782–7.
15. Pouch D, Bohne W, Enkel B, Pilet P, Calas P, Laboux O. Cleaning qualities of Rinsendo: an *in vitro* study. European Cells and Materials 2007;13:7.
16. Roy G, Laurence JW. Apical extrusion of root canal irrigants when using Er:YAG and Er, Cr:YSGG lasers with optical fibers: an *in vitro* dye study. J Endod 2008;34: 706–8.
17. Fukumoto Y, Kikuchi I, Yoshioka T, Kobayashi C, Suda H. An *ex vivo* evaluation of a new root canal irrigation technique with intracanal aspiration. Int Endod J 2006; 39:93–9.
18. Hauman CH, Chandler NP, Tong DC. Endodontic implications of the maxillary sinus: a review. Int Endod J 2002;35:127–41.
19. Zairi A, Lambrianidis T. Accidental extrusion of sodium hypochlorite into the maxillary sinus. Quintessence Int 2008;39:745–8.
20. Bradford CE, Eleazer PD, Downs KE, Scheetz JP. Apical pressures developed by needles for canal irrigation. J Endod 2002;28:333–5.
21. Hockett JI, Dommisch JK, Johnson JD, Cohenca N. Antimicrobial efficacy of two irrigation techniques in tapered and nontapered canal preparations: an *in vitro* study. J Endod 2008;34:1374–7.

Review of Contemporary Irrigant Agitation Techniques and Devices

Li-sha Gu, DDS, MS, * *Jong Ryul Kim, DMD, PhD,*[†] *Junqi Ling, DDS, PhD,* * *Kyung Kyu Choi, DMD, PhD,*[†] *David H. Pashley, DMD, PhD,*[‡] *and Franklin R. Tay, BDSc (Hons), PhD*[§]

Abstract

Introduction: Effective irrigant delivery and agitation are prerequisites for successful endodontic treatment. **Methods:** This article presents an overview of the irrigant agitation methods currently available and their debridement efficacy. **Results:** Technological advances during the last decade have brought to fruition new agitation devices that rely on various mechanisms of irrigant transfer, soft tissue debridement, and, depending on treatment philosophy, removal of smear layers. These devices might be divided into the manual and machine-assisted agitation systems. Overall, they appear to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation. Despite the plethora of *in vitro* studies, no well-controlled study is available. This raises imperative concerns on the need for studies that could more effectively evaluate specific irrigation methods by using standardized debris or biofilm models. In addition, no evidence-based study is available to date that attempts to correlate the clinical efficacy of these devices with improved treatment outcomes. Thus, the question of whether these devices are really necessary remains unresolved. There also appears to be the need to refocus from a practice management perspective on how these devices are perceived by clinicians in terms of their practicality and ease of use. **Conclusions:** Understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems and for manufacturers' contentions that these systems play a pivotal role in contemporary endodontics. *(J Endod 2009;35:791–804)*

Key Words

Agitation, debris, irrigation, machine-assisted, manual, smear layer

From the *Department of Operative Dentistry and Endodontics, Guanghua School of Stomatology, Sun Yat-sen University, Guangzhou, China; [†]Department of Conservative Dentistry, School of Dentistry, KyungHee University, Seoul, Korea; and [‡]Department of Oral Biology and [§]Department of Endodontics, School of Dentistry, Medical College of Georgia, Augusta, Georgia.
Address requests for reprints to Dr Franklin R. Tay, Department of Endodontics, School of Dentistry, Medical College of Georgia, Augusta, GA 30912-1129. E-mail address: ftay@mail.mcg.edu.

Removal of vital and necrotic remnants of pulp tissues, microorganisms, and microbial toxins from the root canal system is essential for endodontic success (1–3). Although this might be achieved through chemomechanical debridement (4–6), it is impossible to shape and clean the root canal completely (7–16) because of the intricate nature of root canal anatomy (17–19). Even with the use of rotary instrumentation (20), the nickel-titanium instruments currently available only act on the central body of the canal, leaving canal fins, isthmi, and cul-de-sacs untouched after completion of the preparation (9–11, 20–24). These areas might harbor tissue debris, microbes, and their by-products (17–19), which might prevent close adaptation of the obturation material (25–27) and result in persistent periradicular inflammation (28, 29). Therefore, irrigation is an essential part of root canal debridement because it allows for cleaning beyond what might be achieved by root canal instrumentation alone (8, 30). Ideal root canal irrigants should meet all the conditions described above for endodontic success (31). However, there is no one unique irrigant that can meet all these requirements, even with the use of methods such as lowering the pH (32–34), increasing the temperature (35–39), as well as addition of surfactants to increase the wetting efficacy of the irrigant (40, 41). Thus, in contemporary endodontic practice, dual irrigants such as sodium hypochlorite (NaOCl) with ethylenediaminetetraacetic acid (EDTA) or chlorhexidine (CHX) (42–44) are often used as initial and final rinses to complement the shortcomings that are associated with the use of a single irrigant. More importantly, these irrigants must be brought into direct contact with the entire canal wall surfaces for effective action (31, 42, 45), particularly for the apical portions of small root canals.

Throughout the history of endodontics, endeavors have continuously been made to develop more effective irrigant delivery and agitation systems for root canal irrigation. These systems might be divided into 2 broad categories, manual agitation techniques and machine-assisted agitation devices (Fig. 1). The objective of this review was to present an overview of contemporary irrigant agitation methods available in endodontics and to provide a critique of their debridement efficacy.

Manual Agitation Techniques
Syringe Irrigation with Needles/Cannulas

Conventional irrigation with syringes has been advocated as an efficient method of irrigant delivery before the advent of passive ultrasonic activation (46). This technique is still widely accepted by both general practitioners and endodontists. The technique involves dispensing of an irrigant into a canal through needles/cannulas of variable gauges, either passively or with agitation. The latter is achieved by moving the needle up and down the canal space. Some of these needles are designed to dispense an irrigant through their most distal ends, whereas others are designed to deliver an irrigant laterally through closed-ended, side-vented channels (47). The latter design has been proposed to improve the hydrodynamic activation of an irrigant and reduce the chance of apical extrusion (48). It is crucial that the needle/cannula should remain loose inside the canal during irrigation. This allows the irrigant to reflux and causes more debris to be displaced coronally, while avoiding the inadvertent expression of the irrigant into periapical tissues. One of the advantages of syringe irrigation is that it allows comparatively easy control of the depth of needle penetration within the canal and the volume of irrigant that is flushed through the canal (46).
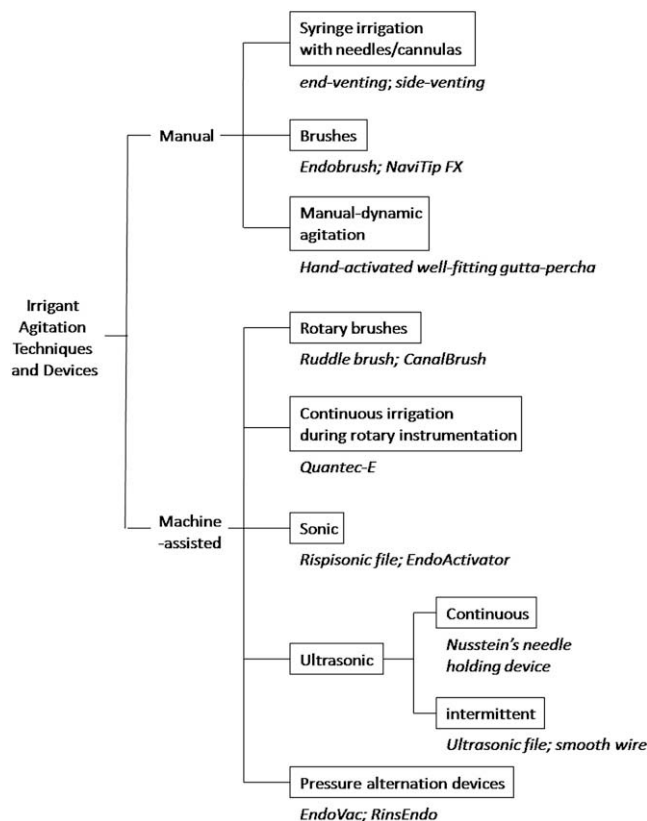
Review Article

Figure 1. Summary of the types of irrigation agitation techniques and devices available for use in endodontics.

Nevertheless, the mechanical flushing action created by conventional hand-held syringe needle irrigation is relatively weak. After conventional syringe needle irrigation, inaccessible canal extensions and irregularities are likely to harbor debris and bacteria, thereby making thorough canal debridement difficult (21, 49–51). A previous study has shown that when conventional syringe needle irrigation was used, the irrigating solution was delivered only 1 mm deeper than the tip of the needle (52). This is a disturbing issue because the needle tip is often located in the coronal third of a narrow canal or, at best, the middle third of a wide canal (53). The penetration depth of the irrigating solution and its ability to disinfect dentinal tubules are therefore limited. The efficacy of syringe needle irrigation in such canals has been challenged (54–56). A study evaluating the effectiveness of 3 kinds of EDTA salts and NaOCl delivered alternately by using a Monoject syringe with a 27-gauge needle reported that the debridement properties of the solutions were adequate in the coronal two thirds of the canals but were less effective in the apical third (57). Even after EDTA and NaOCl irrigation was performed with a specially developed side-vented, closed-end needle that was placed within 1 mm of the working length, abundant smear layer remained in the apical region of the root canals (58, 59). Indeed, the need for adequate enlargement of the root canal to improve irrigation efficacy was recognized by Grossman (60) as early as 1943. It has been reported that hand-held syringe needle irrigation is less effective when the canal is enlarged to less than size 40 at the apex (61, 62). The data from the study of Falk and Sedgley (62) further showed that the efficacy of irrigation was significantly reduced in canals prepared to size 36 compared with size 60, but with no advantage provided by further enlargement to size 77. Therefore, clinicians need to balance the need for optimizing the mechanical efficacy of irrigation via canal

enlargement with the negative consequences of inadvertent reduction in radicular dentin thickness and subsequent weakening of the root structure (63).

Factors that have been shown to improve the efficacy of syringe needle irrigation include closer proximity of the irrigation needle to the apex (53, 59, 64), larger irrigation volume (65), and smaller-gauge irrigation needles (53). Smaller-gauge needles/cannulas might be chosen to achieve deeper and more efficient irrigant replacement and debridement (46, 53, 64). However, the closer the needle tip is positioned to the apical tissue, the greater is the chance of apical extrusion of the irrigant (52, 53). Slow irrigant delivery in combination with continuous hand movement will minimize NaOCl accidents. With careful use, the benefits of deep intracanal irrigation should outweigh its risks (66). Moreover, irrigant flow rate and the exchange of irrigant should also be considered as factors directly influencing fluid flow beyond the needle/cannula (67). However, it is difficult to standardize and control the fluid flow rate during syringe needle irrigation (67). Thus, it would be advantageous to develop new application systems that increase dentin tubular penetration depths. This ensures more thorough debridement of the prepared canals, while minimizing apical extrusion to eliminate the cytotoxic effects of canal irrigants such as NaOCl on the periapical tissues (68, 69). The ultrasonic irrigation systems discussed subsequently in this review have the potential to achieve these goals (70, 71).

