Study on the influence of refreshment/activation cycles and irrigants on mechanical cleaning efficiency during ultrasonic activation of the irrigant*

Abstract

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 three ultrasonic refreshment/activation cycles of the irrigant using the intermittent flush technique. Root canals with a standardized groove in one 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.

The results showed that ultrasonic activation of the irrigant combined with the intermittent flush method produces a cumulative effect over three 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.

Introduction

The aim of irrigation of the root canal system is to remove pulp tissue, and or micro-organisms, smear layer, and dentine debris from the root canal system, neutralize endotoxins, and lubricate canal walls and instruments (Zehnder 2006). Irrigation of the root canal system allows the irrigant to be chemically active (chemical) and permits the flushing of debris (mechanical).

Passive ultrasonic irrigation (PUI) is ultrasonic activation of an irrigant in the root canal via a small, ultrasonically oscillating instrument (diameter 0.15 or 0.20mm) placed in the center of the root canal after the root canal has been shaped up to the master apical file (Ahmad et al. 1987). PUI can induce acoustic streaming and/or cavitation of an irrigant, thereby enhancing the flushing effect (mechanical) (Ahmad et al. 1987; Roy et al. 1994). Furthermore, PUI results in an increase in the temperature of the irrigant (Cameron 1988), which will increase the tissue dissolving capacity of NaOCl (chemical) (Sirtes et al. 2005; Al-Jadaa et al. 2009). These factors facilitate the removal of pulp tissue, bacteria, the smear layer, dentin debris, and Ca(OH)$_2$ from the root canal (Ahmad et al. 1987; Burleson et al. 2007; Van der Sluis et al. 2007). However, if 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, plain water is less effective than 2% NaOCl (Van der Sluis et al. 2007). However, whether 10% NaOCl or carbonated water (water with CO$_2$ bubbles to enhance cavitation) are more effective than plain water or 2% NaOCl is unknown.

To refresh the irrigant during PUI, the Intermittent Flush Method (IntFM) can be used. During the IntFM, a syringe is used to inject the irrigant into the root canal; then, the irrigant is activated ultrasonically (Cameron 1988). Depending on the irrigation time, this method is equally or more effective than refreshment with a continuous flow of irrigant in the pulp chamber (van der Sluis et al. 2009). In previous studies, three refreshment/activation cycles were used (Van der Sluis et al. 2007). However, it is not known if a cumulative effect resulting from the three cycles indeed occurs. Therefore, the purposes of this study were 1) to evaluate the effect of different irrigants (2% and 10% NaOCl as well as carbonated and distilled water) on the removal of dentin debris from the root canal during passive ultrasonic irrigation, 2) to measure the fluidic properties of these irrigants, and 3) to evaluate the effect of three ultrasonic refreshment/activation cycles during the Intermittent Flush Method.

**Materials and Methods**

**Fluid property measurements**

Density was measured on a balance (Sartorius LE324S, Elk Grove, Illinois, USA). Surface tension was measured 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 using a rheometer (Haake RheoStress 600, Kansas, USA) by measuring the stress during rotation at speeds of 10 to 200 s⁻¹. The temperature during the measurements was 21°C.

**Dentin debris removal**

Twenty canines (maxillary and mandibular) were instrumented with the GT system (Dentsply Maileffer, Ballaigues, Switzerland) until size 30, taper 0.06 (master apical file (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 one canal wall 2 to 6 mm from the apex, the dimension of the groove is comparable to an apical oval root canal (Lee et al. 2004) (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 (Van der Sluis et al. 2007).

Images of the grooves were taken using a Photomakroskop M 400 microscope with a digital camera (Wild, Heerbrugg, Switzerland) at 40x magnification; the photos were then scanned as tagged-image file format images. After reassembling the two 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 (diameter 0.20 mm, taper 0.00) (Irrisafe\Acteon, Merignac, France) powered by a piezoelectronic unit (PMax\Acteon) 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 7.5 Watt and the displacement amplitude varied between 20 and 30 μm. For syringe irrigation and IntFM, a syringe (Terumo, Leuven, Belgium) and a 30 gauge needle (Navitip, Ultradent, South Jordan, UT, USA) were used. The needle was inserted until it reached 1 mm coronal from the WL. For both techniques, the total irrigant volume was 6 ml. The total irrigation time was 2 minutes, divided in 3 sequences of 40 seconds. In the ultrasonic activation group the sequence was divided in 20 seconds ultrasonic activation and 20 seconds refreshment. 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; pH 10.8), and distilled water (pH 7), were tested. 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 of NaOCl is as effective as 60 seconds with regard to the removal of dentin debris.

