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2

Evaluation of a sonic device designed to activate irrigant in the root canal

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Abstract

Introduction The aims of this study were to evaluate the removal of dentin debris from the root canal by sonic or ultrasonic activation of the irrigant and the physical mechanisms of sonic activation by visualizing the oscillations of the sonic tip, both inside and outside the confinement of the root canal. **Methods** Roots of 18 canines were embedded, split and prepared into standardized root canals. A standard groove was cut on the wall of one half of each root canal and filled with the same amount of dentin debris before irrigation procedures. The removal of dentin debris was evaluated after different irrigation procedures. The oscillations of the sonic tip were visualized *ex-vivo* by using high-speed imaging at a timescale relevant to the irrigation process and the oscillation amplitude of the tip was determined under 20x magnification. **Results** After irrigation, there was a statistically significant difference between the experimental groups ($p<0.0001$). Without irrigant activation, the grooves were still full of dentin debris. From the ultrasonic activated group, 89% of the canals were completely free of dentin debris, whereas from the sonic group 5.5% - 6.7% ($p=0.0001$). There was no significant difference between the sonic activation groups. **Conclusions** Activation of the irrigant resulted in significantly more dentin debris removal, ultrasonic activation being significantly more efficient than sonic activation. The oscillation amplitude of the sonically driven tips is 1.2 ± 0.1 mm resulting in much wall contact and no cavitation of the irrigant.

Introduction

Irrigation of the root canal space is a fundamental aspect of root canal treatment. Techniques for acoustic and hydrodynamic activation of the irrigant have been developed (1-3), because syringe irrigation is not effective in the apical part of the root canal (4, 5).

It has been shown that acoustic streaming and cavitation contribute to the cleaning efficiency of root canal irrigation (2, 3, 6). Acoustic streaming can be defined as a rapid movement of fluid in a circular or vortex-like motion around a vibrating file (7). Cavitation can be defined as the creation of vapor bubbles or the expansion, contraction and/or distortion of pre-existing bubbles (so-called cavitation nuclei) in a liquid, the process being coupled to acoustic energy (8). Studies have shown that passive sonic activation of irrigant is inferior to its counterpart in ultrasonic (9, 10). However, the details concerning those mechanisms have not been clarified.

The EndoActivator® system, a sonic device, has recently been developed for root canal irrigation. Special polymer tips can be driven sonically at three different frequencies in order to activate the irrigant. No data are currently available to support its use.

The aims of this study were (i) to determine the removal of dentin debris from the root canal by sonic or ultrasonic activation of the irrigant, and (ii) to evaluate the physical mechanisms of sonic activation by visualizing the oscillation amplitude of EndoActivator® tips.

Materials and Methods

High speed imaging experiments

An optical setup was constructed in order to visualize the effect of sonic activation in a glass model of the root canal containing water. The canal was 10 mm in length with an apical diameter of 0.30 mm and a taper of approximately 0.06. Imaging was performed using a high speed camera (Shimadzu Corp., Japan) at a frame rate of 4000 frames per second. From these recordings the oscillation amplitude of the tip was measured using a calibrated reference grid (Edmund Optics, etc.)

A microscope with 1.25x to 20x magnification was used (BX-FM, Olympus, Japan) for magnification. The root canal was illuminated in bright-field by a continuous wave light source (ILP-1, Olympus, Japan).

Dentin debris removal model

Straight roots from 18 extracted human maxillary canines were decoronated to obtain uniform root sections of 15 mm. The roots were embedded in self-curing resin (GC Ostron 100, GC Europe, Belgium) and then bisected longitudinally through the canal in mesio-distal direction with a saw microtome (Leica Microsystems SP1600, Wetzlar, Germany). The surfaces of both halves were ground successively with 240-, P400- and 600-grit sandpaper, resulting in smooth surfaces on which only little of the original root canal lumen was left. Four holes were drilled in the resin part and the two halves could be reassembled by four self-tapping bolts through the holes (Fig. 1A).

New root canals were prepared by K-files #15/.02 (Dentsply Maillefer, Ballaigues, Switzerland) and HERO 642 (MicroMega, Besançon, France) nickel-titanium rotary instruments to a working length (WL) of 15 mm, ISO size 30 and taper 0.06 resulting in standardized root canals. During preparation, the canals were rinsed with 1 mL of 2% NaOCl after each file, delivered by a 10 mL syringe (Terumo, Leuven, Belgium) and a 30-gauge needle (Navitip, Ultradent, South Jordan, UT, USA).