Brushes

Strictly speaking, brushes are not directly used for delivering an irrigant into the canal spaces. They are adjuncts that have been designed for debridement of the canal walls or agitation of root canal irrigant. They might also be indirectly involved with the transfer of irrigants within the canal spaces. Recently, a 30-gauge irrigation needle covered with a brush (NaviTip FX; Ultradent Products Inc, South Jordan, UT) was introduced commercially. A recent study reported improved cleanliness of the coronal third of instrumented root canal walls irrigated and agitated with the NaviTip FX needle over the brushless type of NaviTip needle (45). Nevertheless, the differences in the apical and middle thirds were not statistically significant. The results might have been improved if the brush-covered needle was mechanically activated in an active scrubbing action during the irrigation process to increase the efficiency of the brush (45). However, friction created between the brush bristles and the canal irregularities might result in the dislodgement of the radiolucent bristles in the canals that are not easily recognized by clinicians, even with the use of a surgical microscope.

During the early 1990s, similar findings indicating improved canal debridement with the use of canal brushes were reported by Keir et al (72). They used the Endobrush in an active brushing and rotary motion. The Endobrush (C&S Microinstruments Ltd, Markham, Ontario, Canada) is a spiral brush designed for endodontic use that consists of nylon bristles set in twisted wires with an attached handle and has a relatively constant diameter along the entire length. In that study, the brush was advanced to working length with a 90-degree rotary motion combined with a 2- to 3-mm push-pull motion for 1 minute at the conclusion of instrumentation. During debridement, the bristles of the brush were claimed to extend to the noninstrumented canal walls and into the fins, cul-de-sacs, and isthmi of the canal system to remove trapped tissue and debris. Indeed, the results in that study indicated that instrumentation with the Endobrush was significantly better than instrumentation alone in debriding the root canal (72). However, the Endobrush could not be used to full working length because of its size, which might lead to packing of debris into the apical section of the canal after brushing (72).

Manual-Dynamic Irrigation

An irrigant must be in direct contact with the canal walls for effective action. However, it is often difficult for the irrigant to reach the apical portion of the canal because of the so-called vapor lock effect (73, 74). Research has shown that gently moving a well-fitting gutta-percha master cone up and down in short 2- to 3-mm strokes (manual-dynamic irrigation) within an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent (75, 76). This was recently confirmed by the studies of McGill et al (77) and Huang et al (78). These studies demonstrated that manual-dynamic irrigation was significantly more effective than an automated-dynamic irrigation system (RinsEndo; Dürr Dental Co, Bietigheim-Bissingen, Germany) and static irrigation. Several factors could have contributed to the positive results of manual-dynamic irrigation (77): (1) the push-pull motion of a well-fitting gutta-percha point in the canal might generate higher intracanal pressure changes during pushing movements, leading to more effective delivery of irrigant to the "untouched" canal surfaces; (2) the frequency of push-pull motion of the gutta-percha point (3.3 Hz, 100 strokes per 30 seconds) is higher than the frequency (1.6 Hz) of positive-negative hydrodynamic pressure generated by RinsEndo, possibly generating more turbulence in the canal; and (3) the push-pull motion of the gutta-percha point probably acts by physically displacing, folding, and cutting of fluid under "viscously-dominated flow" (79) in the root canal system. The latter probably allows better mixing of the fresh unreacted solution with the spent, reacted irrigant.

Although manual-dynamic irrigation has been advocated as a method of canal irrigation as a result of its simplicity and cost-effectiveness, the laborious nature of this hand-activated procedure still hinders its application in routine clinical practice. Therefore, there are a number of automated devices designed for agitation of root canal irrigants that are either commercially available or under production by manufacturers.

Machine-assisted Agitation Systems
Rotary Brushes

A rotary handpiece–attached microbrush has been used by Ruddle (80) to facilitate debris and smear layer removal from instrumented root canals. The brush includes a shaft and a tapered brush section. The latter has multiple bristles extending radially from a central wire core. During the debridement phase, the microbrush rotates at about 300 rpm, causing the bristles to deform into the irregularities of the preparation. This helps to displace residual debris out of the canal in a coronal direction. However, this product has not been commercially available since the patent was approved in 2001.

CanalBrush (Coltene Whaledent, Langenau, Germany) is an endodontic microbrush that has recently been made commercially available. This highly flexible microbrush is molded entirely from polypropylene and might be used manually with a rotary action. However, it is more efficacious when attached to a contra-angle handpiece running at 600 rpm. A recent report by Weise et al (81) showed that the use of the small and flexible CanalBrush with an irrigant removed debris effectively from simulated canal extensions and irregularities.

Continuous Irrigation During Rotary Instrumentation

The Quantec-E irrigation system (SybronEndo, Orange, CA) is a self-contained fluid delivery unit that is attached to the Quantec-E Endo System. It uses a pump console, 2 irrigation reservoirs, and tubing to provide continuous irrigation during rotary instrumentation (82). Ideally, continuous irrigant agitation during active rotary instrumentation would generate an increased volume of irrigant, increase irrigant contact time, and facilitate greater depth of irrigant penetration inside the root canal. This should result in more effective canal debridement compared with syringe needle irrigation. These speculations, however, were not supported by the work of Setlock et al (83). Compared with needle irrigation, Quantec-E irrigation did result in cleaner canal walls and more complete debris and smear layer removal in the coronal third of the canal walls. However, these advantages were not observed in the middle and apical thirds of the root canal (83). This is also confirmed by Walters et al (82), who found that there was no significant difference between standard syringe needle irrigation and irrigation with the Quantec-E pump.

Sonic Irrigation
Frequency and Oscillating Pattern of Sonic Instrument

Tronstad et al (84) were the first to report the use of a sonic instrument for endodontics in 1985. Sonic irrigation is different from ultrasonic irrigation in that it operates at a lower frequency (1–6 kHz) and produces smaller shear stresses (85). The sonic energy also generates significantly higher amplitude or greater back-and-forth tip movement. Moreover, the oscillating patterns of the sonic devices are different compared with ultrasonically driven instruments. A minimum oscillation of the amplitude might be considered a node, whereas a maximum oscillation of the amplitude represents an antinode. They have 1 node near the attachment of the file and 1 antinode at the tip of the file (86). When the movement of the sonic file is constrained, the sideway oscillation disappears. This results in a pure longitudinal file oscillation. This mode of vibration has been shown to be particularly efficient for root canal debridement, because it is largely unaffected by loading and exhibits large displacement amplitudes (86).

Effect of Sonic Irrigation

Sonic activation has been shown to be an effective method for disinfecting root canals (87). Table 1 is a summary of the research articles on sonic irrigation from 1985–2008 (84, 88–95). Sabins et al (94) and Stamos et al (89) surmised that the more powerful ultrasonic systems removed more dentin debris from the root canal than the less powerful sonic irrigation systems. The positive relationship between acoustic streaming velocity and frequency might explain the superior efficiency of the ultrasonic systems over the sonic systems. In contrast to their findings, Jensen et al (93) found no significant difference in residual debris between these 2 endosonic agitation techniques. However, preshaping of the canals was not mentioned in the study by Jensen et al, which could have accounted for their findings. Another possibility is that the time for sonic irrigation has been set at 3 minutes in the study by Jensen et al, which is longer than the 30 or 60 seconds used in the studies by Sabins et al and Stomas et al. Thus, it is reasonable to assume that when sonic irrigation is applied for a longer time period, there will probably be no difference in the remaining debris between these 2 endosonic agitation techniques. This hypothesis has to be tested in future work.

Conventionally, sonic irrigation is performed by using a Rispisonic file attached to a MM 1500 sonic handpiece (Medidenta International, Inc, Woodside, NY) after canal shaping. The Rispisonic files have a nonuniform taper that increases with file size. Because they are barbed, these files might inadvertently engage the canal wall and damage the finished canal preparation during agitation. The EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) is a more recently introduced sonically driven canal irrigation system (95). It consists of a portable handpiece and 3 types of disposable polymer tips of different sizes. These tips are claimed to be strong and flexible and do not break easily. Because they are smooth, they do not cut dentin. The EndoActivator System was reported to be able to effectively clean debris from lateral canals, remove the smear layer, and dislodge

Review Article

TABLE 1. Research Articles on Sonic Irrigation, in Chronological Order

Year	Author (reference no.)	MAF	Irrigation instrument	Irrigation			Evaluation		Isthmus
				PSI	Time	Irrigant	Evaluation method	Evaluation criteria	
1985	Tronstad et al (84)	—	#20 K-file	No		2.5% NaOCl	SEM	Smear layer, dentin debris	No
1985	Barnett et al (88)	—	#20 K-file, #35 K-file	No		15% EDTA	—	—	No
1987	Stamos et al (89)	—	#25 K-file, #30 K-file	No	—	2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Reynolds et al (90)	—	#15, #20	No	—	Water	Histologic evaluation	Predentin and dentin debris	No
1989	Pugh et al (91)	—	—	No	2–3 min	Tap water	Injection with impression material and clearing	Canal morphology	No
1989	Walker and del Rio (92)	#25	#15, 20 Trisonic file, #15 Endostar file	No	80 s (Trisonic), 3 min (Endostar)	Tap water	Histologic evaluation	Debris	No
1999	Jensen et al (93)	#35/.10	#15 Rispisonic file	Yes	3 min	5.25% NaOCl	Stereomicroscopic evaluation	Dentin debris	No
2003	Sabins et al (94)	#35	#15 Rispisonic file	Yes	30 s, 60 s	5.25% NaOCl	Surgical operating microscope	Dentin debris	No
2008	Ruddle (95)	—	EndoActivator tips	Yes	—	—	—	—	—

MAF, master apical file; PSI, passive sonic irrigation; SEM, scanning electron microscopy.

clumps of simulated biofilm within the curved canals of molar teeth (76). During use, the action of the EndoActivator tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber. Vibrating the tip, in combination with moving the tip up and down in short vertical strokes, synergistically produces a powerful hydrodynamic phenomenon (96). In general, 10,000 cycles per minute (cpm) has been shown to optimize debridement and promote disruption of the smear layer and biofilm (76). A possible disadvantage of the polymer tips used in the EndoActivator system is that they are radiolucent. Although these tips are designed to be disposable and do not break easily during use, it would be difficult to identify them if part of a tip separates inside a canal. Presumably, these tips might be improved by incorporating a radiopacifier in the polymer.

Ultrasonics

Ultrasonic devices had long been used in periodontics before Richman (97) introduced ultrasound to endodontics as a means of canal debridement in 1957. In 1980, an ultrasonic unit designed by Martin et al (98) became commercially available for endodontic use. Compared with sonic energy, ultrasonic energy produces high frequencies but low amplitudes (99). The files are designed to oscillate at ultrasonic frequencies of 25–30 kHz, which are beyond the limit of human auditory perception (>20 kHz). They operate in a transverse vibration, setting up a characteristic pattern of nodes and antinodes along their length (99, 100). Table 2 is a summary of the research articles on ultrasonic irrigation from 1980–2008 (7, 16, 46, 54, 70, 71, 85, 89–94, 98, 101–145).

