Study on the Influence of Refreshment/Activation Cycles and Irrigants on Mechanical Cleaning Efficiency During Ultrasonic Activation of the Irrigant

Lucas W.M. van der Sluis, PhD, Maikel P.J.M. Vogels, DDS,† Bram Verhaagen, Msc,‡ Ricardo Macedo, DDS,* and Paul R. Wesselink, PhD**

Abstract

Introduction: The aims of this study were to evaluate dentin debris removal from the root canal during ultrasonic activation of sodium hypochlorite (2% and 10%), carbonated water, and distilled water and to determine the influence of 3 ultrasonic refreshment/activation cycles of the irrigant by using the intermittent flush technique. **Methods:** Root canals with a standardized groove in 1 canal wall, which was filled with dentin debris, were irrigated ultrasonically. The irrigant was refreshed and ultrasonically activated 3 times for 20 seconds. The quantity of dentin debris after irrigation was determined after each refreshment/activation cycle. **Results and Conclusions:** Ultrasonic activation of the irrigant combined with the intermittent flush method produces a cumulative effect over 3 refreshment/activation cycles. Sodium hypochlorite as an irrigant is significantly more effective than carbonated water, which is significantly more effective than distilled water, in removing dentin debris from the root canal during ultrasonic activation. *(J Endod 2010;36:737–740)*

Key Words

Cavitation, irrigation, root canal, streaming, ultrasonic

From the *Department of Cariology, Endodontology & Pedodontology, Academic Center for Dentistry, Amsterdam, The Netherlands; †Department of Periodontology, Cariology, Endodontology & Pedodontology, Academic Center Dentistry and Oral Health, Groningen, The Netherlands; and ‡Physics of Fluids Group, Faculty of Science and Technology, University of Twente, and Research Institute for Biomedical Technology & TM MIRA, University of Twente, Enschede, The Netherlands.

Address requests for reprints to Dr Lucas van der Sluis, ACTA, CEP-Endodontology, Louwesweg 1, 1066 EA Amsterdam, The Netherlands. E-mail address: l.vd.sluis@acta.nl.
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The aim of irrigation of the root canal system is to remove pulp tissue and/or microorganisms, smear layer, and dentin debris from the root canal system, neutralize endotoxins, and lubricate canal walls and instruments (1). Irrigation of the root canal system allows the irrigant to be chemically active (chemical aspect) and permits the flushing of debris (mechanical aspect).

Passive ultrasonic irrigation (PUI) is ultrasonic activation of an irrigant in the root canal via a small, ultrasonically oscillating instrument (#15 or #20) placed in the center of the root canal after the root canal has been shaped up to the master apical file (2). PUI can induce acoustic streaming and/or cavitation of an irrigant, thereby enhancing the flushing effect (mechanical) (2, 3). Furthermore, PUI results in an increase in the temperature of the irrigant (4), which will enhance the tissue-dissolving capacity of NaOCl (chemical) (5, 6). These factors facilitate the removal of pulp tissue, bacteria, the smear layer, dentin debris, and $Ca(OH)_2$ from the root canal (2, 7, 8). However, whether this is due to the acoustic streaming, cavitation, or both is unknown.

The mechanical effect of irrigation is not similar for all irrigants activated by ultrasound. For example, distilled water is less effective than 2% NaOCl (8). However, whether a higher concentration of NaOCl or carbonated water (water with CO_2 bubbles) is more effective than distilled water or 2% NaOCl is unknown. In this study we have chosen for a 10% NaOCl solution to make the difference with the 2% more significant.

To refresh the irrigant during PUI, the intermittent flush method (IntFM) can be used. During the IntFM, a syringe is used to deliver the irrigant into the root canal; then the irrigant is activated ultrasonically (4). Depending on the irrigation time, this method is equally or more effective than refreshment with a continuous flow of irrigant in the pulp chamber (9). In previous studies, 3 refreshment/activation cycles were used (8), but it is not clear whether a cumulative effect occurs. In another study, however, that used the IntFM in removing bovine pulp tissue from lateral canals, a cumulative effect was reported with a plateau of efficiency after the third activation cycle (6).