In groups 1 and 3 (n=20), the root canals were irrigated 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 in order 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 three calibrated dentists using the 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 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 in debris scores at different irrigation times were analyzed by means of the Friedman test. The level of significance was set at \( P=0.05 \).

Results

The fluid 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 (\( P<0.001 \)). 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 \( P<0.001 \)) 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 demonstrate that each of the three refreshment/activation cycles removed additional dentin debris, indicating the presence of a cumulative effect. In another study, using the IntFM to remove bovine pulp tissue from lateral canals, also a cumulative effect was reported with a plateau of efficiency after the third activation cycle (Al-Jadaa et al. 2009). 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 processes then 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 pre-existing bubbles (so-called nuclei) in a liquid; this process is coupled to acoustic energy could be one of them (Leighton 1994). When a salt solution like NaOCl is activated by ultrasound, it is known that the coalescence of bubbles is inhibited and results in a greater number of smaller bubbles (Wall et al. 1999). Furthermore, the oscillation of a bubble depends on gas dissolved in liquid, temperature and impurities of the liquid (Brennen 1995). Further research should try to find an answer to these questions.

Carbonated water is supersaturated with CO₂. 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 (Baur et al. 2006), which could have a positive influence on the removal of dentin debris during PUI. However, the exact mechanism remains unknown.

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

Because the increase in temperature of NaOCl alone does not contribute to the effect of the ultrasonic activation (Al-Jadaa et al. 2009), this can be ruled out as a contributing factor.

This study used dentin debris, which has an organic component of approximately 30% (Haapasalo et al. 2007). The organic tissue dissolving capacity of NaOCl is higher than that of carbonated water and distilled water. However, the dentin debris, used in this study, was abundantly soaked for 5 minutes in NaOCl, thereby dissolving a portion of the organic component. Furthermore, there was no significant difference between 2% and 10% NaOCl, even though the organic dissolving capacity of the latter is higher (Sirtes et al. 2005). In an earlier study, water was also less effective than NaOCl during PUI in the removal of non-organic material from the root canal. The pH of the irrigants was comparable (pH 10.8, with the exception of distilled water with pH 7).
Conclusion

When the Intermittent Flush Method is used during ultrasonic activation of the irrigant, a cumulative effect occurs over three activation cycles. The use of 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.

Tables

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Density [kg/m³]</th>
<th>Surface tension [mN/m]</th>
<th>Viscosity [mPas]</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>1.010 ± 0.002</td>
<td>72.9 ± 0.0</td>
<td>1.14 ± 0.03</td>
</tr>
<tr>
<td>NaOCl 2.5%</td>
<td>1.065 ± 0.002</td>
<td>74.3 ± 0.1</td>
<td>1.37 ± 0.03</td>
</tr>
<tr>
<td>NaOCl 5%</td>
<td>1.105 ± 0.002</td>
<td>76.6 ± 0.0</td>
<td>1.65 ± 0.03</td>
</tr>
<tr>
<td>NaOCl 10%</td>
<td>1.229 ± 0.002</td>
<td>80.0 ± 0.0</td>
<td>2.58 ± 0.03</td>
</tr>
<tr>
<td>Carbonated water (Spa Barisart)</td>
<td>1.000 ± 0.002</td>
<td>73.5 ± 0.0</td>
<td>1.02 ± 0.03</td>
</tr>
</tbody>
</table>

Table 1: Fluidic properties of distilled water, carbonated water and different concentrations of NaOCl at 21°C.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Before Irr.</th>
<th>After 1 median</th>
<th>After 2 median</th>
<th>After 3 median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 * NaOCl 10% syr.</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2 ° NaOCl 10% PUI</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>3 † H₂CO₃ syr.</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4 * † H₂CO₃ PUI</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>5 * † # NaOCl 2% PUI</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6 ° # H₂O PUI</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

* Sign. Diff. all irrigation moments, group: 1-2, 1-4, 1-5.
† Sign. Diff. all irrigation moments, group: 3-4, 3-5.
# Sign. Diff. all irrigation moments, group: 6-4, 6-5.

Table 2: Dentin debris score before and after each irrigation sequence.
Figures

Figure 1: Schematic drawing of the groove model.

Figure 2: Images of the different scores, from left to right score 0 to 3.
References