Two types of ultrasonic irrigation have been described in the literature. The first type is combination of simultaneous ultrasonic instrumentation and irrigation (UI). The second type, often referred to as passive ultrasonic irrigation (PUI), operates without simultaneous instrumentation. Studies on endosonic systems have shown that teeth prepared ultrasonically with UI devices have significantly cleaner canals than teeth prepared by conventional root canal filing alone (16, 89, 98, 103–105, 108, 112, 122, 127, 136, 137). Nevertheless, other studies have failed to demonstrate the superiority of UI as a primary cleaning and shaping technique (85, 90–92, 101, 110, 115–117, 126). These results might be attributed to the constraint of vibratory motion and cleaning efficacy of an ultrasonic file within the nonflared root canal space (85, 95). In addition, it is difficult to control the cutting of dentin during UI and hence the shape of the prepared root canal. Strip perforations as well as highly irregular-shaped canals were frequently produced (128, 146). Therefore, UI is not generally perceived as an alternative to conventional hand instrumentation (101, 125, 139, 147). On the contrary, the endodontic literature supports that it is more advantageous to apply ultrasonics after completion of canal preparation (31). All the ultrasonic irrigation discussed subsequently in this review will be referred to as PUI.

The term *PUI* was first used by Weller et al (101) to describe an irrigation scenario where there was no instrumentation, planing, or contact of the canal walls with an endodontic file or instrument (93). With this noncutting technology, the potential to create aberrant shapes within the root canal was reduced. During PUI, the energy is transmitted from an oscillating file or a smooth wire to the irrigant in the root canal by means of ultrasonic waves. The latter induces acoustic streaming and cavitation of the irrigant (85, 110, 115). The following section serves as a brief overview on PUI. The review by van der Sluis et al (100) provides a more detailed critique on this issue.

Irrigant Application Methods During PUI

Two flushing methods might be used during PUI, namely a continuous flush of irrigant from the ultrasonic handpiece or an intermittent

TABLE 2. Research Articles on Ultrasonic Irrigation, in Chronological Order

Year	Author (reference no.)	MAF	Irrigation					Evaluation		
			Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
1980	Martin et al (98)	#30	K-file	No	Intermittent	3 min	Tap water	Quantification of dentin-cutting efficiency	Weight loss of dental hard tissue	No
1980	Weller et al (101)	#30	#15 finger plugger	Yes/no	Intermittent	20 s	Distilled water	Radioactively labeled debris model	Radioactivity	No
1982	Cameron (102)	—	Smooth broach	Yes	Intermittent	—	3.0% NaOCl	—	—	—
1982	Cunningham et al (103)	#15	#10, #15 endodontic file	No	\—	—	2.5% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1982	Cunningham et al (16)	#15	#10, #15 endodontic file	No	—	—	2.5% NaOCl	SEM	Dentin debris	No
1982	Cunningham (104)	#25	—	No	Intermittent	3 min	Saline; NaOCl	Bacteriologic evaluation	CFUs	No
1982	Martin and Cunningham (105)	—	—	—	—	—	2.5% NaOCl	Patient's subjective evaluation, radiography	Presence of postoperative pain and a radiolucency	No
1983	Cameron (106)	—	Smooth wire	Yes	Intermittent	1, 3, 5 min	3% NaOCl	SEM	Smear layer	No
1983	Cymerman et al (107)	—	#30 K file	No	—	2 min	Sterile saline	SEM	Canal wall cleanliness	No
1985	Goodman et al (108)	#25–#30	#15 finger plugger	Yes	—	3 min	2.62% NaOCl	Histologic evaluation	Pulpal tissue, dentin debris	Yes
1986	Collinson and Zakariasen (109)	—	—	Yes/no	—	2, 4, 6 min	No	Bacteriologic evaluation (*S. sanguis*)	CFUs	—
1987	Ahmad et al (85)	—	#15–#45 endosonic files	No	—	—	Water, 2.5% NaOCl	SEM	Smear layer; dentin debris	No
1987	Ahmad et al (110)		I, #15–35 files; II, #15 file	I, No; II, yes		I, 4 min; II, 5 min	I, 2.5% NaOCl; II, 1.0% NaOCl	SEM	Smear layer; dentin debris	No
1987	Alacam (70)	#40	#15 file	Yes	Intermittent	3 min	5% NaOCl alone; 5% NaOCl + 3% H₂O; 17%EDTA; 2% glutaraldehyde; sterile saline	SEM	Smear layer	No
1987	Cameron (111)	#40–#50	Smooth broach	Yes	Intermittent	2 min	Distilled water; 0.5%, 1%, 2%, 4% NaOCl	SEM	Smear layer; dentin debris	No
1987	Lev et al (112)	#25–#30	#20 file	Yes	Continuous	1 min; 3 min	2.62% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Reynolds et al (90)	—	#15, #20, #25 files	No	—	—	Water; 2.6% NaOCl	Histologic evaluation	Predentin and dentin debris	No

(Continued)

TABLE 2. *Continued*

			Irrigation					Evaluation		
Year	Author (reference no.)	MAF	Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
1987	Stamos et al (89)	#25; #30	I, Zipperer K–files; II, endosonic files	No	—	—	Water; 2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Sjögren and Sundqvist (113)	—	#20 endosonic file	No	—	3 min	0.5% NaOCl	Bacteriologic evaluation	CFUs	No
1987	Teplitsky et al (114)	#10–40	#15 endosonic file	Yes	—	1 min	No	Radiopaque dye method	Dye penetration depth	No
1988	Ahmad et al (115)	#40	#15 file	Yes	—	5 min	2.5% NaOCl	SEM	Smear layer, dentin debris	No
1988	Baker et al (116)	—	#15, #20, #25 files	No	Intermittent	—	2.625% NaOCl	SEM	Canal wall cleanliness	No
1988	Goldman et al (117)	#25	#15, #20, #25 K-files; #25, #35, #45 endosonic diamond files	No	Continuous	—	5.25% NaOCl	Root canal silicone model; SEM	Canal morphology; dentin debris	No
1989	Ahmad et al (118)	—	#15 K-file	Yes	—	1 min; 5 min; 15 min	No (*E. intermedius* suspension)	Bacteriologic evaluation	CFUs	No
1989	Ciucchi et al (119)	#35	#20 ultrasonic file	Yes	Continuous	2 min	3% NaOCl; 15% EDTA	SEM	Smear layer	No
1989	DeNunzio et al (120)	#25	#15, #20, #25	No	Continuous	1 min/file	Sterile saline	Bacteriologic evaluation (*S. marcescens*)	CFUs	No
1989	Druttman and Stock (121)	#15, #20, #25	#15, #20, #25 endosonic files	—	—	—	Distilled water	1% toluene dye method	Degree of dye displacement	No
1989	Haidet et al (122)	#25 or #30	#20 endosonic file	No	—	3 min	2.5% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1989	Metzler et al. (123)	—	#15 endosonic file	Yes	—	2 min	2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1989	Pugh et al (91)	—	#15, #30 file	No	Continuous	1 min	Tap water	Injection with impression material and clearing	Canal morphology	No
1989	Walker and del Rio (92)	#25	#25 endosonic file; #15 Zipperer K-file	No	Continuous	1 min	Tap water	Histologic evaluation	Debris	No
1990	Ahmad et al (124)	—	#15 K-file	Yes	—	5 min	2.5% NaOCl	Bacteriologic evaluation	CFUs	No
1991	Abbott et al (125)	#45	#20 ultrasonic file with Cavi-Endo	Yes	Intermittent	4 min	Savlon solution*; 15% EDTAC and 1% NaOCl	SEM	Smear layer; dentin debris	No

(*Continued*)

TABLE 2. *Continued*

Review Article

Year	Author (reference no.)	MAF	Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
					Irrigation			Evaluation		
1991	Walker and del Rio (126)	#25	#15 endosonic file, #25 diamond file	No	Continuous	4 min (3 + 1)	Tap water; 2.6% NaOCl	Histologic evaluation	Canal wall planning and soft tissue debridement scores	No
1992	Archer et al (127)	#25/#30	#15 endosonic file	No	—	3 min	5.25% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1992	Lumley et al (128)	#25	#15, #20, #25 endosonic files	No	—	2 min	2.6% NaOCl	SEM	Smear layer; dentin debris	No
1993	Cheung and Stock (54)	#35	—	Yes	Continuous	2 min	Distilled water; 0.5% NaOCl; 1% NaOCl; biological washing liquid	SEM; stained-debris scoring	Smear layer; dentin debris	No
1993	Lumley et al (129)	#30	#15 endosonic file	No	—	2 min	Sterile water	SEM	Smear layer; dentin debris	No
1995	Cameron et al (71)	#35, #40, #45, #50	#15 endosonic file, #20 endosonic file, smooth broach	Yes	—	30 s; 1 min	Tap water; 4% NaOCl; EDTAC	SEM	Dentin debris	No
1997	Siqueira et al (130)	#50	#15 ultrasonic file	Yes	Intermittent	1 min	4.0% NaOCl; 4.0% NaOCl + 3% H_2O_2	Bacteriologic evaluation	Occurrence of broth turbidity	No
1998	Huque et al (131)	#40 or #60 K-file	# 15 file	Yes	Intermittent	20 s	0.5%, 2.5%, 5.5%, 12% NaOCl; 15% EDTA; sterile water	Bacteriologic evaluation	CFUs	No
1999	Jensen et al (93)	# 35/.10	# 15 ultrasonic file	Yes	Intermittent	3 min	5.25% NaOCl	Stereomicroscopic evaluation	Dentin debris	No
2002	Guerisoli et al (132)	—	#15 file	No	Continuous	1 min	1% NaOCl; 15% EDTAC	SEM	Smear layer	No
2002	Mayer et al (133)	#45/.04	#15 K-file; a noncutting nickel-titanium wire	—	—	—	5.25% NaOCl; 17% EDTA	SEM	Smear layer; dentin debris	No
2003	Sabins et al (94)	#35	#15 ultrasonic file	Yes	Intermittent	30 s; 60 s	5.25% NaOCl	Surgical operating microscope	Dentin debris	No
2003	Spoleti et al (134)	#35 or #50	#20 file	Yes	Intermittent	10 s	Sterile saline	Bacteriologic evaluation (S. aureus, S. viridans, E. coli)	CFUs	No

(*Continued*)

TABLE 2. *Continued*

Year	Author (reference no.)	MAF	Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
2003	Weber et al (135)	—	#20 file	Yes	Intermittent	1 min	2% CHX, 5.25% NaOCl	Bacteriologic evaluation (*S. sanguis*)	Zone of inhibition around agar	No
2004	Lee et al (136)	#20/.04; #20/.06; #20/.08	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole'model	Dentin debris	No
2004	Lee et al (137)	#50	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole'model	Dentin debris	No
2004	Gulabivala et al (138)	#30/.06	#20 ultrasonic file	Yes	Intermittent	—	Neutral anolyte; acidic anolyte; catholyte; catholyte alternated with neutral anolyte; 3% NaOCl; PBS	Bacteriologic evaluation	CFUs	No
2005	Gutarts et al (7)	#35/.12	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
2005	van der Sluis et al (139)	# 20/.08	#15 smooth file; #15 K file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2005	van der Sluis et al (140)	#20/.06, #20/.08, #20/.10	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2006	Passarinho-Neto et al (141)	#30/.04	#20 ultrasonic file	Yes	Intermittent	1 min; 3 min; 5 min	1.0% NaOCl	Histologic evaluation	Dentin debris	No
2006	van der Sluis et al (46)	#20/.10	#15/.02 smooth wire	Yes	Intermittent / continuous	3 min	Water; 2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2007	Carver et al (142)	#30/.04; #30/.06	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	CFUs	No
2007	Munley and Goodell (143)	#40/.04	#15 FlexoFile; a yellow finger spreader	Yes	Intermittent	1 min; 3 min	6.0% NaOCl	Dental operating microscope	Dentin debris	No
2007	Burleson et al (144)	#30	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	Bacterial biofilm and necrotic debris	Yes
2008	Ferreira et al (145)	#40/.02	#15 file	Yes	Intermittent	3 min	Water; 0.2% CHX; 2.5% NaOCl	Histologic evaluation	Dentin debris	No

CFU, colony-forming unit; CHX, chlorhexidine; EDTAC, ethylenediaminetetraacetic acid plus Cetavlon; MAF, master apical file; PUI, passive ultrasonic irrigation; SEM, scanning electron microscopy.