A standard groove of 4 mm in length, 0.5 mm deep and 0.2 mm wide, situated at 2 to 6 mm from working length (11) (Fig. 1B-1, 1B-2), was cut in the wall of one half of each root canal with a customized ultrasonic tip. A periodontal probe with an adapted 0.2 mm wide tip was used to verify the dimension of each groove during and after preparation. The dimension of the groove is comparable to an apical oval root canal (12). Each groove was filled with dentin debris, which was mixed with 2% NaOCl for five minutes, to simulate a situation in which dentin debris accumulates in uninstrumented canal extensions (11). This model was introduced to standardize the root canal space and the amount of dentin debris present in the root canal before the irrigation procedure, to increase the reliability of the dentin debris removal evaluation. The methodology is sensitive and the data are reproducible (13). A pilot study has shown that a single model could be reused up to at least 8 times without any visible defect on the surface of the canal wall. Therefore the 18 models were used repeatedly in the six experimental groups, which are ultrasonic activated group, sonic activated groups by different frequencies or tips or irrigants and control group (Table 1).

Irrigation Procedure

Specimens in all the experimental groups were rinsed with 2 mL irrigant (2% NaOCl or water) using 10 mL syringes with 30-gauge needles placed 1 mm from WL. Then the residue of irrigant was passively activated for

20 seconds sonically or ultrasonically. In group 6, the sonic tip was inserted but not activated. Passive activation meant that every attempt was made to keep the file centered in the canal to minimize contact with the canal walls. This sequence was repeated twice resulting in a total irrigation volume of 6 mL and a total irrigation time of 1 min.

The ultrasonic activation was performed with a stainless steel #20/.00 file (IrriSafe, Acteon) energized by a piezoelectronic unit (Suprasson PMax, Satelec, Acteon) at power setting 'blue' 4. The sonic activation was performed with the EndoActivator® system (Advanced Endodontics, Santa Barbara, USA).

Image evaluation and statistical analyses

Before and after each irrigation procedure, the root halves were separated and the grooves were viewed through a stereomicroscope (Stemi® SV6, Carl Zeiss, Göttingen, Germany) using a cold light source (KL 2500 LCD, Carl Zeiss). Controls verified that no debris had fallen out of the groove during the assembly or disassembly process. Pictures were taken with a digital camera (Axio Cam, Carl Zeiss) and saved as ZVI files on a computer.

The debris left in the groove after irrigation was scored independently and blindly by three calibrated dentists using the following score system: 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 complete groove is filled with debris (11) (Fig. 1C). The percentage of inter agreement should be more than 95%. If this percentage was lower than 95%, a consensus had to be reached.

The differences in debris scores between the groups were analyzed by means of the Kruskal-Wallis test and the Mann-Whitney test. The level of significance was set at $\alpha = 0.05$.

Results

The oscillation amplitude of the sonic tips in free air and in water was respectively 1.1 ± 0.1 mm, 0.6 ± 0.1 mm at the attachment point and 3.1 ± 0.1 mm, 1.2 ± 0.1 mm at the free end. The sonic tip didn't show an oscillatory pattern down its length, but had just one node (at the attachment point) and one anti-node (at the free end), as previously observed by Walmsley *et al.* (14). The actual frequencies of the sonic device turned out to be different from the frequencies listed in the sale brochure. Mode 1 was 160 ± 5 Hz instead of 33 Hz (2000 CPM), mode 2 was 175 ± 5 Hz instead of 100 Hz (6000 CPM) and mode 3 was 190 ± 5 Hz instead of 166 Hz (10,000 CPM). The high speed imaging experiments showed a lot of wall contact of the sonic tips during activation, and no cavitation was observed.

The three investigators differed in scoring six specimens; agreement was reached following discussion. After irrigation, the number and the percentage of samples at each score rank are presented in Table 1. There was a statistically significant difference between the experimental groups ($p<0.0001$). When the irrigant was activated, significantly more dentin debris was removed than control group, ultrasonic activation being significantly more efficient than sonic activation ($p=0.0001$). There was no significant difference between the sonic activation groups. From the ultrasonic activated group, 89% of the canals were completely free of dentin debris, whereas from the sonic group 5.5% - 6.7%.

