Temperature changes during ultrasonic irrigation with different inserts and modes of activation

Zeltner, M; Peters, O A; Paqué, F
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Abstract

This study evaluated temperature changes during passive ultrasonic irrigation. Root canals of three extracted maxillary canines were enlarged to size #45. Thermocouples were mounted 3, 6, and 9 mm from the apical foramen. Teeth were placed in a water bath at 37 degrees C. Distilled water (20 degrees C) was continuously delivered through an ultrasonic unit (group 1) or deposited into the root canal before ultrasonic activation (group 2); for activation, noncutting nickel-titanium (NiTi) inserts or stainless steel K-files #15, #25, and #35 were used. Before and during ultrasonic activation, temperatures were continuously measured for 210 seconds. Statistical analysis was performed using analysis of variance and Scheffé post hoc tests. Temperatures initially decreased by up to 7.4 degrees C; these drops were significantly smaller in group 1 than in group 2 (p < 0.001) in the middle and apical root canal third. The decreases were followed by temperature rises for all inserts in group 2. However, in group 1, temperatures just reached baseline values in middle and apical thirds; in the coronal root canal third, lower temperatures were measured. In group 2, mean temperature rises were 7.7 degrees C, 7.5 degrees C, and 4.2 degrees C in coronal, middle, and apical root canal thirds. Here, K-file type inserts size #35 generated highest and inserts size #15 the lowest temperatures rises; NiTi inserts were more effective than size #15 K-files and less effective than #35 K-files. Continuous flow negated the potential of ultrasonic activation to heat irrigation solutions. Noncutting NiTi instruments and large K-files were more effective than small K-files in warming deposited irrigants.
Temperature changes during ultrasonic irrigation with different inserts and modes of activation

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Abstract

Introduction This study evaluated temperature changes during passive ultrasonic irrigation (PUI) of intracanal solutions.

Methods Non-cutting Nickel Titanium inserts or stainless steel K-Files #15, #25 and #35 were used. Root canals of three extracted human maxillary canines were enlarged to apical size #45. Thermocouples were mounted inside root canals 3, 6 and 9 mm from the apical foramen. Teeth were placed in a water bath at 37°C. Distilled water (20°C) was continuously delivered through the ultrasonic unit (Group 1) or deposited into the root canal prior to ultrasonic activation (Group 2). Baseline temperatures were determined before irrigation and averaged. Ultrasonic activation was subsequently performed; fifteen measurements were done with each insert. Temperatures were recorded every second and expressed as differences to baseline values. Statistical analysis was done using ANOVA and Scheffé post-hoc tests.

Results Initially, temperature decreased by up to 7.4°C; these drops were significantly smaller in Group 1 than in Group 2 (p<0.001) in the middle and apical root canal third. The decreases were followed by temperature rises for all inserts in Group 2. However, in Group 1, temperatures just reached baseline values in middle and apical thirds; in the coronal root canal third lower temperatures were measured. In Group 2, mean maximum temperature rises over baseline were 7.7, 7.5 and 4.2°C in coronal, middle and canal thirds, respectively. There were significant differences between activation modes for all inserts (p<0.001). In Group 2, K-file type inserts size #35 generated highest and insert size #15 the lowest temperatures; the NiTi inserts was more effective than size #15 K-files and less effective than #35 K-files.

Conclusions Continuous flow negated the potential of ultrasonic activation to heat irrigation solutions inside root canals. Non-cutting NiTi instruments and large K-files were more effective than small K-files in warming the irrigation solution.

Key words: ultrasonic, irrigation, heating
Introduction

Since endodontic disease is caused by intracanal microorganisms, the main therapeutic strategy is to eradicate intracanal infection (1). Byström (2) established in 1981 that mechanical preparation of root canals alone was insufficient to reduce bacterial contamination. Subsequently Sjögren & Sundqvist (3) indicated that the use of ultrasonic instrumentation in the presence of 0.5% sodium hypochlorite was more effective than hand instrumentation alone in eliminating intracanal bacteria. Since then, the relative efficacy of vibration in the ultrasonic (>20’000 Hz) and sonic frequency range (<20’000Hz) in root canal debridement has been assessed (4, 5). There appears to be a consensus that activation of irrigant enhances irrigant efficacy (6, 7), however there is disagreement in the relative efficacy of ultrasonic vs. sonic activation to remove microbial contaminants (4, 5).