*Savlon solution (0.3% cetrimide and 0.03% chlorhexidine).

flush technique by using syringe delivery (148). In the intermittent flush technique, the irrigant is injected into the root canal by a syringe and replenished several times after each ultrasonic activation cycle. The amount of irrigant flowing through the apical region of the canal can be controlled because both the depth of syringe penetration and the volume of irrigant administered are known. This is not possible with the use of the continuous flush regime. Both flushing methods have been shown to be equally effective in removing dentin debris from the root canal in an *ex vivo* model when the irrigation time was set at 3 minutes (46).

Continuous Ultrasonic Irrigation

Chlorine, which is responsible for the dissolution of organic tissues and the antibacterial property of NaOCl (31), is unstable and is consumed rapidly during the first phase of tissue dissolution, probably within 2 minutes (149). Therefore, an improved delivery system that is capable of continuous replenishment of root canal irrigants is highly desirable. Recently, a needle-holding adapter to an ultrasonic handpiece has been developed by Nusstein (150). During ultrasonic activation, a 25-gauge irrigation needle is used instead of an endosonic file. This enables ultrasonic activation to be performed at the maximum power setting without causing needle breakage. The unique feature of this needle-holding adapter is that the needle is simultaneously activated by the ultrasonic handpiece, while an irrigant is delivered from an intravenous tubing connected via a Luer-lok to an irrigation-delivering syringe. The irrigant can thus be delivered apically through the needle under a continuous flow instead of being intermittently replenished from the coronal access opening, as reported in previous studies (108, 112, 122, 123, 127). The use of this continuous irrigation technology for final irrigation after hand/rotary instrumentation had been investigated *in vivo*. The data from these studies demonstrated that 1 minute of continuous ultrasonic irrigation produced significantly cleaner canals and isthmi in both vital and necrotic teeth (7, 144). It also resulted in a significantly greater reduction of colony-forming unit (CFU) counts in infected necrotic human molars (142). These positive results might be attributed to the delivery of fresh irrigating solution within the root canal. The technique also resulted in a reduction of the time required for ultrasonic irrigation (121, 141).

Intermittent Flush Ultrasonic Irrigation

In intermittent flushed ultrasonic irrigation, the irrigant is delivered to the root canal by a syringe needle. The irrigant is then activated with the use of an ultrasonically oscillating instrument. The root canal is then flushed with fresh irrigant to remove the dislodged or dissolved remnants from the canal walls. Because most of the previous studies evaluated the effectiveness of ultrasonic irrigation by using the intermittent flush technique, the efficacy of this technique in removing pulpal tissues, dentin debris, smear layers, and bacteria from the root canal system will be briefly described.

Removal of Pulpal Tissues and Dentin Debris

There is a general consensus that PUI is more effective than syringe needle irrigation in removing pulpal tissue remnants and dentin debris (94, 108, 111, 123, 136). This might be due to the much higher velocity and volume of irrigant flow that are created in the canal during ultrasonic irrigation (137). It has been shown that large amounts of dentin debris remain in canal irregularities and oval-shaped canals after syringe irrigation (21, 29, 103, 108). During ultrasonic irrigation, oscillation of the file adjacent to canal irregularities might also have removed more debris from these hard-to-reach locations (129, 137). Nevertheless, Mayer et al (133) reported no significant difference in the extent of dentin debris

removal between PUI and syringe irrigation. In that study, EDTA was left in the root canal before ultrasonic activation of the subsequently introduced NaOCl. Removal of EDTA before the delivery of NaOCl was not mentioned, which could have been responsible for the authors' findings. When compared with sonic irrigation, the more powerful ultrasonic irrigation technique has been shown to be capable of removing more debris (94). However, it is possible that both techniques might produce similar degrees of canal cleanliness when sonic irrigation is applied for a longer time period (93, 136, 137).

Removal of Smear Layers

A large body of evidence has been accumulated indicating that PUI with water as an irrigant did not remove the smear layer (55, 106, 111, 131). When PUI was used with 3% NaOCl, complete removal of smear layer was reported by Cameron (106, 111). These results were confirmed in subsequent studies by Alacam (70) and Huque et al (131) with different concentrations of NaOCl. Guerisoli et al (132) reported that smear layers were effectively removed from the apical, middle, and cervical thirds of the canal walls by ethylenediaminetetraacetic acid plus Cetavlon (EDTAC) and NaOCl by using a size 15 file energized by ultrasonic agitation. Other studies reported conflicting results on the increased efficacy of ultrasonic irrigation on smear layer removal. Although PUI was shown to be significantly better than syringe needle irrigation, Cheung and Stock (54) could not completely remove the smear layer by using PUI with 1% NaOCl for 10 seconds. Other studies (71, 119, 125) also demonstrated that PUI with EDTA or a combination of EDTA and NaOCl did not completely remove smear layers from the apical third of the canal walls.

Removal of Bacteria

Numerous investigations have demonstrated that the use of PUI after hand or rotary instrumentation resulted in a significant reduction of the number of bacteria (16, 98, 103, 104, 109, 113, 118, 120, 130, 134, 135) or achieved significantly better results than syringe needle irrigation (131, 134, 135). These positive results with the use of PUI might be attributed to 2 main factors. (1) High-power ultrasound causes de-agglomeration of bacterial biofilms via the action of acoustic streaming. De-agglomeration of biofilms within a root canal might render the resultant planktonic bacteria more susceptible to the bactericidal activity of NaOCl (151). (2) Cavitation might have produced temporary weakening of the cell membrane, making the bacteria more permeable to NaOCl.

Pressure Alternation Devices

There are 2 apparently dilemmatic phenomena associated with conventional syringe needle delivery of irrigants. It is desirable for the irrigants to be in direct contact with canal walls for effective debris debridement and smear layer removal. Yet, it is difficult for these irrigants to reach the apical portions of the canals because of air entrapment (152), when the needle tips are placed too far away from the apical end of the canals. Conversely, if the needle tips are positioned too close to the apical foramen, there is an increased possibility of irrigant extrusion from the foramen that might result in severe iatrogenic damage to the periapical tissues (153). Concomitant irrigant delivery and aspiration via the use of pressure alternation devices provide a plausible solution to this problem.

Early Experimental Protocols

The first experimental use of a pressure alternation irrigation technique was the non-instrumentation technology (NIT) invented by Lussi et al (154). This technique did not enlarge root canals because there

Review Article

was no mechanical instrumentation of the canal walls. Instead, canal debridement and dissolution of organic debris, including the predentin collagen matrix, were achieved solely with the use of low concentration NaOCl that was introduced to and removed from the canal by using alternating, subambient pressure fields. The latter created bubble implosion and hydrodynamic turbulence that facilitated penetration of the NaOCl into the canal ramifications. Although NIT was unique and successful *in vitro* (155, 156) in creating cleaning canals when compared with conventional syringe needle irrigation with either balanced force hand instrumentation or GT Rotary (Tulsa Dental) instrumentation, the technique was not considered safe in *in vivo* animal studies and did not proceed to human clinical trials. Nevertheless, the reduced-pressure sealer obturation protocol originally designed to support the filling of noninstrumented canals was subsequently evaluated *in vivo* for filling instrumented canals with different gutta-percha–sealer combinations (157). Clinical root canal obturations performed by using the reduced-pressure sealer obturation protocol demonstrated radiographic qualities that were equivalent to those filled with conventional filling techniques (158).

Another experimental pressure alternation irrigation system was introduced by Fukumoto et al (159). This system comprised an injection needle (external diameter, 0.41 mm; internal diameter, 0.19 mm; Nipro Co, Osaka, Japan) and an aspiration needle (external diameter, 0.55 mm; internal diameter, 0.30 mm; Terumo Co, Tokyo, Japan) connected to an apex locator (Root ZX; J Morita USA, Inc, Irvine, CA). The aspiration pressure of the unit was maintained at –20 kPa. The device was evaluated by using different placement positions of the injection needle and the aspiration needle for the efficacy of smear layer removal from the apical third of the canal walls and the frequency of extrusion of NaOCl from the apical foramen. The most reliable results were achieved when NaOCl was introduced by using a coronally placed injection needle and aspirated via placement of the aspiration needle at 2 mm from the apex. Of particular importance was that when the aspiration needle was placed either 2 or 3 mm from the apical end of the root, the Root ZX readings registered a value of 0.5, indicating that the irrigant had reached the instrumented end of the apical delta. The authors surmised that the discrepancy between the physical location of the aspiration needle and the Root ZX reading could be explained by the NaOCl and EDTA irrigants displacing air trapped between the tip of the aspirating needle and the root end.

Vapor Lock Effect

Air entrapment by an advancing liquid front in closed-end microchannels is a well-recognized physical phenomenon (160–163). The ability of a liquid to penetrate these closed-end channels is dependent on the contact angle of the liquid and the depth and size of the channel (73). Under all circumstances, these closed-end microchannels will eventually be flooded after sufficient time (hours to days) (73). This phenomenon of air entrapment and the time frame in which complete flooding occurs has practical clinical implications when irrigants are delivered by using syringe needles from the coronal or middle third of a root canal. Because endodontic irrigation is performed within a time frame of minutes instead of hours or days, air entrapment in the apical portion of the canal might preclude this region from contact or disinfection by the irrigant.

The aforementioned physical phenomenon has been referred to as the vapor lock effect in the endodontic literature. In the classic study by Senia et al (152), they demonstrated that NaOCl did not extend any closer than 3 mm from working length, even after the root apex was enlarged to a size 30. This might be attributed to the fact that NaOCl reacts with organic material in the root canal and quickly forms micro

gas bubbles at the apical termination that coalesce into an apical vapor lock with subsequent instrumentation (74). Because the apical vapor lock cannot be displaced within a clinically relevant time frame through simple mechanical actions, it prevents further irrigants from flowing into the apical region. More importantly, acoustic microstreaming and cavitation can only occur in a liquid phase. Therefore, once a sonic or ultrasonically activated tip leaves the irrigant and enters the apical vapor lock, acoustic microstreaming and/or cavitation becomes physically impossible (74).

A simple method to disrupt the vapor lock might be achieved via the use of a hand-activated well-fitting root filling material (77, 78) (eg, a size 40, 0.06 taper gutta-percha point) that is introduced to working length after instrumentation with the corresponding nickel-titanium rotary instrument (ie, size 40, 0.06 taper). This method, although cumbersome, eliminates the vapor lock because the space previously occupied by air is replaced by the root filling material, carrying with it a film of irrigant to the working length.

