SUMMARY OF ENDOACTIVATOR RESEARCH
FROM DR. 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*

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 *

Akved 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 *


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. Ongoing Studies

- **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. Discussion

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. Common Sense Factor

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

  *See ATTACHMENT D*

  *See ATTACHMENT E*

  *See ATTACHMENT F*

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

G. Caron¹, K. Nham², F. Bronnec¹ & P. Machtou¹

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.hypomoclon@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 (≤ 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 or 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 silicone 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). Sjögren 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 shown 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.
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) 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, Merignac Cedex, France). 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 |
|-------------------------------|-----------------|-----------------|-----------------|
| Direct observation method     | 1: Sonic, NaOCl | 2: Ultrasonic, NaOCl | p value |
| N 20                          | 1.83 (0.37)     | 1.60 (0.75)     | 0.66            |
| 4.5 mm Mean (SD)              | 1.20 (0.75)     | 1.43 (0.67)     | 0.37            |
| 2 mm Mean (SD)                | 1.00 (0.84)     | 0.60 (0.77)     | 0.16            |
| 2: Ultrasonic, NaOCl          | 20              | 2.00 (0.00)     | 0.01            |
| 3: Sonic, NaOCl + EDTA        | 20              | 1.62 (0.48)     | 1.91 (0.27)     |
| 4: Ultrasonic, NaOCl + EDTA   | 20              | 0.01            | 1.61 (0.63)     |
| p value                       |                 |                 | 0.04            |
| Sonic activation (groups 1 and 3) | 40         | 1.10 (0.80)     | 0.80 (0.80)     |
| Ultrasonic activation (groups 2 and 4) | 40    | 1.03 (0.79)     | 0.21            |
| p value                       |                 |                 |                 |
| Radiographic observation method | 1: Sonic, NaOCl | 2: Ultrasonic, NaOCl | p value |
| 20                            | 0.75 (0.91)     | 0.55 (0.89)     | 0.50            |
| 0.45 (0.63)                   | 0.45 (0.60)     | 1.00            |
| 1.00 (0.84)                   | 0.05 (0.22)     | 0.80            |
| 3: Sonic, NaOCl + EDTA        | 20              | 0.80 (0.89)     | 0.51            |
| 4: Ultrasonic, NaOCl + EDTA   | 20              | 0.55 (0.60)     | 0.38 (0.55)     |
| p value                       |                 | 0.37 (0.53)     | 0.93            |
| Sonic activation (groups 1 and 3) | 40         | 0.12 (0.33)     | 0.03 (0.16)     |
| Ultrasonic activation (groups 2 and 4) | 40    | 0.29            | 0.09            |

EDTA, ethylenediamine tetraacetic acid; NaOCl, sodium hypochlorite; SD, standard deviation.
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 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. 2A). 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. 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.

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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. 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. 2A). 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. 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.
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

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 Rinsendo 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 sucking 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

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 ethylenediamine-tetracetic 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 designed 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

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. 0099-2399/00 - see front matter
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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. 3A) of a removable 20-mL collection vial (Research Product International Corp, Mt Prospect, IL) (Fig. 34–4) next to an atmospheric equalization 18-gauge needle (Ultradent Products Inc) (Fig. 34-3). 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. 34–2). 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. 1C) (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. 34–5) collected coronally expressed irrigant in group 3 (Fig. 34–7) or the irrigant flow through the Micro and Macro cannulae in groups 1 and 2 (Fig. 34).