Similarly, there is no consensus, which type of powered insert is most beneficial for ultrasonic activation of irrigation solutions, files with cutting flutes or non-cutting inserts. Non-cutting inserts have the benefit that they avoid creating unfavorable canal shapes reported for actual canal preparation with ultrasonics (8) and they appeared to be as effective in debris removal as fluted files (9, 10). However, in the latter studies finger spreaders or smoothed and polished size K-files were used while non-cutting inserts made of Nickel Titanium (NiTi) are currently commercially available (EMS Endosoft, EMS, Nyon, Switzerland).

There are several distinctly different methods in which ultrasonic and sonic energy can be utilized to enhance the efficacy of irrigation during root canal treatment: (i) irrigated canals may be shaped with powered inserts (11), (ii) solution placed in the canal with a syringe/needle may be activated (7), or (iii) irrigant may be delivered continuously while being activated (12). The two latter modes of activation are summarized as passive ultrasonic activation (PUI). The term “passive” sometimes is confusing here because PUI per se is an active process and is related to the non-cutting action of the activated files. PUI may be used with continuous irrigant flow (here termed PUI-CF) from the ultrasonic handpiece or by
activation of the ultrasonic power source after syringe delivery of the irrigant (here termed PUI-SD).

Due to irregular shapes with excessive canal wall thinning, the ultrasonically canal instrumentation (UI) has produced canal preparation errors and fallen into disregard (8, 13) but the two latter approaches are currently utilized in endodontic therapy. In fact, new devices continue to be developed to improve irrigation efficacy, amongst them special ultrasonic inserts (e.g. EndoSoft) and sonic handpieces dedicated solely to irrigation activation (EndoActivator, Dentsply Tulsa Dental, Tulsa, OK).

The mechanism of action for ultrasonics and sonics in root canal irrigation is not fully understood. Cameron conducted a series of studies on the efficacy of ultrasonics in conjunction with conventional canal preparation and irrigation with sodium hypochlorite. He concluded that there was a synergistic effect of ultrasonics and sodium hypochlorite (14). Extending Cameron’s findings, Ahmad and coworkers (15) excluded cavitation as the mode of energy transfer and concluded that acoustic streaming was important for activation of irrigants and that this flow was effective in dislodging of adherent flora and potentially even in killing of bacteria (16).

The presence of sodium hypochlorite in ultrasonically and sonically activated irrigation allows considering another mechanism of action beyond acoustic streaming, intracanal warming of irrigation solutions, as described by Cameron (17). Such an effect may be helpful in increasing sodium hypochlorite action both against microbes as well as soft tissue (18, 19). However, no data is available regarding the mode of activation when using inserts of different sizes and materials. Therefore the aim of the present investigation was to measure intracanal temperatures using different inserts during various modes of activated irrigation.
Materials and Methods

Preparation of root/thermocouple assemblies

Three human canines that had been stored in 0.1% thymol solution were selected. The teeth had been extracted for reasons not related to this study and permission had been obtained to use these teeth for in vitro research. Pulp chambers were accessed and working lengths determined by passing a size #10 K-file just through the apical foramen and deducting 0.5 mm from this length. Canals were then shaped with K-Flexofiles (Dentsply Maillefer, Ballaigues, Switzerland) used with balanced force motion to an apical size #45. Shaping was completed by stepping back further sizes of K-Flexofiles in 0.5 mm increments up to a size #80 and recapitulating with a size #45 file. During preparation, canals were irrigated with 1%NaOCl delivered from a syringe with a 30g needle (Max-i-Probe, Dentsply Tulsa Dental). Using a stereomicroscope (Leica Wild M3Z, Wild, Heerbrugg, Switzerland), openings were drilled across radicular dentin to the canal with a round diamond (FG Diamond 2.3 mm ∅, Heico, Steinach, Switzerland). These openings were created at 3, 6 and 9 mm from the apex to mount thermocouples (Z2-T-2M, Labfacility, Hanau, Germany) flush with the canal walls (Fig. 1a). To secure this position, the largest K-file that fit at the respective position was placed into the root canal; the thermocouple was positioned against the file and very slightly pulled back. This ensured that there was no direct contact between the oscillating file and the thermocouple. After application of the Syntac Classic dentin bonding system (Vivadent Ivoclar, Schaan, Liechtenstein) the thermocouples were fixed in position with Tetric composite (Vivadent Ivoclar) and final position of the thermocouple was verified with radiographs (Fig. 1a).

Specimens were mounted individually in an opening of the lid of plastic containers, so that the roots were submerged in the containers to the CEJ; the containers were then filled with tap water and placed in a servo-controlled water bath (Compenstat, Gallenkamp, London, UK) at 37°C. Thermocouples were connected to a data recorder (Agilent 34970, Agilent, Santa Clara
CA) running Agilent BenchLink software. Accuracy of temperature measurements was verified in pilot studies to be 0.1°C, by comparing results from the thermocouples submerged in water with calibrated thermometer readings.