Therefore, the purposes of this study were (1) to measure the fluidic properties of 2% and 10% NaOCl and carbonated and distilled water, (2) to evaluate the effect of these irrigants on the removal of dentin debris from the root canal during passive ultrasonic irrigation, and (3) to evaluate the effect of 3 ultrasonic refreshment/activation cycles during the IntFM.

Materials and Methods

Fluidic Properties Measurements

Density was measured on a balance (Sartorius LE324S, Elk Grove, IL). Surface tension was measured by using a tensiometer (Krüss K11, Hamburg, Germany) by submerging a plate into the fluid, slowly pulling it out, and measuring the resultant force. Viscosity was measured by using a rheometer (Haake RheoStress 600; Thermo Scientific) by measuring the stress during rotation at speeds of 10–200 s^{-1}. The experiments were done at room temperature (21°C).

Dentin Debris Removal

Twenty canines (maxillary and mandibular) were instrumented with the GT system (Dentsply Maillefer, Ballaigues, Switzerland) until size 30, taper 0.06 (master apical file

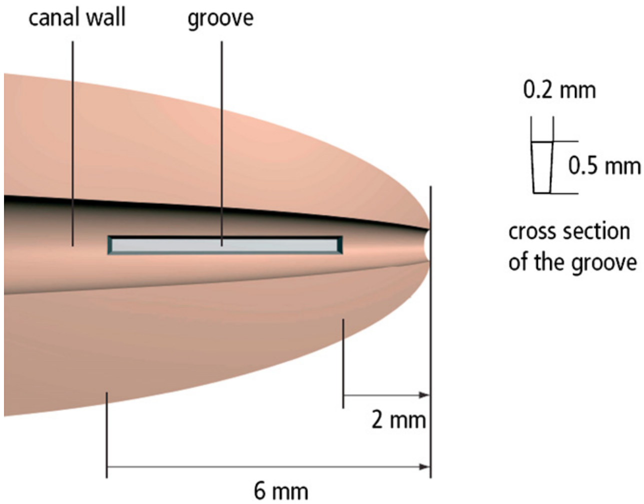

Figure 1. Schematic representation of the groove model.

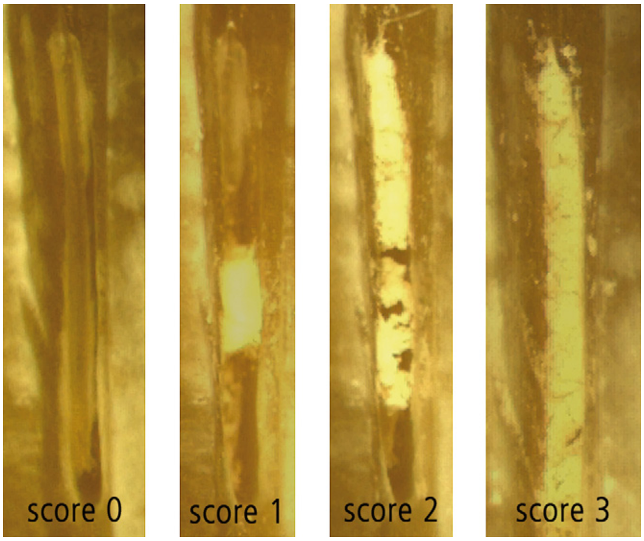

Figure 2. Examples of the different score scales.

(MAF) reached the apical foramen (working length [WL]). Only canines with root canals smaller than size 30, taper 0.06 were included (radiographic evaluation 3, 5, and 8 mm from the root apex). After instrumentation, the teeth were longitudinally split through the canal. A standard groove 4 mm in length, 0.2 mm in width, and 0.5 mm in depth was cut in 1 canal wall 2–6 mm from the apex; the dimension of the groove is comparable to an apical oval root canal (10) (Fig. 1). Each groove was filled with dentin debris that had been mixed for 5 minutes with 2% NaOCl to simulate a situation in which dentin debris accumulates in uninstrumented canal extensions during root canal preparation. This model was introduced to standardize the root canal anatomy and the amount of dentin debris present in the root canal before the irrigation procedure, and it was intended to increase the reliability of the evaluation of dentin debris removal. The methodology is sensitive, and the data are reproducible (8).