Testing Procedure

Group 1: Micro Cannula, EndoVac. The MDT was attached to the PSP to deliver irrigant into the pulp chamber (Fig. 34–6). The micro cannula was attached to FRT (Fig. 34–8), 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. 3C). The
shows the MDT as an abstract schematic without the detail shown here. The cannula was placed into the coronal third of the canal without and weighed before and after the experiment to confirm the volume of with water as the irrigant, no conversion between the weight and volume extrusion. Because the experiment was conducted at room temperature vial again and subtracting the pre-test tare weight to calculate the apical assembly was separated from the collection vial, weighing the collection was recorded from the pump ‘s digital display. After each test, the lid Data Collection and Analysis Group 6: Rinsendo. The Ultrasonic unit Group 5: Ultrasonic Needle Irrigation. Group 4: Manual Syringe and Max-I-Probe Needle. while moving in an up and down motion for 30 seconds. EndoActivator tip (35/04) was placed within 2 mm of WL and activated with its 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. 3D). 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 modeled with full-strength sodium hypochlorite would most likely occur. 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 Scheffe 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 Lambriani-dis 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.

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**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. 3A). Fig. 3A shows the MDT as an abstract schematic without the detail shown here.

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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 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 Scheffe test (P < .05).
length. This goal seems to have been accomplished by using the EndoVac 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 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.

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

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

<table>
<thead>
<tr>
<th>Group Comparison</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICRO Macro</td>
<td>&gt; 0.9999</td>
</tr>
<tr>
<td>MICRO EA</td>
<td>0.9025</td>
</tr>
<tr>
<td>MICRO MAX</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>MICRO UN</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>MICRO RE</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>MACRO EA</td>
<td>0.8729</td>
</tr>
<tr>
<td>MACRO MAX</td>
<td>&lt; 0.0001*</td>
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<tr>
<td>MACRO UN</td>
<td>&lt; 0.0001*</td>
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<td>MACRO RE</td>
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<td>EA MAX</td>
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<td>EA UN</td>
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<tr>
<td>EA RE</td>
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</tr>
<tr>
<td>MAX UN</td>
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<tr>
<td>MAX RE</td>
<td>0.0990</td>
</tr>
<tr>
<td>UN RE</td>
<td>0.9014</td>
</tr>
</tbody>
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*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.

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References

Review of Contemporary Irrigant Agitation Techniques and Devices

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

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, debridement, irrigation, machine-assisted, manual, smear layer

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).
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 optimal irrigation 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 (55). 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 irrigation (52, 55). 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 (68). 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).

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

**Manual-Dynamic Irrigation**

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**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 (85). 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**

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Author (reference no.)</th>
<th>Irrigation instrument</th>
<th>Irrigation method</th>
<th>Evaluation criterion</th>
<th>Evaluation method</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>Tromstad et al (84)</td>
<td>#20 K-file, #25 K-file</td>
<td>SEM</td>
<td>Smear layer, dentin debris</td>
<td>Histologic evaluation</td>
<td>Predentin, dentin debris, canal morphology</td>
</tr>
<tr>
<td>1985</td>
<td>Barnett et al (88)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1987</td>
<td>Stamos et al (89)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Histologic evaluation</td>
<td>Pulpal tissue, and dentin debris</td>
</tr>
<tr>
<td>1987</td>
<td>Reynolds et al (90)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Histologic evaluation</td>
<td>Predentin, dentin debris</td>
</tr>
<tr>
<td>1989</td>
<td>Pugh et al (91)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Top water</td>
<td>Injection with water, Debris, Predentin, Dentin morphology</td>
</tr>
<tr>
<td>1989</td>
<td>Walker and Del Rio (92)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Top water</td>
<td>Injection with Tap water, Debris, Predentin, Dentin morphology</td>
</tr>
<tr>
<td>1989</td>
<td>Sabins et al (94)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Top water</td>
<td>Injection with Tap water, Debris, Predentin, Dentin morphology</td>
</tr>
<tr>
<td>1999</td>
<td>Jensen et al (93)</td>
<td>#35, #15 Ripsionics file</td>
<td>#15, #20 Trisonic file</td>
<td>Histologic evaluation</td>
<td>Histologic evaluation</td>
<td>Predentin, Dentin debris</td>
</tr>
<tr>
<td>2003</td>
<td>Ruddle (95)</td>
<td>EndoActivator tips</td>
<td>Yes</td>
<td>—</td>
<td>Surgical operating microscope</td>
<td>—</td>
</tr>
<tr>
<td>2008</td>
<td>Sabins et al (94)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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

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).

