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Abstract

INTRODUCTION: It was the goal of this study to compare different NaOCl activation schemes regarding a desired and an untoward outcome. Ultrasonic tips and a currently marketed sonic system were used in conjunction with a 2.5% sodium hypochlorite solution. Necrotic pulp tissue dissolution in simulated accessory canals and transportation of the main canal were assessed. METHODS: Epoxy resin models (10 per group) with a curved simulated main root canal and two simulated accessory canals filled with necrotic bovine pulp tissue were irrigated passively with one of three ultrasonic setups (straight stainless steel files, prebent stainless steel files, or nickel-titanium tips) or a sonic device in conjunction with a plastic tip. Activation was performed four times for 30 seconds with replenishment of the NaOCl solution in between. All the files/tips had a 2% taper and a 0.15-mm tip diameter according to the manufacturer. Data from superimposing and analyzing digital photos before and after treatment were statistically analyzed using one-way analysis of variance followed by Bonferroni's correction for multiple comparisons (alpha < 0.05). RESULTS: Passive ultrasonic irrigation (PUI) in all the groups dissolved significantly more tissue than sonic activation ($p < 0.05$). No detectable canal transportation with sonic activation was observed. The difference in this outcome was not significant compared with ultrasonically activated nickel-titanium tips, whereas the straight stainless steel files caused significantly more ledging compared with these setups ($p < 0.05$). CONCLUSION: Under the current conditions, PUI with a nickel-titanium tip promoted superior tissue-dissolving effects over sonic irrigant activation while maintaining simulated canal anatomy.

Acoustic Hypochlorite Activation in Simulated Curved Canals

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Methods Epoxy resin models (10 per group) with a curved simulated main root canal and 2 simulated accessory canals filled with necrotic bovine pulp tissue were irrigated passively with either of 3 ultrasonic set-ups (straight stainless steel files, pre-bent stainless steel files, nickel-titanium tips) or a sonic device in conjunction with a plastic tip. Activation was 4 times 30 sec with replenishment of the NaOCl solution in between. All the files/tips had a 2% taper and a 0.15 mm tip diameter according to the manufacturer. Data from superimposing and analyzing digital photos before and after treatment were statistically analyzed using one-way ANOVA followed by Bonferroni's correction for multiple comparisons (alpha < 0.05).

Results Passive ultrasonic irrigation (PUI) in all the groups dissolved significantly more tissue than sonic activation ($p<0.05$). No detectable canal transportation with sonic activation was observed. The difference in this outcome was not significant compared to ultrasonically activated nickel-titanium tips, while the straight stainless steel files caused significantly more ledging compared to these set-ups ($p<0.05$).

Conclusions Under the current conditions, PUI with a nickel-titanium tip promoted superior tissue-dissolving effects over sonic irrigant activation while maintaining simulated canal anatomy.

Introduction

It has become evident over the past decades that complete debridement of an infected root canal system is a goal that is impossible to achieve. Mechanical preparation does obviously not suffice to clean necrotic root canals (1). It has thus been suggested to use acoustic irrigant activation to improve cleanliness and disinfection of root canal systems prior to root filling (2, 3). The synergistic effects of ultrasonic energy and sodium hypochlorite in aqueous solution appear to be especially useful in that context (2, 4, 5). Currently, passive ultrasonic irrigation (PUI) is probably the most established method to activate a sodium hypochlorite irrigant after root canal instrumentation (6-8). PUI relates to activation of an irrigant by an ultrasonically activated file or tip that is not used for canal preparation. The term can refer to both, placement of the irrigant by a syringe with subsequent activation or delivery of the irrigant through the ultrasonic handpiece. PUI has shown promising results in the removal of debris from root canals. Previous studies, however, were mostly carried out in straight simulated canals (9, 10), which are rarely encountered in teeth. One study showed no impact of canal width, taper or curvature in disinfecting the root canal system using ultrasonic sodium hypochlorite activation after canal preparation (11). On the other hand, there is evidence that performance of ultrasonically activated files or tips will be dramatically reduced in the case of instrument restriction (12, 13). A straight instrument placed in a curved canal will have at least three contact points with root canal walls. This might stress the need of bending the instrument to follow the canal curvature and ensure maximum efficiency and to avoid the risk of canal transportation (14). Alternative measures to avoid canal transportation and maintain instrument efficacy during acoustic irrigant activation include the use of a smooth wire in an ultrasonic device (15, 16), or a plastic tip in a sonic handpiece (17). There is, however, limited information regarding the effectiveness of these approaches. One reason for this has been the lack of model systems that allow comparative