The EndoVac System

In the EndoVac system (Discus Dental, Culver City, CA), a macrocannula or microcannula is connected via tubing to a syringe of irrigant and the high-speed suction of a dental unit (74). The plastic macrocannula has a size 55 open end with a .02 taper and is attached to a titanium handle for gross, initial flushing of the coronal part of the root canal. The size 32 stainless steel microcannula has 4 sets of 3 laser-cut, laterally positioned, offset holes adjacent to its closed end. This is attached to a titanium finger-piece for irrigation of the apical part of the canal by positioning it at the working length. The microcannula can be used in canals that are enlarged to size 35 or larger. During irrigation, the delivery/evacuation tip delivers irrigant to the pulp chamber and siphons off the excess irrigant to prevent overflow. The cannula in the canal simultaneously exerts negative pressure that pulls irrigant from its fresh supply in the chamber, down the canal to the tip of the cannula, into the cannula, and out through the suction hose. Thus, a constant flow of fresh irrigant is being delivered by negative pressure to working length. A recent study showed that 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 (164). This study also supported that the use of the EndoVac system resulted in significantly more debris removal at 1 mm from the working length than needle irrigation. Because the device is new, no clinical study is available yet on its clinical debridement efficacy. Although the device is promoted rather vigorously (74, 165, 166), it is not known whether the adjunctive use of such a device increases treatment outcomes that use stringent evaluation criteria for either initial treatment (167–169) or retreatment of persistent endodontic infections (170, 171).

Apart from being able to avoid air entrapment, the EndoVac system is also advantageous in its ability to safely deliver irrigants to working length without causing their undue extrusion into the periapex (164). During conventional root canal irrigation, clinicians must be careful in determining how far an irrigation needle is placed into the canal. Recommendations for avoiding NaOCl accidents include not binding the needle in the canal, not placing the needle close to working length, and using a gentle flow rate (153). With the EndoVac, irrigant is pulled into the canal at working length and removed by negative pressure.

The RinsEndo System

The RinsEndo system (Dürr Dental Co) is another root canal irrigation device that is based on pressure-suction technology (48, 77). With this system, 65 μL of a rinsing solution oscillating at a frequency

of 1.6 Hz is drawn from an attached syringe and transported to the root canal via an adapted cannula. During the suction phase, the used solution and air are extracted from the root canal and automatically merged with fresh rinsing solution. The pressure-suction cycles change approximately 100 times per minute.

The manufacturer of RinsEndo claims that the apical third of the canal might be effectively rinsed, with the cannula restricted to the coronal third of the root canal because of the pulsating nature of the fluid flow. This system has been shown in an extracted tooth model to be superior to conventional static irrigation in dentin penetration of a dye marker; however, a higher risk of apical extrusion of the irrigant was also observed (48). The effectiveness of the RinsEndo system in cleaning canal walls was more recently challenged by McGill et al (77). In view of the difficulty in the generation of realistic and standardized multispecies biofilm in extracted teeth, they used a split-tooth model containing stained solubilized collagen to simulate a bacterial biofilm along the canal walls. Within any limitations imposed by the model, RinsEndo was found to be less effective in removing the stained collagen from root canal walls when compared with manual-dynamic irrigation by hand agitation of the instrumented canals with well-fitting gutta-percha points. Similar to the EndoVac system, there is no clinical study available to date supporting either the clinical debridement efficacy or improvements in treatment outcomes that are associated with the use of the RinsEndo system.

Concluding Remarks and Directions for Future Research

Effective irrigant delivery and agitation are prerequisites for successful endodontic treatment. This article presents an overview of the irrigant agitation methods currently available and their debridement efficacy. Technological advances during the last decade have brought to fruition new agitation devices that rely on various mechanisms of irrigant transfer, soft tissue debridement, and, depending on treatment philosophy, removal of smear layers. These devices might be divided into the manual and machine-assisted agitation systems. Overall, they appeared to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation.

To date, the existing literature on microbial mass reduction after root canal irrigation (104, 109, 113, 120, 134) encompassed the use of CFU counts of planktonic bacteria culture as the gold standard method for evaluating disinfection efficacy. However, numerous *in vitro* studies have demonstrated the ability of multiple bacteria to form a biofilm architecture on root canal walls (172–175). With the advent of the biofilm concept, the increased resistance of bacterial strains in biofilms, compared with their planktonic, "free-floating" counterparts (176–178), raises concerns on the validity of laboratory studies that reported their results on the basis of liquid-grown cultures. Such an issue has been further elaborated recently by Ehrlich et al (179). They introduced the concept of bacteria plurality in an attempt to account for the chronicity of biofilm-related infections and the difficulty in eradicating such chronic infections by antibiotic therapy (179). One of the most important conceptual parameters to understanding bacterial persistence is the realization of phenotypic diversity within an infecting population of bacteria. Bacterial plurality also embodies the concept of genotypic diversity that includes 2 separate phenomena, namely genetic heterogeneity and genomic plasticity (179). These heterogeneities can provide the "primitive" biofilm community with great capacity to withstand challenges from host defense systems or from pharmaceuticals (179). The bacteria plurality concept helps to explain the chronicity of biofilm infections in endodontics. During the past few years, more and more *ex vivo* biofilm models that were grown in wells (180–183) or on

root dentin (43, 172, 174) by using single (138, 183, 184) or multiple (185) bacteria species have been developed and used in dentistry (180–184, 186–188). However, the potential of biofilm experimentation in endodontics has not been fully exploited. The Zürich biofilm model (180), for example, is a well-developed oral biofilm model. However, it is dubious whether this supragingival plaque model might be applicable to the anaerobic ecological niches within the root canal space (173). Although the importance of developing standardized intracanal microbial biofilm models for endodontic experiments has been well-recognized, no study has yet been published on the validity of single species versus dual or multiple endodontic biofilm models. Thus, future studies involving the efficacy of selected irrigation regimens on bacteria eradication should be oriented to include clinically relevant endodontic bacterial biofilm models.

Despite the plethora of studies on the effectiveness of various endodontic irrigation regimens, it is noteworthy that no well-controlled clinical study is available in the current endodontic literature. This raises imperative concerns on the need for studies in endodontic science that could more effectively measure the efficiency of specific agitation methods for root canal irrigation with the use of standardized dentin debris or microbial biofilm models. Development of such an approach will not only boost the importance of reviewing the current literature but will serve as an inspiring guide for future investigations on endodontic debridement. In addition, from a practical point of view, no evidence-based study is available to date that attempts to correlate the clinical efficacy of these devices with improved treatment outcomes. Thus, the question of whether these devices are really necessary remains unresolved. There is a need to determine from a practice management perspective how these devices are perceived in terms of their practicality and ease of use. Understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems.

References

1. Siqueira JF Jr, Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. J Endod 2008;34:1291–301.
2. Wong R. Conventional endodontic failure and retreatment. Dent Clin North Am 2004;48:265–89.
3. Basmadjian-Charles CL, Farge P, Bourgeois DM, Lebrun T. Factors influencing the long-term results of endodontic treatment: a review of the literature. Int Dent J 2002;52:81–6.
4. Sjögren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16:498–504.
5. European Society of Endodontology. Consensus report of the European Society of Endodontology on quality guidelines for endodontic treatment. Int Endod J 1994;27:115–24.
6. Peters OA, Koka RS. Preparation of coronal and radicular spaces. In: Ingle JI, Bakland LK, Baumgartner JC, eds. Endodontics. 6th ed. Hamilton: Canada: BC Decker Inc; 2008:877–991.
7. Gutarts R, Nusstein J, Reader A, Beck M. In vivo debridement efficacy of ultrasonic irrigation following hand-rotary instrumentation in human mandibular molars. J Endod 2005;31:166–70.
8. Svec TA, Harrison JW. Chemomechanical removal of pulpal and dentinal debris with sodium hypochlorite and hydrogen peroxide vs normal saline solution. J Endod 1977;3:49–53.
9. Walton RE. Histologic evaluation of different methods of enlarging the pulp canal space. J Endod 1976;2:304–11.
10. Haga CS. Microscopic measurements of root canal preparations following instrumentation. J Br Endod Soc 1968;2:41–6.
11. Gutierrez JH, Garcia J. Microscopic and macroscopic investigation on results of mechanical preparation of root canals. Oral Surg Oral Med Oral Pathol 1968;25:108–16.

12. Shuping GB, Østravik D, Sigurdsson A, Trope M. Reduction of intracanal bacteria using nickel-titanium rotary instrumentation and various medications. J Endod 2000;26:751–5.

13. Card SJ, Sigurdsson A, Østravik D, Trope M. The effectiveness of increased apical enlargement in reducing intracanal bacteria. J Endod 2002;28:779–83.

14. Fariniuk LF, Baratto-Filho F, da Cruz-Filho AM, de Sousa-Neto MD. Histologic analysis of the cleaning capacity of mechanical endodontic instruments activated by the ENDOflash system. J Endod 2003;29:651–3.

15. Ferreira RB, Alfredo E, Porto de Arruda M, Silva Sousa YT, Sousa-Neto MD. Histological analysis of the cleaning capacity of nickel-titanium rotary instrumentation with ultrasonic irrigation in root canals. Aust Endod J 2004;30:56–8.

16. Cunningham WT, Martin H. A scanning electron microscope evaluation of root canal debridement with the endosonic ultrasonic synergistic system. Oral Surg Oral Med Oral Pathol 1982;53:527–31.

17. Hess W. The anatomy of the root-canals of the teeth of the permanent dentition: part I. New York: William Wood & Co; 1925. 1–47.

18. Skidmore AE, Bjorndal AM. Root canal morphology of the human mandibular first molar. Oral Surg Oral Med Oral Pathol 1971;32:778–84.

19. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 1984;58:589–99.

20. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–67.

21. Wu MK, Wesselink PR. A primary observation on the preparation and obturation of oval canals. Int Endod J 2001;34:137–41.

22. Schäfer E, Zapke K. A comparative scanning electron microscopic investigation of the efficacy of manual and automated instrumentation of root canals. J Endod 2000;26:660–4.

23. Tan BT, Messer HH. The quality of apical canal preparation using hand and rotary instruments with specific criteria for enlargement based on initial apical file size. J Endod 2002;28:658–64.

24. Wu MK, van der Sluis LW, Wesselink PR. The capability of two hand instrumentation techniques to remove the inner layer of dentine in oval canals. Int Endod J 2003;36:218–24.

25. Wollard RR, Brough SO, Maggio J, Seltzer S. Scanning electron microscopic examination of root canal filling materials. J Endod 1976;2:98–110.

26. Ardila CN, Wu MK, Wesselink PR. Percentage of filled canal area in mandibular molars after conventional root-canal instrumentation and after a noninstrumentation technique (NIT). Int Endod J 2003;36:591–8.

27. Wu MK, van der Sluis LW, Wesselink PR. A preliminary study of the percentage of gutta-percha-filled area in the apical canal filled with vertically compacted warm gutta-percha. Int Endod J 2002;35:527–35.

28. Naidorf IJ. Clinical microbiology in endodontics. Dent Clin North Am 1974;18: 329–44.

29. Wu MK, de Schwartz FB, van der Sluis LW, Wesselink PR. The quality of root fillings remaining in mandibular incisors after root-end cavity preparation. Int Endod J 2001;34:613–9.

30. Gulabivala K, Patel B, Evans G, Ng YL. Effects of mechanical and chemical procedures on root canal surfaces. Endodontic Topics 2005;10:103–22.

31. Zehnder M. Root canal irrigants. J Endod 2006;32:389–98.

32. Cotter JL, Fader RC, Lilley C, Herndon DN. Chemical parameters, antimicrobial activities, and tissue toxicity of 0.1 and 0.5% sodium hypochlorite solutions. Antimicrob Agents Chemother 1985;28:118–22.