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>
<thead>
<tr>
<th>Year</th>
<th>Author (reference no.)</th>
<th>MAF</th>
<th>Irrigation instrument</th>
<th>PUI</th>
<th>Flushing method</th>
<th>Time</th>
<th>Irrigant</th>
<th>Evaluation method</th>
<th>Evaluation criteria</th>
<th>Isthmus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>Martin et al (98)</td>
<td>#30</td>
<td>K-file</td>
<td>No</td>
<td>Intermittent</td>
<td>3 min</td>
<td>Tap water</td>
<td>Quantification of dentin-cutting efficiency</td>
<td>Weight loss of dental hard tissue</td>
<td>No</td>
</tr>
<tr>
<td>1980</td>
<td>Weller et al (101)</td>
<td>#30</td>
<td>#15 finger plugger</td>
<td>Yes/no</td>
<td>Intermittent</td>
<td>20 s</td>
<td>Distilled water</td>
<td>Radioactively labeled debris model</td>
<td>Radioactivity</td>
<td>No</td>
</tr>
<tr>
<td>1982</td>
<td>Cameron (102)</td>
<td>—</td>
<td>Smooth broach</td>
<td>Yes</td>
<td>Intermittent</td>
<td>—</td>
<td>3.0% NaOCl</td>
<td>Histologic evaluation</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1982</td>
<td>Cunningham et al (103)</td>
<td>#15</td>
<td>#10, #15 endodontic file</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>2.5% NaOCl</td>
<td>SEM</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1982</td>
<td>Cunningham et al (16)</td>
<td>#15</td>
<td>#10, #15 endodontic file</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>2.5% NaOCl</td>
<td>Bacteriologic evaluation (S. sanguis)</td>
<td>CFUs</td>
<td>No</td>
</tr>
<tr>
<td>1982</td>
<td>Cunningham (104)</td>
<td>#25</td>
<td>—</td>
<td>No</td>
<td>Intermittent</td>
<td>3 min</td>
<td>Saline; NaOCl</td>
<td>Bacteriologic evaluation</td>
<td>Presence of postoperative pain and a radiolucency</td>
<td>No</td>
</tr>
<tr>
<td>1982</td>
<td>Martin and Cunningham (105)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2.5% NaOCl</td>
<td>CFUs</td>
<td>No</td>
<td></td>
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<tr>
<td>1983</td>
<td>Cameron (106)</td>
<td>—</td>
<td>Smooth wire #30 K file</td>
<td>Yes</td>
<td>Intermittent</td>
<td>1, 3, 5 min</td>
<td>3% NaOCl</td>
<td>SEM</td>
<td>Smear layer</td>
<td>No</td>
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<tr>
<td>1983</td>
<td>Cymerman et al (107)</td>
<td>#25–#30</td>
<td>#15 finger plugger</td>
<td>Yes</td>
<td>—</td>
<td>3 min</td>
<td>2.62% NaOCl</td>
<td>SEM</td>
<td>Smear layer</td>
<td>No</td>
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<tr>
<td>1985</td>
<td>Goodman et al (108)</td>
<td>—</td>
<td>—</td>
<td>Yes/no</td>
<td>—</td>
<td>2, 4, 6 min</td>
<td>No</td>
<td>Bacteriologic evaluation</td>
<td>Smear layer, canal wall cleanliness</td>
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<td>1986</td>
<td>Collinson and Zakariasen (109)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2.5% NaOCl</td>
<td>SEM</td>
<td>Smear layer, ductin debris</td>
<td>No</td>
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<tr>
<td>1987</td>
<td>Ahmad et al (85)</td>
<td>—</td>
<td>#15–#45 endosonic files</td>
<td>I, No; II, yes</td>
<td>Intermittent</td>
<td>I, 4 min; II, 5 min</td>
<td>Water, 2.5% NaOCl</td>
<td>SEM</td>
<td>Smear layer, ductin debris</td>
<td>No</td>
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<tr>
<td>1987</td>
<td>Ahmad et al (110)</td>
<td>I, #15–35 files; II, #15 file</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>I, 2.5% NaOCl; II, 1.0% NaOCl</td>
<td>SEM</td>
<td>Smear layer</td>
<td>No</td>
<td></td>
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<tr>
<td>1987</td>
<td>Alacam (70)</td>
<td>#40</td>
<td>#15 file</td>
<td>Yes</td>
<td>Intermittent</td>
<td>3 min</td>
<td>5% NaOCl alone; 5% NaOCl + 3% H₂O; 17% EDTA; 2% glutaraldehyde; sterile saline</td>
<td>SEM</td>
<td>Smear layer, ductin debris</td>
<td>No</td>
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<tr>
<td>1987</td>
<td>Cameron (111)</td>
<td>#40–#50</td>
<td>Smooth broach</td>
<td>Yes</td>
<td>Intermittent</td>
<td>2 min</td>
<td>Distilled water; 0.5%, 1%, 2%, 4% NaOCl</td>