Images of the grooves were taken by using a Photomakroskop M 400 microscope with a digital camera (Wild, Heerbrugg, Switzerland) at 40× magnification; the photos were then scanned as Tagged-Image File format images. After reassembling the 2 root halves by means of wires and sticky wax, the root canals were irrigated with PUI combined with the IntFM or syringe irrigation.

Irrigation Procedures

PUI was performed with a 21 mm, stainless steel, non-cutting wire (#0.20, taper 0.00) (Irrisafe; Acteon, Merignac, France) powered by a piezoelectronic unit (PMax; Acteon) at 1 mm coronal from the WL. The oscillation of the wire was directed toward the groove. According to the manufacturer, the frequency used under these conditions was approximately 30 kHz, the intensity was 7.5 W, and the displacement amplitude varied between 20 and 30 μm. For syringe irrigation and IntFM, a 10-mL syringe (Terumo, Leuven, Belgium) and a 30-gauge needle (Navitip; Ultradent, South Jordan, UT) were used. The needle was inserted until it reached 1 mm coronal from the WL and the flow rate was approximately 0.3 mL/sec. For both techniques, the total irrigant volume was 6 mL. The total irrigation time was 2 minutes, divided into 3 sequences of 40 seconds. In the ultrasonic activation group the 3 sequences were subdivided into 20-second ultrasonic activation and 20-second refreshment (procedure similar to syringe irrigation). After each sequence, the amount of dentin debris in the groove was determined.

Four irrigation solutions, including NaOCl 10% (pH 10.9), NaOCl 2% (pH 10.8), carbonated water (Spa Barisart, Spadel Group, Spa, Belgium; pH 10.8), and distilled water (pH 7), were tested. The NaOCl at both concentrations was a laboratory agent, and the amount of free chlorine was tested by titration before every experiment. In total, 6 experiments were performed with the 20 models after a pilot experiment demonstrated that the non-cutting wire did not damage or alter the root canal wall or the oval extension during ultrasonic activation of the irrigant. Another pilot study demonstrated that 20 seconds of ultrasonic activation is as effective as 60 seconds of continuous activation without refreshment, with regard to the removal of dentin debris.

In control groups 1 and 3 (n = 20), the root canals were irrigated by using syringe irrigation with NaOCl 10% and carbonated water, respectively, as the irrigant. In groups 2, 4, 5, and 6 (n = 20), the root canals were irrigated with PUI and 10% NaOCl, carbonated water, 2% NaOCl, and distilled water, respectively, as the irrigant.

The root halves were separated after the irrigation procedure to permit evaluation of the removal of dentin debris from the groove by images as described above.

The quantity of the debris in the groove before and after irrigation was scored independently by 2 blinded calibrated dentists by using the

TABLE 1. Fluidic Properties of Distilled Water, Carbonated Water, and Different Concentrations of NaOCl at 21°C

	Density (kg/m^3)	Surface tension (mN/m)	Viscosity (mPas)
Water	1010 ± 2	72.9 ± 0.0	1.14 ± 0.03
NaOCl 2.5%	1065 ± 2	74.3 ± 0.1	1.37 ± 0.03
NaOCl 5%	1105 ± 2	76.6 ± 0.0	1.65 ± 0.03
NaOCl 10%	1229 ± 2	80.0 ± 0.0	2.58 ± 0.03
Carbonated water (Spa Barisart)	1000 ± 2	73.5 ± 0.0	1.02 ± 0.03

TABLE 2. Median of Dentin Debris Score before and after Each Irrigation Sequence

Groups	Before irrigation	After 1	After 2	After 3
1* (NaOCl 10% syringe)	3	3	2	2
2*,† (NaOCl 10% PUI)	3	1	1	0.5
3†,‡ (H_2CO_3 syringe)	3	3	2	2
4*,‡,§ (H_2CO_3 PUI)	3	2	1.5	1
5*,‡,§ (NaOCl 2% PUI)	3	2	1	0
6†,§ (H_2O PUI)	3	3	3	2

*Significant difference all irrigation moments, group: 1-2, 1-4, 1-5.