**Application of ultrasonic energy during irrigation**

Stainless steel K-files size #15, #25 and #35 (Endosonore, Dentsply Maillefer) and blunt NiTi inserts (Endosoft, EMS) were clamped in the EMS file holder and activated with the EMS 400 unit. The dials on the EMS unit were set to 1/4 for power and 3/4 for flow (in the experiments with constant irrigation flow).

Irrigation solution was equilibrated at 20°C and delivered immediately after taken out of a heating/cooling cabinet (Lauda MS-3 Circulator, Lauda-Königshofen, Germany). In Group 1 irrigation solution was delivered via the EMS unit from an attached container with a flow rate was 55ml/min (PUI-CF). In Group 2, irrigant was placed in the root canal to working length without binding using a 30g needle and a syringe (PUI-SD). Preliminary experiments had demonstrated that water and 1% NaOCl behaved similarly regarding temperature changes under the present conditions and all experiments in this study were done using water as the irrigation solution to avoid any corrosion of the thermoelements.

Each measurement consisted of time periods of about 210s, with 20 to 30s baseline recordings preceding irrigant deposition and then 180s of ultrasonic activation. Each insert (K-files size #15, 25, 35 and Endosoft) was used in the three prepared root/thermocouple assemblies; five independent measurements were performed using each of the three assemblies, giving n=15 per insert. A control group consisted of 10 measurements without ultrasonic activation, in which temperature was recorded during conventional irrigation and without ultrasonics.

Temperatures were continuously measured from the three thermocouples; data was digitized at 1 Hz and stored for off-line analysis. No attempts were made to measure or to shield against electromagnetic interference.
Data analysis

Temperatures recorded during periods before irrigant deposition and ultrasonic activation were averaged and served as baselines. Relative maximum and minimum temperatures were determined in time periods beginning 30s after irrigant delivery. Data was compared using Analysis of Variance with Scheffé post hoc tests, using \( \alpha=0.05 \) as the level of statistical significance. Repeated-measures ANOVA was used to compare maximum temperatures after activation to baseline values; all data was deemed to fulfill the criteria for parametric tests.
Results

A total of 130 temperature measurements consisting of approximately 210 data points each were obtained. During the baseline period of 23.2±3.2 s before deposition of irrigation solutions or activation, temperatures were stable in the range of 33.9 to 37.0°C. There were significant variations among the thermocouple positions (Fig. 1b & 2, p<0.01); the temperatures measured coronally were consistently lower than the ones determined for the apical and middle position in all three assemblies. There were also slight but significant differences among baseline temperatures comparing the three assemblies (p<0.01). Due to these systematic variations, temperature changes during activated irrigation were expressed as differences to baseline.

Typically, deposition of irrigation solution without use of ultrasonics resulted in drops of up to 9°C, with means of 5.3±0.6, 6.1±0.8 and 7.5±0.8°C for coronal, middle and apical measurements, respectively. These initial drops were followed by gradual warming towards baseline values over about 35 seconds (Fig. 1b). The use of ultrasonic activation with a continuous flow of irrigant (Group 1, PUI-CF) resulted in a different pattern (Fig. 2): a consistent temperature drop was present only in the coronal third; a more variable pattern and sometimes slight increases towards baseline were noted for middle and apical thirds toward the end of the recording periods (Table 1).

In Group 2 (PUI-SD), temperatures decreased initially similarly to control (and significantly more than in Group 1, p<0.001) but increased thereafter continuously over time beyond baseline (Fig. 2, Table 1). Towards the end of the recording periods, mean maximum temperatures increases of up to 7.7°C occurred in coronal and middle locations but the apical increases were significantly lower (Table 1, p<0.05).

Both PUI-CF and PUI-SD were performed with four different inserts, stainless steel K-files sizes #15, #25 and #35 as well as Nickel Titanium non-cutting tips. Regarding attenuation of temperature drops during PUI-CF (Group 1), inserts were similarly effective. Regarding
temperature increases in Group 2, K-files in size #35 were most effective and size #15 were least effective (p<0.05).