33. Christensen CE, McNeal SF, Eleazer P. Effect of lowering the pH of sodium hypochlorite on dissolving tissue in vitro. J Endod 2008;34:449–52.

34. Bloomfield SF, Miles G. The relationship between residual chlorine and disinfection capacity of sodium hypochlorite and sodium dichlorisocyanurate solutions in the presence of E. coli and milk. Microbios 1979;10:33–43.

35. Sirtes G, Waltimo T, Schaetzle M, Zehnder M. The effects of temperature on sodium hypochlorite short-term stability, pulp dissolution capacity, and antimicrobial efficacy. J Endod 2005;31:669–71.

36. Abou-Rass M, Oglesby SW. The effects of temperature, concentration, and tissue type on the solvent ability of sodium hypochlorite. J Endod 1981;7:376–7.

37. Cunningham WT, Joseph SW. Effect of temperature on the bactericidal action of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol 1980; 50:569–71.

38. Cunningham WT, Balekjian AY. Effect of temperature on collagen-dissolving ability of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol 1980; 49:175–7.

39. Kamburis JJ, Barker TH, Barfield RD, Eleazer PD. Removal of organic debris from bovine dentin shavings. J Endod 2003;29:559–61.

40. Lui JN, Kuah HG, Chen NN. Effect of EDTA with and without surfactants or ultrasonics on removal of smear layer. J Endod 2007;33:472–5.

41. Giardino L, Ambu E, Becce C, Rimondini L, Morra M. Surface tension comparison of four common root canal irrigants and two new irrigants containing antibiotic. J Endod 2006;32:1091–3.

42. Grande NM, Plotino G, Falanga A, Pomponi M, Somma F. Interaction between EDTA and sodium hypochlorite: a nuclear magnetic resonance analysis. J Endod 2006;32: 460–4.

43. Kishen A, Sum CP, Mathew S, Lim CT. Influence of irrigation regimens on the adherence of Enterococcus faecalis to root canal dentin. J Endod 2008;34:850–4.

44. Ringel AM, Patterson SS, Newton CW, Miller CH, Mulhern JM. In vivo evaluation of chlorhexidine gluconate solution and sodium hypochlorite solution as root canal irrigants. J Endod 1982;8:200–4.

45. Al-Hadlaq SM, Al-Turaiki SA, Al-Sulami U, Saad AY. Efficacy of a new brush-covered irrigation needle in removing root canal debris: a scanning electron microscopic study. J Endod 2006;32:1181–4.

46. van der Sluis LW, Gambarini G, Wu MK, Wesselink PR. The influence of volume, type of irrigant and flushing method on removing artificially placed dentine debris from the apical root canal during passive ultrasonic irrigation. Int Endod J 2006;39: 472–6.

47. Kahn FH, Rosenberg PA, Gliksberg J. An in vitro evaluation of the irrigating characteristics of ultrasonic and subsonic handpieces and irrigating needles and probes. J Endod 1995;21:277–80.

48. Hauser V, Braun A, Frentzen M. Penetration depth of a dye marker into dentine using a novel hydrodynamic system (RinsEndo). Int Endod J 2007;40:644–52.

49. Nair PN, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after "one-visit" endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005; 99:231–52.

50. Wu MK, Wesselink PR. A primary observation on the preparation and obturation in oval canals. Int Endod J 2001;34:137–41.

51. Wu MK, Dummer PM, Wesselink PR. Consequences of and strategies to deal with residual post-treatment root canal infection. Int Endod J 2006;39:343–56.

52. Ram Z. Effectiveness of root canal irrigation. Oral Surg Oral Med Oral Pathol 1977; 44:306–12.

53. Chow TW. Mechanical effectiveness of root canal irrigation. J Endod 1983;9:475–9.

54. Cheung GS, Stock CJ. In vitro cleaning ability of root canal irrigants with and without endosonics. Int Endod J 1993;26:334–43.

55. Heard F, Walton RE. Scanning electron microscope study comparing four root canal preparation techniques in small curved canals. Int Endod J 1997;30:323–31.

56. Langeland K, Liao K, Pascon EA. Work-saving devices in endodontics: efficacy of sonic and ultrasonic techniques. J Endod 1985;11:499–510.

57. O'Connell MS, Morgan LA, Beeler WJ, Baumgartner JC. A comparative study of smear layer removal using different salts of EDTA. J Endod 2000;26:739–43.

58. Yamada RS, Armas A, Goldman M, Lin PS. A scanning electron microscopic comparison of a high volume final flush with several irrigating solutions: part 3. J Endod 1983;9:137–42.

59. Goldman M, Kronman JH, Goldman LB, Clausen H, Grady J. New method of irrigation during endodontic treatment. J Endod 1976;2:257–60.

60. Grossman LI. Irrigation of root canals. J Am Dent Assoc 1943;30:1915–7.

61. Wu MK, Wesselink PR. Efficacy of three techniques in cleaning the apical portion of curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79: 492–6.

62. Falk KW, Sedgley CM. The influence of preparation size on the mechanical efficacy of root canal irrigation in vitro. J Endod 2005;31:742–5.

63. Lertchirakarn V, Palamara JE, Messer HH. Patterns of vertical root fracture: factors affecting stress distribution in the root canal. J Endod 2003;29:523–8.

64. Sedgley CM, Nagel AC, Hall D, Applegate B. Influence of irrigant needle depth in removing bioluminescent bacteria inoculated into instrumented root canals using real-time imaging in vitro. Int Endod J 2005;38:97–104.

65. Sedgley C, Applegate B, Nagel A, Hall D. Real-time imaging and quantification of bioluminescent bacteria in root canals in vitro. J Endod 2004;30:893–8.

66. Abou-Rass M, Piccinino MV. The effectiveness of four clinical irrigation methods on the removal of root canal debris. Oral Surg Oral Med Oral Pathol 1982;54: 323–8.

67. Boutsioukis C, Lambrianidis T, Kastrinakis E, Bekiaroglou P. Measurement of pressure and flow rates during irrigation of a root canal ex vivo with three endodontic needles. Int Endod J 2007;40:504–13.

68. Bradford CE, Eleazer PD, Downs KE, Scheetz JP. Apical pressures developed by needles for canal irrigation. J Endod 2002;28:333–5.

69. Serper A, Ozbek M, Calt S. Accidental sodium hypochlorite-induced skin injury during endodontic treatment. J Endod 2004;30:180–1.

70. Alacam T. Scanning electron microscope study comparing the efficacy of endodontic irrigating systems. Int Endod J 1987;20:287–94.

71. Cameron JA. Factors affecting the clinical efficiency of ultrasonic endodontics: a scanning electron microscopy study. Int Endod J 1995;28:47–53.

72. Keir DM, Senia ES, Montgomery S. Effectiveness of a brush in removing postinstrumentation canal debris. J Endod 1990;16:323–7.

73. Pesse AV, Warrier GR, Dhir VK. An experimental study of the gas entrapment process in closed-end microchannels. Int J Heat Mass Transfer 2005;48:5150–65.

74. Schoeffel GJ. The EndoVac method of endodontic irrigation: part 2—efficacy. Dent Today 2008;27:82,84,86–87.

75. Machtou P. Irrigation investigation in endodontics. Paris VII University, Paris, France: Masters thesis; 1980.

76. Caron G. Cleaning efficiency of the apical millimeters of curved canals using three different modalities of irrigant activation: an SEM study. Paris VII University, Paris, France: Masters thesis; 2007.

77. McGill S, Gulabivala K, Mordan N, Ng YL. The efficacy of dynamic irrigation using a commercially available system (RinsEndo) determined by removal of a collagen 'bio-molecular film' from an ex vivo model. Int Endod J 2008;41:602–8.

78. Huang TY, Gulabivala K, Ng Y-L. A bio-molecular film ex-vivo model to evaluate the influence of canal dimensions and irrigation variables on the efficacy of irrigation. Int Endod J 2008;41:60–71.

79. Wiggins S, Ottino JM. Foundations of chaotic mixing. Philos Transact A Math Phys Eng Sci 2004;362:937–70.

80. Ruddle CJ. Microbrush for endodontic use. Washington, DC: United States Patent 6,179,617; 2001.

81. Weise M, Roggendorf MJ, Ebert J, Petschelt A, Frankenberger R. Four methods for cleaning simulated lateral extensions of curved root canals: a SEM evaluation. Int Endod J 2007;40:991–2.

82. Walters MJ, Baumgartner JC, Marshall JG. Efficacy of irrigation with rotary instrumentation. J Endod 2002;28:837–9.

83. Setlock J, Fayad MI, BeGole E, Bruzick M. Evaluation of canal cleanliness and smear layer removal after the use of the Quantec-E irrigation system and syringe: a comparative scanning electron microscope study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:614–7.

84. Tronstad L, Barnett F, Schwartzben L, Frasca P. Effectiveness and safety of a sonic vibratory endodontic instrument. Endod Dent Traumatol 1985;1:69–76.

85. Ahmad M, Pitt Ford TR, Crum LA. Ultrasonic debridement of root canals: an insight into the mechanisms involved. J Endod 1987;13:93–101.

86. Walmsley AD, Lumley PJ, Laird WR. Oscillatory pattern of sonically powered endodontic files. Int Endod J 1989;22:125–32.

87. Pitt WG. Removal of oral biofilm by sonic phenomena. Am J Dent 2005;18:345–52.

88. Barnett F, Godick R, Tronstad L. Clinical suitability of a sonic vibratory endodontic instrument. Endod Dent Traumatol 1985;1:77–81.

89. Stamos DE, Sadeghi EM, Haasch GC, Gerstein H. An in vitro comparison study to quantitate the debridement ability of hand, sonic, and ultrasonic instrumentation. J Endod 1987;13:434–40.

90. Reynolds MA, Madison S, Walton RE, Krell KV, Rittman BR. An in vitro histological comparison of the step-back, sonic and ultrasonic instrumentation techniques in small, curved root canals. J Endod 1987;13:307–14.

91. Pugh RJ, Goerig AC, Glaser CG, Luciano WJ. A comparison of four endodontic vibratory systems. Gen Dent 1989;37:296–301.

92. Walker TL, del Rio CE. Histological evaluation of ultrasonic and sonic instrumentation of curved root canals. J Endod 1989;15:49–59.

93. Jensen SA, Walker TL, Hutter JW, Nicoll BK. Comparison of the cleaning efficacy of passive sonic activation and passive ultrasonic activation after hand instrumentation in molar root canals. J Endod 1999;25:735–8.

94. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003;29:674–8.

95. Ruddle CJ. Endodontic disinfection: tsunami irrigation. Endod Practice 2008. Feb:7–15.

96. Ruddle CJ. Cleaning and shaping the root canal system. In: Cohen S, Burns RC, eds. Pathways of the pulp. 8th ed. St Louis: Mosby, Inc; 2002:231–91.

97. Richman MJ. The use of ultrasonics in root canal therapy and root resection. J Med 1957;12:12–8.

98. Martin H, Cunningham WT, Norris JP, Cotton WR. Ultrasonic versus hand filing of dentin: a quantitative study. Oral Surg Oral Med Oral Pathol 1980;49:79–81.

99. Walmsley AD, Williams AR. Effects of constraint on the oscillatory pattern of endosonic files. J Endod 1989;15:189–94.

100. van der Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. Int Endod J 2007;40:415–26.