<td>SEM</td>
<td>Smear layer</td>
<td>No</td>
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<td>1987</td>
<td>Lev et al (112)</td>
<td>#20 file</td>
<td>Yes</td>
<td>Continuous 1 min; 3 min</td>
<td>2.62% NaOCl</td>
<td>Histologic evaluation</td>
<td>Pulpal tissue and dentin debris</td>
<td>Yes</td>
<td></td>
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<tr>
<td>1987</td>
<td>Reynolds et al (90)</td>
<td>—</td>
<td>#15, #20, #25 files</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>Water; 2.6% NaOCl</td>
<td>Histologic evaluation</td>
<td>—</td>
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(Continued)
<table>
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<tr>
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<th>Irrigant</th>
<th>Evaluation method</th>
<th>Evaluation criteria</th>
<th>Isthmus</th>
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<tr>
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<td>I, Zipperer K-files; II, endosonic files</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>Water; 2.6% NaOCl</td>
<td>Histologic evaluation</td>
<td>Pulpal tissue and dentin debris</td>
<td>Yes</td>
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<tr>
<td>1987</td>
<td>Sjögren and Sundqvist (113)</td>
<td>—</td>
<td>#20 endosonic file</td>
<td>No</td>
<td>—</td>
<td>3 min</td>
<td>0.5% NaOCl</td>
<td>Bacteriologic evaluation</td>
<td>CFUs</td>
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<td>1987</td>
<td>Teplitzky et al (114)</td>
<td>#10–40</td>
<td>#15 endosonic file</td>
<td>Yes</td>
<td>—</td>
<td>1 min</td>
<td>No</td>
<td>Radiopaque dye method</td>
<td>Dye penetration depth</td>
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<td>1988</td>
<td>Ahmad et al (115)</td>
<td>#40</td>
<td>#15 file</td>
<td>Yes</td>
<td>—</td>
<td>5 min</td>
<td>2.5% NaOCl</td>
<td>SEM</td>
<td>Smear layer, dentin debris</td>
<td>No</td>
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<tr>
<td>1988</td>
<td>Baker et al (116)</td>
<td>—</td>
<td>#15, #20, #25 files</td>
<td>No</td>
<td>Intermittent</td>
<td>—</td>
<td>2.625% NaOCl</td>
<td>SEM</td>
<td>Canal wall cleanliness</td>
<td>No</td>
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<tr>
<td>1988</td>
<td>Goldman et al (117)</td>
<td>#25</td>
<td>#15, #20, #25 K-files; #25, #35, #45 endosonic diamond files</td>
<td>No</td>
<td>Continuous</td>
<td>—</td>
<td>5.25% NaOCl</td>
<td>Root canal silicone model; SEM</td>
<td>Pulpal tissue and dentin debris</td>
<td>No</td>
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<tr>
<td>1989</td>
<td>Ahmad et al (118)</td>
<td>—</td>
<td>#15 K-file</td>
<td>Yes</td>
<td>—</td>
<td>1 min; 5 min; 15 min</td>
<td>No (E. intermedius suspension)</td>
<td>Bacteriologic evaluation</td>
<td>CFUs</td>
<td>No</td>
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<tr>
<td>1989</td>
<td>Ciucchi et al (119)</td>
<td>#35</td>
<td>#20 ultrasonic file</td>
<td>Yes</td>
<td>Continuous</td>
<td>2 min</td>
<td>3% NaOCl; 15% EDTA</td>
<td>SEM</td>
<td>Smear layer</td>
<td>No</td>
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<tr>
<td>1989</td>
<td>De Nunzio et al (120)</td>
<td>#25</td>
<td>#15, #20, #25</td>
<td>No</td>
<td>Continuous</td>
<td>1 min/file</td>
<td>Sterile saline</td>
<td>Bacteriologic evaluation (S. marcescens)</td>
<td>CFUs</td>
<td>No</td>
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<tr>
<td>1989</td>
<td>Druttman and Stock (121)</td>
<td>#15, #20, #25</td>
<td>#15, #20, #25 endosonic files</td>
<td>—</td>
<td>—</td>
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<td>Distilled water</td>
<td>1% toluene dye method</td>
<td>Degree of dye displacement</td>
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<td>1989</td>
<td>Haidet et al (122)</td>
<td>#25 or #30</td>
<td>#20 endosonic file</td>
<td>No</td>
<td>—</td>
<td>3 min</td>
<td>2.5% NaOCl</td>
<td>Histologic evaluation</td>
<td>Pulpal tissue and dentin debris</td>
<td>Yes</td>
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<td>1989</td>