Discussion

The results indicate that activation of the irrigant enhances the removal of dentin debris from the apical root canal. Because the ultrasonic file or sonic tips could not physically disturb the dentin debris in the groove, it can be concluded that the activated irrigant removed the dentin debris from the groove.

The fact that ultrasonic activation removed significantly more dentin debris than the sonic activation confirms the study of Sabins *et al.* (10). A possible explanation is that the driving frequency of ultrasound (30 kHz) is higher than that of the sonic device (160-190 Hz). In principle, a higher frequency should result in a higher flow velocity (15):

$$v = \frac{\omega \varepsilon_0^{\,2}}{a} \qquad (1)$$

where v is the flow velocity (in *m/s*), ω is 2π times the driving frequency (in *Hz*), ε_0 is the oscillation amplitude (in *m*) and a the radius of the wire (in *m*). Equation 1 also suggests that the flow velocity increases with increase in the oscillation amplitude of the tip. However, the oscillation amplitude of the sonically activated tip in water is approximately 1 mm while the diameter of the apical root canal is smaller than 0.5 mm, which implies extensive wall contact between the tip and the root canal wall. This inhibits free oscillation of the sonic tip, reducing the efficient streaming of the irrigant (15), and consequently the activation of the irrigant. This is confirmed both by the outcome of dentin debris removal and by the visualization experiment in which wall contact was observed (Fig. 2).

The difference between the lowest (160Hz) and the highest (190Hz) oscillation frequency of EndoActivator® as we have tested is small, implying only small differences in streaming between frequency settings. That explained why there was no significant difference between the two frequency settings of the sonic activation.

It was also observed that no cavitation seemed to take place, neither on the sonic tip itself nor on the wall of the glass model of the root canal. This can be related to the velocity of the sonic tip, which was below the threshold needed for cavitation. Such a cavitation threshold can be determined by estimating the pressure required. If the pressure falls below the vapor pressure by a magnitude of the tensile strength, then rupture of the fluid can occur (cavitation). The tensile strength of pure water is very high, and therefore cavitation is often unobtainable. In many situations, however, there are microscopic voids containing gas on the interface between a solid surface (contaminant particles, cracks in the container) and the fluid. These nucleation sites have a much lower tensile strength and therefore make cavitation possible at much lower pressures. In order to get cavitation the pressure decrease ∇P must exceed the ambient pressure (1 atm. or 10^5 Pa) plus the vapor pressure of the fluid (2000 Pa) (16). In first approximation the velocity *u* leading to an onset of cavitation can be obtained from the Bernoulli equation:

$$\frac{1}{2}\rho u^2 = \nabla P \qquad (2)$$

Roughly speaking then, the left-hand term of equation 2 should be larger than 10^5 Pa. Using ρ = 1000 kg/m^3 for water, the threshold velocity *u* is approximately 14 m/s. A sinusoidal oscillation at a frequency of 190 Hz and with an oscillation amplitude of 1.2 mm gives a velocity of only 1.4 m/s. Ultrasonic file, typically driven at 30 kHz and with an oscillation amplitude of 75 µm, reaches velocities above this threshold and can therefore generate cavitation, as previously observed by Ahmad *et al.* (15).

There are three types of EndoActivator® tips currently available, 15#/.02, 25#/.04 and 35#/.04. A different dimension of the tip applied in the same size root canal might produce different oscillations and irrigant flow, which could influence the effectiveness of the instruments. The size of the standardized model used in this study was 30#/.06, which is clinical relevant. Therefore we tested the 15#/.02 and 25#/.04 tips. The 35#/.04 tip should be tested with larger size and tapered root canal, so we did not include it. The results showed that there was no difference between the two types of sonic tips, not in amplitude, oscillatory pattern or wall contact. The irrigant flow and streaming pattern of the irrigant were therefore equal, resulting in the same effectiveness of the irrigation.

There was no significant difference between NaOCl and water as irrigant when it was sonically activated. Since the fluidic properties of water and NaOCl are comparable (17), no differences in acoustic streaming between them were to be expected.