studies on desired and untoward effects of acoustic irrigant activation methods. The term acoustic activation was chosen in this communication to have a common denominator for both, sonic and ultrasonic activation. With both methods, compression waves, albeit of different frequencies, are generated in the irrigant.

Using a modification of a recently introduced epoxy resin model (10), it was the goal of the current study to compare the effects of different ultrasonic tips and a currently marketed sonic system on necrotic pulp tissue dissolution in conjunction with a 2.5% sodium hypochlorite solution and transportation of the simulated main canal.

Materials and Methods

Model Fabrication

50 epoxy resin (Stycast, Emerson & Cuming, Westerlo, Belgium) models were fabricated with minor modifications as previously described (10). Each model was used for just one experiment. The simulated main canal was cast using a size-D spreader (Dentsply Maillefer, Ballaigues, Switzerland). This instrument had a length of 25 mm, a tip diameter of 0.35 mm, and a .06 taper. The design modification was that the spreader was bent and controlled by a scale drawing on a sheet of paper representing the targeted curvature of a 20-degree angle between the long axis of the main canal and a line passing the apex to the start of the curvature, representing the transition point between moderately curved and severely curved canals (18). The curvature started in the last 10 mm of the total canal length, which was 25 mm. A coronal space simulating a pulp chamber was created using a rubber tube placed over the spreader coronally and sealed before model casting. The tube was 3 mm high with a 3-mm internal diameter. Two simulated accessory canals of 0.2 mm diameter opposing each other and forming 45-degree angle with the

simulated main canal tangent at 3 mm from the apex were created. A millimetric paper scale was placed close to the simulated accessory canals to facilitate photo analysis (Fig. 1, A).

Bovine Pulp Tissue Preparation

The simulated accessory canals of all models were filled with minced bovine pulp tissue, which had been obtained from bovine anterior teeth. Animals were raised and slaughtered for food production according to the Swiss standards of animal welfare. Consequently, this study was not considered an animal study, and the internal review board had no objections to the current protocol. The teeth were decoronated, and pulps were extirpated and frozen at -20°C in 0.9% NaCl solution. Preparation and handling of the tissue was carried as previously described (10). In brief, frozen tissue was thawed, dried with paper tissues, and then each piece was immersed in liquid nitrogen to achieve a solid dry material. Subsequently, tissue was transformed into fine particles using a scalpel to scratch the hard surface. A 22-gauge needle (Ultradent Products Inc., South Jordan, UT) was used to aspirate the minced tissue. The needle was inserted in its place in the model until it reached the outer end of the simulated accessory canal. The tissue was injected until part of it extruded into the main canal. Excess tissue was placed in the wide entrance of the carrying needle to obtain a passive closure simulating a pathosis rather than a tight seal of the simulated accessory canals. A simulated accessory canal was considered filled when it showed no voids interrupting the continuity of the tissue in the canal. The models were filled immediately before the experiment.

Experiment

In all specimens, the simulated main canal was filled with 2.5% (wt/vol) NaOCl using a 30-gauge irrigation needle (KerrHawe SA, Bioggio, Switzerland). Subsequently, in 4

experimental groups (N = 10, each) the solution in the simulated main canal was activated for 4 times 30 sec. In-between these activation procedures, the NaOCl solution in the simulated main canal was replenished by delivering 1 ml of fresh solution using the irrigation needle described above. In 3 of these groups, the NaOCl was activated using an ultrasonic device (Mini Master Piezon, EMS, Nyon, Switzerland) with the power set at the first level of the "Endo" mode. The first group was activated with K-Type stainless steel files (Endosonore, Dentsply Maillefer) without pre-bending. The second group was activated using a pre-bent K-Type stainless steel file (Endosonore, Dentsply Maillefer). The files in that group were bent using a file bender (Flexobend, Dentsply Maillefer). The third group was activated using blank ESI Ni-Ti tapered wires (EMS). The fourth group was activated using a sonic device equipped with plastic tips (EndoActvator, Advanced Endodontics, Santa Barbara, CA). All the files and tips had an ISO size 15 according to their respective manufacturers and a 2% taper. Files and tips were used in only one model and then discarded. During activation, the files/tips were introduced to 1 mm from the total canal length and moved up and down. In the negative control group (N = 10), sodium hypochlorite was delivered as in the experimental groups, but it was not activated.