<td>Metzler et al. (123)</td>
<td>—</td>
<td>#15 endosonic file</td>
<td>Yes</td>
<td>—</td>
<td>2 min</td>
<td>2.6% NaOCl</td>
<td>Histologic evaluation</td>
<td>Pulpal tissue and dentin debris</td>
<td>Yes</td>
</tr>
<tr>
<td>1989</td>
<td>Pugh et al (91)</td>
<td>—</td>
<td>#15, #30 file</td>
<td>No</td>
<td>Continuous</td>
<td>1 min</td>
<td>Tap water</td>
<td>Injection with impression material and clearing</td>
<td>Canal morphology</td>
<td>No</td>
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<td>1989</td>
<td>Walker and del Rio (92)</td>
<td>#25</td>
<td>#25 endosonic file; #15 Zipperer K-file</td>
<td>No</td>
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<td>1 min</td>
<td>Tap water</td>
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<td>Ahmad et al (124)</td>
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<td>#15 K-file</td>
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<td>—</td>
<td>5 min</td>
<td>2.5% NaOCl</td>
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<td>1991</td>
<td>Abbott et al (125)</td>
<td>#45</td>
<td>#20 ultrasonic file with Cavi-Endo</td>
<td>Yes</td>
<td>Intermittent</td>
<td>4 min</td>
<td>Savlon solution*; 15% EDTAC and 1% NaOCl</td>
<td>SEM</td>
<td>Smear layer; dentin debris</td>
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<th>Year</th>
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<th>MAF</th>
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<th>Evaluation method</th>
<th>Evaluation criteria</th>
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<td>4 min (3 + 1)</td>
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<td>#25</td>
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<td>2 min</td>
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<td>1993</td>
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<td>2 min</td>
<td>Distilled water; 0.5% NaOCl; 1% NaOCl; biological washing liquid</td>
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<td>30 s; 1 min</td>
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<td>Yes</td>
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<td>1 min</td>
<td>4.0% NaOCl; 4.0% NaOCl + 3% H₂O₂; 0.5%; 2.5%; 5.5%; 12% NaOCl; 15% EDTA; sterile water</td>
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<td>1998</td>
<td>Huque et al (131)</td>
<td>#40 or #60 K-file</td>
<td>#15 file</td>
<td>Yes</td>
<td>Intermittent</td>
<td>20 s</td>
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<td>#35/.10</td>
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<td>1 min</td>
<td>1% NaOCl; 15% EDTAC</td>
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<td>#15 K-file; a noncutting nickel-titanium wire</td>
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<td>Intermittent</td>
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<td>2003</td>
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<td>#35 or #50</td>
<td>#20 file</td>
<td>Yes</td>
<td>Intermittent</td>
<td>10 s</td>
<td>Sterile saline</td>
<td>Bacteriologic evaluation (S. aureus, S. viridans, E. coli)</td>
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<th>Year</th>
<th>Author</th>
<th>Reference no.)</th>
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<th>Time</th>
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<td>Intermittent</td>
<td>1 min</td>
<td>2% CHX, 5.25% NaOCl</td>
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<td>Lee et al (136)</td>
<td>#20/0.04; #20/0.06; #20/0.08</td>
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<td>Yes</td>
<td>Intermittent</td>
<td>3 min</td>
<td>2.0% NaOCl</td>
<td>’Groove and hole’ model</td>
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<td>Lee et al (137)</td>
<td>#50</td>
<td>#15 file</td>
<td>Yes</td>
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<td>’Groove and hole’ model</td>
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<td>2004</td>
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<td>#30/0.06</td>
<td>#20 ultrasonic file</td>
<td>Yes</td>