101. Weller RN, Brady JM, Bernier WE. Efficacy of ultrasonic cleaning. J Endod 1980;6:740–3.

102. Cameron JA. The use of ultrasound in the cleaning of root canals: a clinical report. J Endod 1982;8:472–4.

103. Cunningham WT, Martin H, Forrest WR. Evaluation of root canal debridement by the endosonic ultrasonic synergistic system. Oral Surg Oral Med Oral Pathol 1982;53:401–4.

104. Cunningham WT, Martin H, Pelleu GB Jr., Stoops DE. A comparison of antimicrobial effectiveness of endosonic and hand root canal therapy. Oral Surg Oral Med Oral Pathol 1982;54:238–41.

105. Martin H, Cunningham WT. An evaluation of postoperative pain incidence following endosonic and conventional root canal therapy. Oral Surg Oral Med Oral Pathol 1982;54:74–6.

106. Cameron JA. The use of ultrasonics in the removal of the smear layer: a scanning electron microscope study. J Endod 1983;9:289–92.

107. Cymerman JJ, Jerome LA, Moodnik RM. A scanning electron microscope study comparing the efficacy of hand instrumentation with ultrasonic instrumentation of the root canal. J Endod 1983;9:327–31.

108. Goodman A, Reader A, Beck M, Melfi R, Meyers W. An in vitro comparison of the efficacy of the step-back technique versus a step-back/ultrasonic technique in human mandibular molars. J Endod 1985;11:249–56.

109. Collinson KL, Zakariasen MA. Microbiological assessment of ultrasonics in root canal therapy. J Endod 1986;12:131.

110. Ahmad M, Pitt Ford TJ, Crum LA. Ultrasonic debridement of root canals: acoustic streaming and its possible role. J Endod 1987;13:490–9.

111. Cameron JA. The synergistic relationship between ultrasound and sodium hypochlorite: a scanning electron microscope evaluation. J Endod 1987;13:541–5.

112. Lev R, Reader A, Beck M, Meyers W. An in vitro comparison of the step-back technique versus a step-back/ultrasonic technique for 1 and 3 minutes. J Endod 1987;13:523–30.

113. Sjögren U, Sundqvist G. Bacteriologic evaluation of ultrasonic root canal instrumentation. Oral Surg Oral Med Oral Pathol 1987;63:366–70.

114. Teplitsky PE, Chenail BL, Mack B, Macnee CH. Endodontic irrigation: a comparison of endosonic and syringe delivery system. Int Endod J 1987;20:233.

115. Ahmad M, Pitt Ford TR, Crum LA, Walton AJ. Ultrasonic debridement of root canals: acoustic cavitation and its relevance. J Endod 1988;14:486–93.

116. Baker MC, Ashrafi SH, Van Cura JE, Remeikis NA. Ultrasonic compared with hand instrumentation: a scanning electron microscope study. J Endod 1988;14:435–40.

117. Goldman M, White RR, Moser CR, Tenca JI. A comparison of three methods of cleaning and shaping the root canal in vitro. J Endod 1988;14:7–12.

118. Ahmad M. Effect of ultrasonic instrumentation on Bacteroides intermedius. Endod Dent Traumatol 1989;5:83–6.

119. Ciucchi B, Khettabi M, Holz J. The effectiveness of different endodontic irrigation procedures on the removal of the smear layer: a scanning electron microscopic study. Int Endod J 1989;22:21–8.

120. DeNunzio MS, Hicks ML, Pelleu GB Jr., Kingman A, Sauber JJ. Bacteriological comparison of ultrasonic and hand instrumentation of root canals in dogs. J Endod 1989;15:290–3.

121. Druttman AC, Stock CJ. An in vitro comparison of ultrasonic and conventional methods of irrigant replacement. Int Endod J 1989;22:174–8.

122. Hiadet J, Reader AL, Beck M, Meyers W. An in vitro comparison of the step-back technique versus step-back/ultrasonic technique in human mandibular molars. J Endod 1989;15:195–9.

123. Metzler RS, Montgomery S. Effectiveness of ultrasonics and calcium hydroxide for the debridement of human mandibular molars. J Endod 1989;15:373–8.

124. Ahmad M, Pitt Ford TR, Crum LA, Wilson RF. Effectiveness of ultrasonic files in the disruption of root canal bacteria. Oral Sur Oral Med Oral Pathol Oral Radiol Endod 1990;70:328–32.

125. Abbott PV, Heijkoop PS, Cardaci SC, Hume WR, Heithersay GS. An SEM study of the effects of different irrigation sequences and ultrasonics. Int Endod J 1991;24:308–16.

126. Walker TL, del Rio CE. Histological evaluation of ultrasonic debridement comparing sodium hypochlorite and water. J Endod 1991;17:66–71.

127. Archer R, Reader A, Nist R, Beck M, Meyers WJ. An in vivo evaluation of the efficacy of ultrasound after step-back preparation in mandibular molars. J Endod 1992;18:549–52.

128. Lumley PJ, Walmsley AD, Walton RE, Rippin JW. Effect of precurving endosonic files on the amount of debris and smear layer remaining in curved root canals. J Endod 1992;18:616–9.

129. Lumley PJ, Walmsley AD, Walton RE, Rippin JW. Cleaning of oval canals using ultrasonic or sonic instrumentation. J Endod 1993;19:453–7.

130. Siqueira JF Jr., Machado AG, Silveira RM, Lopes HP, de Uzeda M Evaluation of the effectiveness of sodium hypochlorite used with three irrigation methods in the elimination of Enterococcus faecalis from the root canal, in vitro. Int Endod J 1997;30:279–82.

131. Huque J, Kota K, Yamaga M, Iwaku M, Hoshino E. Bacterial eradication from root dentine by ultrasonic irrigation with sodium hypochlorite. Int Endod J 1998;31:242–50.

132. Guerisoli DM, Marchesan MA, Walmsley AD, Lumley PJ, Pecora JD. Evaluation of smear layer removal by EDTAC and sodium hypochlorite with ultrasonic agitation. Int Endod J 2002;35:418–21.

133. Mayer BE, Peters OA, Barbakow F. Effects of rotary instruments and ultrasonic irrigation on debris and smear layer scores: a scanning electron microscopic study. Int Endod J 2002;35:582–9.

134. Spoleti P, Siragusa M, Spoleti MJ. Bacteriological evaluation of passive ultrasonic activation. J Endod 2003;29:12–4.

135. Weber CD, McClanahan SB, Miller GA, Diener-West M, Johnson JD. The effect of passive ultrasonic activation of 2% chlorhexidine or 5.25% sodium hypochlorite irrigant on residual antimicrobial activity in root canals. J Endod 2003;29:562–4.

136. Lee SJ, Wu MK, Wesselink PR. The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from different-sized simulated plastic root canals. Int Endod J 2004;37:607–12.

137. Lee SJ, Wu MK, Wesselink PR. The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls. Int Endod J 2004;37:672–8.

138. Gulabivala K, Stock CJR, Lewsey JD, Ghori S, Ng YL, Spratt DA. Effectiveness of electrochemically activated water as an irrigant in an infected tooth model. Int Endod J 2004;37:624–31.

139. van der Sluis LW, Wu MK, Wesselink PR. A comparison between a smooth wire and a K-file in removing artificially placed dentine debris from root canals in resin blocks during ultrasonic irrigation. Int Endod J 2005;38:593–6.

140. van der Sluis LWM, Wu MK, Wesselink PR. The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from human root canals prepared using instruments of varying taper. Int Endod J 2005;38:764–8.

141. Passarinho-Neto JG, Marchesan MA, Ferreira RB, Silva RG, Silva-Sousa YT, Sousa-Neto MD. In vitro evaluation of endodontic debris removal as obtained by rotary instrumentation coupled with ultrasonic irrigation. Aust Endod J 2006;32:123–8.

142. Carver K, Nusstein J, Reader A, Beck M. In vivo antibacterial efficacy of ultrasound after hand and rotary instrumentation in human mandibular molars. J Endod 2007;33:1038–43.

143. Munley PJ, Goodell GG. Comparison of passive ultrasonic debridement between fluted and nonfluted instruments in root canals. J Endod 2007;33:578–80.

144. Burleson A, Nusstein J, Reader A, Beck M. The in vivo evaluation of hand/rotary/ultrasound instrumentation in necrotic, human mandibular molars. J Endod 2007;33:782–7.

145. Ferreira RB, Marchesan MA, Silva-Sousa YT, Sousa-Neto M. Effectiveness of root canal debris removal using passive ultrasound irrigation with chlorhexidine digluconate or sodium hypochlorite individually or in combination as irrigants. J Contemp Dent Pract 2008;9:68–75.

146. Walmsley AD, Murgel C, Krell KV. Canal markings produced by endosonic instruments. Endod Dent Traumatol 1991;7:84–9.

147. Giangrego E. Changing concepts in endodontic therapy. J Am Dent Assoc 1985;110:470–8.

148. Cameron JA. The effect of ultrasonic endodontics on the temperature of the root canal wall. J Endod 1988;14:554–9.

149. Moorer WR, Wesselink PR. Factors promoting the tissue dissolving capability of sodium hypochlorite. Int Endod J 1982;15:187–96.

150. Nusstein J. Ultrasonic dental device. Washington, DC: United States Patent 6,948,935; 2005.

151. Joyce E, Phull SS, Lorimer JP, Mason TJ. The development and evaluation of ultrasound for the treatment of bacterial suspensions: a study of frequency, power and sonication time on cultured Bacillus species. Ultrason Sonochem 2003;10:315–8.

152. Senia ES, Marshall FJ, Rosen S. The solvent action of sodium hypochlorite on pulp tissue of extracted teeth. Oral Surg Oral Med Oral Pathol 1971;31:96–103.

153. Hülsmann M, Hahn W. Complications during root canal irrigation: literature review and case reports. Int Endod J 2000;33:186–93.

154. Lussi A, Nussbächer U, Grosrey J. A novel noninstrumented technique for cleansing the root canal system. J Endod 1993;19:549–53.

155. Lussi A, Hotz M, Stich H. Die Balanced force und die GT-Rotary-Technik im vergleich zur nicht instrumentellen technik (NIT). Schweiz Monatsschr Zahnmed 2004;114:12–8.

156. Portmann P, Imwinkelried S, Lussi A. Obturation quality after four years of storage using the non-instrumentation technique. Schweiz Monatsschr Zahnmed 2005;115:431–6.

157. Lussi A, Suter B, Grosrey J. Obturation of root canals in vivo with a new vacuum technique. J Endod 1997;23:629–31.

158. Lussi A, Suter B, Fritzche A, Gygax M, Portman P. *In vivo* performance of the new non-instrumentation technology (NIT) for root canal obturation. Int Endod J 2002;35:352–8.

159. Fukumoto Y, Kikuchi I, Yoshioka T, Kobayashi C, Suda H. An ex vivo evaluation of a new root canal irrigation technique with intracanal aspiration. Int Endod J 2006;39:93–9.

160. Bankoff SB. Entrapment of gas in the spreading of a liquid over a rough surface. AICHE J 1958;4:24–6.

161. Dovgyallo GI, Migun NP, Prokhorenko PP. The complete filling of dead-end conical capillaries with liquid. J Eng Phy 1989;56:395–7.

162. Migun NP, Azuni MA. Filling of one-side-closed capillaries immersed in liquids. J Colloid Interface Sci 1996;181:337–40.