Before the experiment and after each interval (before irrigant replenishment), a photo was taken using a Nikon 10-megapixel camera (Nikon D200, Tokyo, Japan) for results interpretation. To enhance visibility, the models were held in position against a light source (Intralux 4000-1, Volpi AG, Schlieren, Switzerland) using a specially designed cone.

Data generation and analysis

The random number-coded digital photographs were analyzed individually by 2 blinded observers for the outcomes tissue dissolution and canal transportation, both in mm. The observers (F.P. and A.A.) were an associate professor and a graduate student, both trained and

calibrated in the analysis described below. The distance of tissue dissolution in a simulated accessory canal, measured from the canal entrance to the closest tissue-irrigant interface, was measured on the standardized photographs obtained after treatment. Canal transportation analysis was performed by superimposing pre- and postoperative images; the maximum deviation from the original canal wall was measured. All images were analyzed using freely available software (ImageJ, www.nih.gov). Calibration was done using the millimeter paper embedded in each individual specimen (Fig. 1).

First, the values obtained were compared between the 2 observers. Values that differed by more than 100% from the mean difference were recorded again. For this purpose, a third observer arbitrated between the 2 observers, who then re-judged the images individually. Subsequently, the mean difference (± standard deviation) between the observers' measurements regarding tissue dissolution was 0.06 ± 0.06 mm, the corresponding difference regarding canal transportation was 0.02 ± 0.03 mm. The original values were calculated to the third decimal by the computer program (0.001 mm). Based on the observer difference, however, results pertaining to tissue dissolution were rounded to the first decimal (0.1 mm), values pertaining to canal transportation to 0.05 mm. Average values between the 2 observers were taken for all further calculations.

Data showed a normal distribution, as was viewed on box plots. Consequently, parametric statistical tests were employed and mean values and standard deviations are presented. To compare for differences between the investigated systems, tissue dissolution values were averaged between the 2 simulated accessory canals per model and then the mean values per group were compared using one-way ANOVA followed by Bonferroni's correction for multiple comparisons. To check whether there was a difference regarding tissue dissolution distance between the simulated accessory canal inside and outside the main canal curvature in

individual treatment groups, mean values were compared within groups using paired t-test. Canal transportation was compared between groups using one-way ANOVA followed by Bonferroni's correction. The alpha-type error for all tests was set at 0.05.

Results

Tissue Dissolution

The mean tissue dissolution values per groups were: 2.0 ± 1.0 mm, 1.4 ± 0.8 mm, 1.9 ± 1.0 mm, and 0.2 ± 0.1 mm for straight stainless steel files, pre-bent stainless steel files, Ni-Ti tips and the sonic system under investigation, respectively. Mere "passive" placement of the sodium hypochlorite solution for 4 times 30 sec in the negative control group dissolved an average of 0.1 ± 0.1 mm tissue, a value that was statistically similar to that observed with the sonic system under investigation ($p>0.05$). The ultrasonic groups did not differ from each other in a statistically significant manner, while the sonic system and the passive irrigant delivery dissolved significantly less tissue than these set-ups ($p<0.05$). There was no significant difference in tissue dissolution between the simulated accessory canals inside and outside the simulated main canal curvature with any treatment (Table 1).

Canal Transportation

The sonic system and ultrasonically activated nickel-titanium tips caused no detectable canal transportation, and in this regard performed significantly ($p<0.05$) better than straight stainless steel files. Ultrasonically activated pre-bent stainless steel files caused intermediate transportation that was between that observed with passive irrigant placement, the sonic set-up or the nickel-titanium tips and straight stainless steel files (Table 2).