<td>Intermittent</td>
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<td>Neutral anolyte; acidic anolyte; catholyte; catholyte alternated with neutral anolyte; 3% NaOCl; PBS</td>
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<td>2005</td>
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<td>Pulpal tissue and dentin debris</td>
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<td>#20/0.08</td>
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<td>van der Sluis et al (140)</td>
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<td>3 min</td>
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<td>Yes</td>
<td>Intermittent</td>
<td>1 min; 3 min; 5 min</td>
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<td>2006</td>
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<td>#20.10</td>
<td>#15/.02 smooth wire</td>
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<td>Intermittent / continuous</td>
<td>3 min</td>
<td>Water; 2.0% NaOCl</td>
<td>’Groove and hole’ model</td>
<td>Dentin debris</td>
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<td>Carver et al (142)</td>
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<td>25-gauge irrigating needle</td>
<td>Yes</td>
<td>Continuous</td>
<td>1 min</td>
<td>6.0% NaOCl</td>
<td>Histologic evaluation</td>
<td>CFUs</td>
<td>No</td>
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<td>2007</td>
<td>Munley and Goodell (143)</td>
<td>#40/0.04</td>
<td>#15 FlexoFile; a yellow finger spreader</td>
<td>Yes</td>
<td>Intermittent</td>
<td>1 min; 3 min</td>
<td>6.0% NaOCl</td>
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<td>Burleson et al (144)</td>
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<td>Histologic evaluation</td>
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<td>2008</td>
<td>Ferreira et al (145)</td>
<td>#40/0.02</td>
<td>#15 file</td>
<td>Yes</td>
<td>Intermittent</td>
<td>3 min</td>
<td>Water; 0.2% CHX; 2.5% NaOCl</td>
<td>Histologic evaluation</td>
<td>Dentin debris</td>
<td>No</td>
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</table>

*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 5 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 technique 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 (135) 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 (151) 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...
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 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 entrapped 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 entrainment 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 entrainment 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 5 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 microgas 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 occur and 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 5 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, 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 undue extrusion into the periradicular \((164)\). 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 \((155)\). With the EndoVac, irrigant is pulled into the canal at working length and removed by negative pressure.

**The RinsEndo System**

The RinsEndo system (Dirr 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 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 (180–185) 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 Zilrich 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.

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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.

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)

**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, InLab 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.

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

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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

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%)

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