Table 1. Experimental groups and the number of specimens at each score rank after irrigation procedure

Group (*n*=18)	Activation system	Freq. (Hz)	Size/ taper	Irrigant	Score **0**	**1**	**2**	**3**
1	Ultrasonic	30,000	20#/ .00	NaOCl	16 (90%)	1 (5%)	1 (5%)	0 (0%)
2	Sonic	190	15#/ .02	NaOCl	3 (17%)	4 (22%)	9 (50%)	2 (11%)
3	Sonic	190	25#/ .04	NaOCl	3 (17%)	6 (33%)	0 (0%)	9 (50%)
4	Sonic	160	15#/ .02	NaOCl	1 (5%)	2 (11%)	12 (67%)	3 (17%)
5	Sonic	190	15#/ .02	Water	0 (0%)	5 (28%)	12 (67%)	1 (5%)
6 (control)	No activation	0	15#/ .02	NaOCl	0 (0%)	0 (0%)	0 (0%)	18 (100%)

Score 0: the groove is empty; score1: less than half of the groove is filled with debris; score 2: more than half of the groove is filled with debris; score 3: the complete groove is filled with debris.

Figure 1. (A) Schematic representations of the standardized root canal model, its groove (B-1) and cross section (B-2). (C) The examples of the different score scales. (This figure is available in color online at www.aae.org/joe/.)

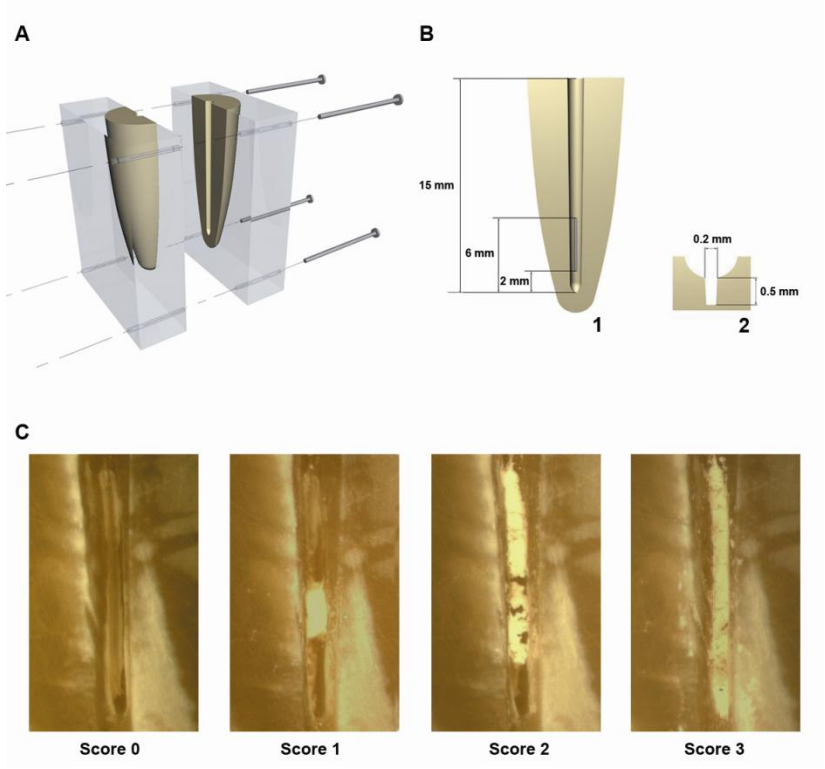
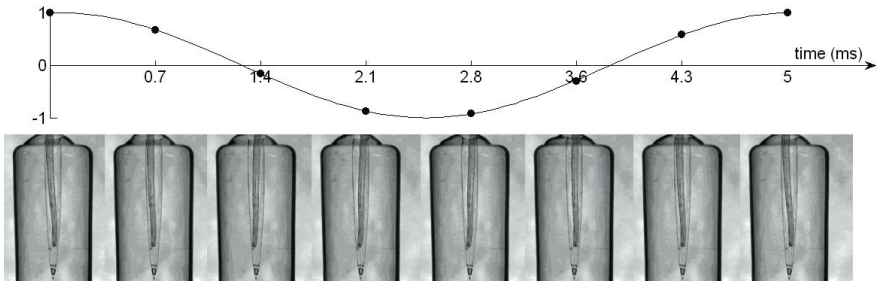


Figure 2. The oscillation of the file inside the root canal during 1 oscillation at mode 3 (190 Hz), recorded at 4000 fps; dots on the graph indicate at which time during the oscillation the frames were recorded.



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