Discussion

Under current study conditions, passive ultrasonic irrigation was by far superior to sonic irrigant activation regarding necrotic pulp tissue dissolution in simulated accessory canals. While there was no divergence regarding necrotic pulp tissue dissolution between different ultrasonically activated files/tips, there were clear differences in canal wall transportation. Taking both these outcomes into consideration, the ultrasonically activated nickel-titanium tips performed best, followed by the pre-bent stainless steel files.

The limitation of the current study is the fact that the models that were used were made of a material that differs considerably from human dentin. Furthermore, simulated main canal curvature was merely in one plane. The potential variability in density of the pulp tissue used in the present investigation and also it's history of being frozen in liquid nitrogen could have affected its solubility in sodium hypochlorite. Consequently, the similarity to in vivo pulpal remnants in clinically treated human teeth is suspect and limits the clinical relevance of this study. On the other hand, the current model system allowed comparative quantitative assessments regarding acoustic hypochlorite activation that are hard to achieve in natural teeth.

Although file restriction may reduce efficiency of passive ultrasonic irrigation, based on the current results it would appear that the binding of the activated tip to one of the canal walls does not totally restrict its oscillation. However, in more severely curved canals, the greater force by which a tip contacts the canal walls might reduce its efficiency (12, 13). It may be interesting to note that nickel-titanium tips fracture readily when allowed to oscillate freely, a feature that limits their usability in the clinic. This is related to the fact that nickel-titanium is not necessarily a suitable metal to be activated ultrasonically, because heat is generated inside the metal upon activation. Nevertheless, with a partly restricted tip, no separations were observed in the current

study. This differs from observations made earlier with simulated straight canals (10). A further somewhat surprising finding of the current study was that there was no significant difference in necrotic pulp tissue dissolution between simulated accessory canals inside and outside the main canal curvature. This could be related to the effective field distance around the oscillating file (19). Apparently, the effective field was large enough to overcome the discrepancy in distance from the simulated accessory canals that was clearly there between the different files/tips. While straight stainless steel files and nickel-titanium tips were closer to the simulated accessory canal in the outer curvature, the pre-bent steel files were more or less centrally located in the simulated main canal when activated.

Under the current conditions, sonic activation of a plastic tip was a safe method to irrigate the simulated root canal system regarding canal transportation. As has been shown in earlier studies in extracted human teeth, the EndoActivator device promotes irrigant penetration into simulated accessory canals to a similar extent as ultrasonic irrigation (20), while there is less extrusion of irrigant over the apex (21). Sonic sodium hypochlorite activation, however, had no effect on tissue dissolution in simulated accessory canals under the current conditions. There are two tentative explanations for this: i) the wavelength of a sonic set-up is too long to cause sufficient streaming of the irrigant into narrow accessory canals, and ii) the energy is too low. In preliminary tests, we used another sonic irrigating system with a metal tip (Vibringe, Vibringe B.V., Amsterdam, The Netherlands). This set-up showed no effect on hypochlorite-mediated pulp tissue dissolution either (data not shown), so the lack of effect is probably not due to the fact that the EndoActivator uses plastic tips. Few studies have compared ultrasonic with sonic irrigant activation. Jensen and co-workers (22) found less organic debris in human root canals when a 5.25% NaOCl solution was activated for 3 min with a sonic or ultrasonic handpiece equipped with a size 15 stainless steel file compared to a control treatment with passive

placement of the irrigant. No difference between sonic and ultrasonic passive irrigant activation was found. The difference between those and the current results could be explained by the unlike outcomes that were evaluated. In the former study, debris in the main canal was stained and scored, while in the current study, tissue dissolution distance in simulated accessory canals was compared. Sonic irrigant activation may thus have desired effects in the main canal. More research is necessary to elucidate this further.

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Caption

Figure 1. (A) Epoxy resin model used in the current study. (B) Close-up of simulated accessory canals filled with minced bovine pulp tissue. Note that the tissue extends into the simulated main canal. (C) Simulated canal system after ultrasonic activation using a straight stainless steel file for 4 times 30 sec. Arrowheads: level of dissolved tissue in simulated accessory canals; arrow: maximum canal transportation.