163. Migun NP, Shnip AI. Model of film flow in a dead-end conic capillary. J End Phys Thermophys 2002;75:1422–8.

164. Nielsen BA, Baumgartner CJ. Comparison of the EndoVac system to needle irrigation of root canals. J Endod 2007;33:611–5.

165. Schoeffel GJ. The EndoVac method of endodontic irrigation: safety first. Dent Today 2007;26:92,94,96.

166. Schoeffel GJ. The EndoVac method of endodontic irrigation, part 3: system components and their interaction. Dent Today 2008;27:106,108–11.

167. de Chevigny C, Dao TT, Basrani BR, et al. Treatment outcome in endodontics: the Toronto study: phase 4—initial treatment. J Endod 2008;34:258–63.

168. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature—part 1: effects of study characteristics on probability of success. Int Endod J 2007;40:921–39.

169. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature—part 2: influence of clinical factors. Int Endod J 2008;41:6–31.

170. de Chevigny C, Dao TT, Basrani BR, et al. Treatment outcome in endodontics: the Toronto study—phases 3 and 4: orthograde retreatment. J Endod 2008;34:131–7.

171. Ng YL, Mann V, Gulabivala K. Outcome of secondary root canal treatment: a systematic review of the literature. Int Endod J 2008;41:1026–46.

172. Distel JWD. Biofilm formation in medicated root canals. J Endod 2002;28:689–93.

173. Chávez de Paz LE. Redefining the persistent infection in root canals: possible role of biofilm communities. J Endod 2007;33:652–62.

174. George S, Kishen A, Song KP. The role of environmental changes on monospecies biofilm formation on root canal wall by Enterococcus faecalis. J Endod 2005;31:867–72.

175. Kishen A, George S, Kumar R. Enterococcus faecalis-mediated biomineralized biofilm formation on root canal dentine *in vitro*. J Biomed Mater Res A 2006;77:406–15.

176. Johnson SA, Goddard PA, Iliffe C, et al. Comparative susceptibility of resident and transient hand bacteria to para-chloro-meta-xylenol and triclosan. J Appl Microbiol 2002;93:336–44.

177. Costerton JW, Lowandowski Z, DeBeer D, Caldwell D, Korber D, James G. Biofilms, the customized microniche. J Bacteriol 1994;176:2137–42.

178. Costerton JW, Stewart PS, Greenberg EP. Bacterial biofilms: a common cause of persistent infections. Science 1999;284:1318–22.

179. Ehrlich GD, Hu FZ, Shen K, Stoodley P, Post JC. Bacterial plurality as a general mechanism driving persistence in chronic infections. Clin Orthop Relat Res 2005;437:20–4.

180. Guggenheim B, Guggenheim M, Gmür R, Giertsen E, Thurnheer T. Application of the Zürich biofilm model to problems of cariology. Caries Res 2004;38:212–22.

181. Foster JS, Pan PC, Kolenbrander PE. Effects of antimicrobial agents on oral biofilms in a saliva-conditioned flowcell. Biofilms 2004;1:5–12.

182. Dunavant TR, Regan JD, Glickman GN, Solomon ES, Honeyman AL. Comparative evaluation of endodontic irrigants against Enterococcus faecalis biofilms. J Endod 2006;32:527–31.

183. Duggan JM, Sedgley CM. Biofilm formation of oral and endodontic Enterococcus faecalis. J Endod 2007;33:815–8.

184. Williamson AE, Cardon JW, Drake DR. Antimicrobial susceptibility of monoculture biofilms of a clinical isolate of Enterococcus faecalis. J Endod 2009;35:95–7.

185. Takenaka S, Pitts B, Trivedi HM, Stewart PS. Diffusion of macromolecules in model oral biofilms. Appl Environ Microbiol 2009;75:1750–3.

186. George S, Kishen A. Augmenting the antibiofilm efficacy of advanced noninvasive light activated disinfection with emulsified oxidizer and oxygen carrier. J Endod 2008;34:1119–23.

187. Brändle N, Zehnder M, Weiger R, Waltimo T. Impact of growth conditions on susceptibility of five microbial species to alkaline stress. J Endod 2008;34:579–82.

188. Fimple JL, Fontana CR, Foschi F, et al. Photodynamic treatment of endodontic polymicrobial infection in vitro. J Endod 2008;34:728–34.

GORDON J. CHRISTENSEN
CLINICIANS REPORT®

Making In-Office CAD/CAM Work for Your Practice

Gordon's Clinical Bottom Line: Some of you don't think you are interested in this topic. I wasn't either years ago. **Read it anyway. This concept is the future!** Over the last 18 years, CRA has completed very positive in-vivo clinical research on CEREC which has shown the acceptable, if not superior, serviceability of the CEREC restorations over lab-made restorations. **Now, after many courses and significant experience, I am a believer!** CEREC by Sirona from Patterson and the competition, E4D by D4D Technologies from Henry Schein, are compared in this conceptual article with a planned subsequent scientific article now in preparation. Whether you presently own in-office CAD/CAM or not, this article will provide guidance on making the concept practical.

Many of you are doing well and are highly successful without CAD/CAM. What does it offer you and your patients?

The following article provides information about CAD/CAM—in-office concept, advantages, disadvantages, and financial feasibility—and a comparative analysis of the features available on the two competing devices: CEREC by Sirona from Patterson and E4D by D4D Technologies from Henry Schein.

Fractured cusp requiring replacement

Enamel and dentin bonding allowing more conservative preparation than conventional technique

Conservative and functional onlay

Ceramic Furnace Designed for Dentists

Gordon's Clinical Bottom Line: Why would you want a ceramic furnace in your office? How many times have you received a PFM or all-ceramic restoration from your lab and it needed just a small amount of additional color to match perfectly or a contact area was open? *After proper communication with your lab tech* about ceramic brands used and firing temperatures, dentists or dental staff can easily change the color of esthetic crowns or add additional ceramic to achieve proper proximal contact. The restorations don't have to go back to the lab, thus saving hundreds of dollars over time. Additionally, the in-office restoration milling concept described in this article relates directly to having a ceramic furnace to characterize some of the restorations. The Programat CS, designed for dentists, satisfies these needs well.

Ceramic furnaces have long been known as the primary tool for the ceramist or dental technician. Occasionally, a prosthodontist or interested general dentist may own a small furnace to make minor corrections or even fabricate their own crowns. However, with the increase in chair-side CAD/CAM design and milling, and the ability to mill stronger ceramics that require crystallization in a furnace (*i.e. IPS e.max CAD, Ivoclar Vivadent*), many dentists are discovering the benefits of owning a versatile ceramic furnace in their office.

This report discusses the indications for owning and using a ceramic furnace, clinical tips for using the furnace properly, and the advantages and disadvantages of the Programat CS.

Proximal contact being added to IPS e.max CAD crown while being stained and glazed

Highly Rated Products—Evaluators Reports and Clinical Tips

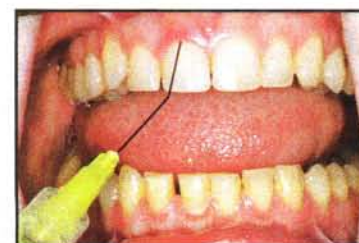**Endo Activator:** Easy and effective agitation of endo irrigation solutions *(Page 4)*

Protemp Plus: Bis-acryl temporary material specially formulated to minimize need to polish *(Page 4)*

Cetacaine Liquid: Significant anesthesia without injection for minimally painful procedures *(Page 4)*

Endo Activator being used during root canal therapy

Polished three-unit provisional made from Protemp Plus

Cetacaine Liquid being applied in the gingival sulcus prior to minor esthetic gingivectomy

Sign up for CR's Self-Instruction CE program *today!*

This month's test and program enrollment form are on page 5. Visit www.cliniciansreport.org for program details.

ATTACHMENT G

Easy and Effective Agitation of Endo Irrigation Solutions

This cordless handpiece is constructed of non-corrosive materials and uses polymer activator tips to agitate irrigation solutions during endo treatment. Snap on tips are pre-marked and available in three sizes: Small *(15/02)*, Medium *(25/04)*, and Large *(35/04)*. Instructional DVD and technique card are included in the starter system kit.

Advantages:
- Loosened particles are almost always observed, demonstrating effectiveness
- Easy to use
- Light weight and comfortable in hand
- Pliable plastic tips are easy to place in canals
- Cordless handpiece
- Potential cleaning of lateral canals

Main Disadvantage:
- Cost

Endo Activator

Dentsply Tulsa Dental Specialties
800-662-1202
Fax: 918-493-6599
www.tulsadentalspecialties.com

$425 / Starter System Kit

CR Conclusions: 70% of 23 evaluators stated they would incorporate Endo Activator into their practice. 83% rated it excellent or good and worthy of trial by colleagues.

Bis-acryl Temporary Material Specially Formulated to Minimize Need to Polish

Protemp Plus Temporization Material replaces Protemp 3 Garant. It is a bis-acryl material with nanotechnology fillers that offers easier handling and basically eliminates the need to polish. Available in five fluorescent shades *(Bleach, A1, A2, A3, and B3)* that match Filtek Supreme Plus Flowable restorative. Also has less air-inhibition layer than similar bis-acrylic materials when allowed to cure for five minutes in preliminary VPS impression.

Advantages:
- Quick intraoral set *(may be removed from oral cavity after 1 minute 40 seconds)*
- The longer the provisional restoration is left in the VPS *(up to 5 minutes)*, the less oxygen inhibition and less need to polish
- Temporaries are strong
- Easy handling and easy to use
- Good variety of shades

Disadvantages:
- Shades are initially lighter than vita guide
- Faster set desired by some evaluators *(23%)*

Protemp Plus

3M ESPE Dental
800-634-2249
Fax: 651-733-2481
www.3mespe.com

$234.70 / Intro Kit ($3.79/ml)

CR Conclusions: 78% of 23 evaluators stated they would incorporate Protemp Plus into their practice. 96% rated it excellent or good and worthy of trial by colleagues.

Significant Anesthesia without Injection for Minimally Painful Procedures

Cetacaine is a profound topical anesthetic *(14% Benzocaine, 2% Butamben, 2% Tetracaine Hydrochloride)*. It may be used as an alternative to injection anesthesia in some situations or as a topical anesthetic prior to injection. Just a few drops rapidly disperse into mucosal tissues *(buccal and lingual sulcus or periodontal pockets)* and achieve rapid onset within seconds. The anesthesia lasts up to 30 minutes. Up to 0.4mL may be used each dental visit. Cetacaine is also available in spray or gel forms.

Advantages:
- Clinician has control over amount dispensed
- Easy to deliver from luer-lock syringe and 27-gauge side-port tip
- Effective anesthesia without needle stick
- Anesthesia had quick onset and lasts up to 30 minutes in some patients

Disadvantages:
- If not placed drop by drop, difficult to confine all anesthetic to sulcus, and runoff anesthetizes unintended areas
- Anesthesia not adequate in all patients, particularly when ultrasonic scaling
- 27-gauge side-port tip is still somewhat sharp and can poke tissue causing bruising unless sulcular tissue is loose

Cetacaine Liquid

Cetylite Industries
800-257-7740
Fax: 856-665-5408
www.cetylite.com

$63 / Kit *(13.5 ml bottle of anesthetic, 20 syringes and tips)*

CR Conclusions: 81% of 25 evaluators stated they would incorporate Cetacaine Liquid into their practice. 88% rated it excellent or good and worthy of trial by colleagues.