†Significant difference all irrigation moments, group: 2-3, 2-6.

‡Significant difference all irrigation moments, group: 3-4, 3-5.

§Significant difference all irrigation moments, group: 6-4, 6-5.

following scores: 0, the groove is empty; 1, less than half of the groove is filled with debris; 2, more than half of the groove is filled with debris; 3, the groove is completely filled with debris (Fig. 2).

The inter-rater agreement was determined (Cohen's kappa), and the differences in debris scores between the different groups were analyzed by means of the Kruskal-Wallis test and Mann-Whitney test. The differences between the debris scores within a group at different irrigation moments were analyzed by means of the Friedman test, because we compare 4 related irrigation moments per group. The Wilcoxon signed rank test is a nonparametric statistical test that can be used for the comparison of 2 related samples. This test was used for further comparison of irrigation moments within the groups. The level of significance was set at .05.

Results

The fluidic properties of the irrigants are listed in Table 1, and the results of the irrigation procedures are listed in Table 2. There was a statistically significant difference between the groups ($P < .001$). Within the PUI groups, both 2% and 10% NaOCl were significantly more effective than carbonated water, which itself was significantly more effective than distilled water, in removing dentin debris. Overall, the PUI groups removed significantly more dentin debris than the syringe irrigation groups.

The differences in debris scores between the refreshment/activation cycles were statistically significant (Friedman test, $P < .001$) for all groups. A further comparison (Wilcoxon signed rank test) demonstrated that all PUI groups revealed statistically significant differences between the irrigation times. Cohen's kappa coefficient of inter-rater agreement was 0.85.

Discussion

The results demonstrated that each of the 3 refreshment/activation cycles removed additional dentin debris, indicating a cumulative effect as also reported in another study (6).

NaOCl (2% or 10%) is the most efficient irrigant tested for the mechanical removal of dentin debris during ultrasonic activation. Because the fluidic properties of the irrigants are comparable, the streaming of the irrigants should be comparable, as also confirmed by the results of the syringe irrigation groups, in which no significant difference was seen between 10% NaOCl and carbonated water.

Therefore, another process than streaming alone should be responsible for the results. Acoustic cavitation, which can be defined as the creation of new bubbles or the expansion, contraction, and/or distortion of preexisting bubbles (so-called nuclei) in a liquid, could be one of them (11). This process is coupled to acoustic energy. When a salt solution like NaOCl is activated by ultrasound, it is known that the coalescence of bubbles is inhibited, which results in a greater number of smaller bubbles (12). Furthermore, the oscillation of a bubble is influenced by gas dissolved in liquid, temperature and impurities of the liquid (13), which can all be affected by NaOCl. Further research should try to elaborate the role of cavitation.

Carbonated water is supersaturated with CO_2. Normally, carbon dioxide loss is slow and occurs via diffusion through the surface layer exposed to the atmosphere and bubble formation. Ultrasound enhances the rate of bubble formation (14); however, the exact mechanism remains unknown.

The chemical effect of the tested irrigants on dentin debris does not influence the dentin debris removal, because there was no difference between NaOCl and carbonated water during syringe irrigation. Whether ultrasound is capable of changing the chemical properties of the irrigant is unknown.

Because the increase in temperature of NaOCl alone does not contribute to the efficacy of the ultrasonic activation (6), this can be ruled out as a contributing factor.

In this study dentin debris was used, which has an organic component of approximately 30% (15). The organic tissue-dissolving capacity of NaOCl is higher than that of carbonated water and distilled water. However, the dentin debris was abundantly soaked for 5 minutes in NaOCl before PUI, thereby dissolving a portion of the organic component. Furthermore, there was no significant difference between 2% and 10% NaOCl treatments, even though the organic dissolving capacity of the latter is higher (5). This confirms the results of an earlier study in which water was also less effective than NaOCl during PUI in the removal of nonorganic material from the root canal (8).

Conclusion

When the IntFM is used during ultrasonic activation of the irrigant, a cumulative effect occurs over 3 activation cycles. The use of sodium hypochlorite as irrigant is significantly more effective than carbonated water, which is significantly more effective than distilled water, in removing dentin debris from the root canal during ultrasonic activation.

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