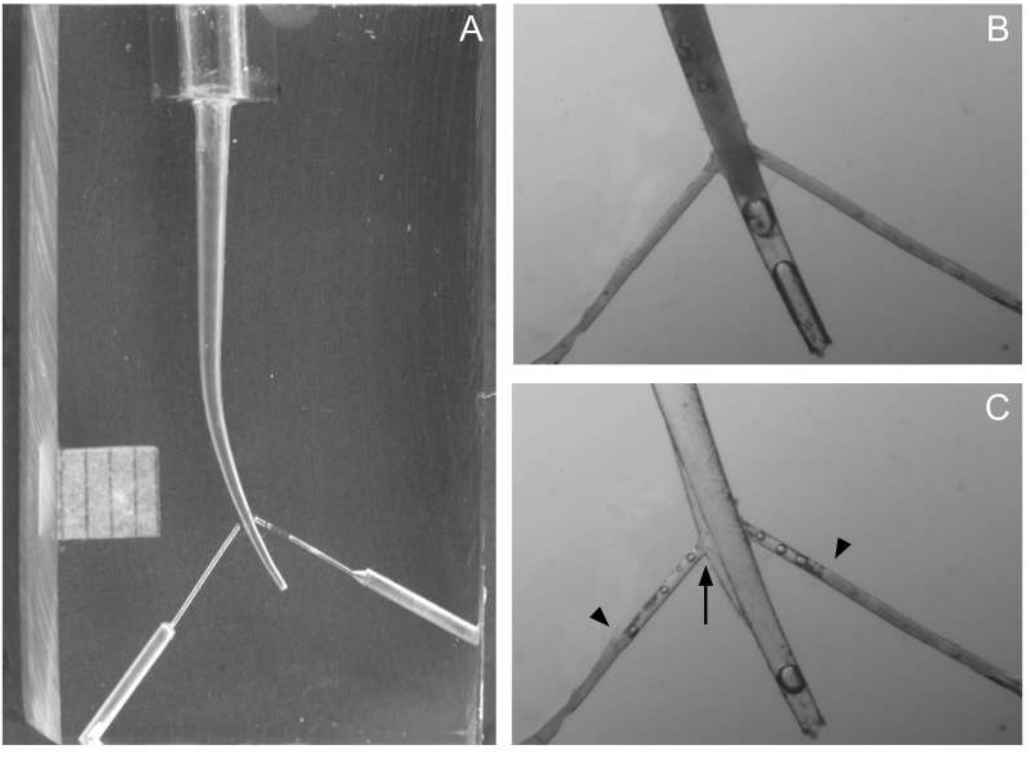
A
B
C

TABLE 1. Bovine necrotic pulp tissue dissolution distance (means ± SD) in simulated accessory canals inside and outside the main canal curvature

Group	Inner SAC	Outer SAC
No activation of NaOCl	0.1 ± 0.1 mm^{A}	0.1 ± 0.2 mm^{A}
US straight stainless steel files	2.0 ± 0.9 mm^{B}	2.0 ± 1.4 mm^{B}
US pre-bent stainless steel files	1.5 ± 1.1 mm^{B}	1.4 ± 0.6 mm^{B}
US nickel-titanium tips	1.6 ± 0.9 mm^{B}	2.9 ± 1.2 mm^{B}
S plastic tips	0.2 ± 0.2 mm^{A}	0.2 ± 0.2 mm^{A}

SAC: simulated accessory canal; US: ultrasonically activated; S: sonically activated. Identical superscript letters indicate that there was no significant difference between data sets at the 0.05 level (ANOVA between, paired t-test within groups).

TABLE 2. Maximum transportation (means ± SD) of the simulated main canal by the treatment modalities under investigation

Group	Transportation
No activation of NaOCl	0.00 ± 0.00 mm^{A}
US straight stainless steel files	0.15 ± 0.05 mm^{B}
US pre-bent stainless steel files	0.05 ± 0.05 mm^{A,B}
US nickel-titanium tips	0.00 ± 0.00 mm^{A}
S plastic tips	0.00 ± 0.00 mm^{A}

US: ultrasonically activated; S: sonically activated. Identical superscript letters indicate that there was no significant difference between data sets at the 0.05 level (ANOVA, Bonferroni).