None of the inserts or the attachments fractured during the course of this study.
Discussion

Main findings
The efficacy of an irrigation solution to decontaminate root canal systems is influenced by many factors. Not only do larger sized apical preparations enhance the efficacy of irrigation, but the use of ultrasonic energy significantly increases the cleaning ability of the irrigants as well (1-3). The purpose of the experiments described in this paper was to analyze temperature changes in irrigation solutions during ultrasonic activation. For irrigation with simultaneous ultrasonic power, we found slight drops in temperature and rarely increases beyond baseline. However, for syringe delivery and subsequent activation, we found different patterns consisting of drops of ~7°C, followed by temperature increases that varied for activated inserts of different size and flexibility. The maximum temperature inside the root canal ex vivo was 51.5°C. Moreover, the temperature increase of the irrigation solution was highest with the stiffest file and with PUI-SD.

Strengths and weaknesses
Regarding the experimental setup, similar to experiments focusing on temperature increases during post removal (20), we used water bath to provide a constant environment and to simulate the heat capacity of the tissues surrounding the tooth, including periodontal ligament perfusion. In contrast, Ahmad (21) used immersion in a water bath set at 20°C and Cameron (17) placed the tooth in an air space over a water bath heated to provide a stable temperature of the thermocouples at 37°C. The present study uses three single rooted teeth with relatively straight roots and large apical preparation size. It is believed that an oscillating file can vibrate relatively freely under these conditions, operating with little or no constraint, a factor that had been identified to reduce the efficacy of ultrasonic activation (22). Narrower and curved canals will likely lead to more wall contract of the oscillating file and potentially less energy transfer. Therefore large straight root canals like the ones prepared here and in other
experiments (17, 21, 23) may present a special scenario regarding any potential temperature increase during ultrasonic activation of irrigation solution.

Comparison to other studies

Two older studies (17, 21) describing temperature changes in ultrasonically activated irrigants vary in conditions such as canal diameter, activation and energized insert. The present study is in keeping with Cameron’s (17), who found similar patterns of a transient drop in temperature and then an increase. Moreover, for continuous irrigant flow, temperature did not reach baseline levels in that study, which is similar to the present results. With intermittent flow, Cameron found maximal intracanal temperatures of 45°C when the energized file was very close to the thermocouple while the greatest heating effect occurred coronally. In contrast to these findings, Ahmad (21) did not find any temperature increase with constant irrigant flow beyond 1°C for an apical thermocouple while the file was placed to midroot. A possible reason for this apparent variance may be different flow rates and recording conditions. Also, the large standard deviations for maximum temperatures in Group 1 in the present study suggest variable intracanal irrigation conditions with continuous flow. Moreover, in a recent investigation using special plastic blocks as a model, mean intracanal temperatures were 53.5±2.71°C after 5 minutes of activation (23); this is in line with a maximum individual temp raise was 15.3°C seen in the present study.

(Meaning/Correlations)

A temperature increase of any solution inside a root canal is considered desirable in principle (24) since it enhances chemical reactivity and hence disinfecting potential (25). On the other hand, any temperature on the outer root surface beyond 47°C is harmful to periodontal ligament and bone (26) and can have in fact catastrophic sequelae (27).

Energy can be transferred from an ultrasonic power source to the solution in various ways. Heat can be directly transferred via the holder and the file into the solution, conversion of
sound energy into heat during cavitation can occur (28) and the file can act against the root canal wall, generating frictional heat.

Larger and as that stiffer files produced greater temperature increases; there was a difference between Nickel Titanium and steel inserts of the approximately the same size. We theorize that a stiffer file does not suffer as much from constraint and may oscillate more freely, such transferring more energy into heat than into streaming or potentially cavitation. Druttman & Stock (11) found no difference in irrigant turnover using dyes in simulated root canals in plastic blocks comparing stainless steel inserts sizes #15, #20 and #25. The apparent better performance of NiTi inserts compared to size #15 K-files is as yet unexplained, specifically since there was no difference in activation of intracanal irrigants in an earlier study evaluating smear layer removal (29).

(Unanswered questions and further research)

This study was not aimed at directly investigating root canal disinfection by way of intracanal temperature raise. However, we have established that PUI-SD is associated with raised temperatures inside root canals, while PUI-CF may merely accelerate the return to baseline. Two aspects of temperature increases deserve attention: (i) is the temperature raise associated with more clinical efficacy, i.e. more rapid dissolution of necrotic tissue and (ii) is the temperature raise safe for bone and periodontal ligament?

It appears that dissolution of necrotic pulp tissue in simulated accessory canals occurs independent of temperature and also streaming effects (23). However, it is unknown at this point whether or not PUI effects in the main canal, including fins and other irregularities (9) may be caused, at least in part, by temperature increases.

Safety concerns remain, specifically when using ultrasonic energy for time periods for more than 2 minutes. In the present study, root surface temperatures were not determined; however, taken together with earlier data (17), the present study suggests that outer root surfaces would not reach critical values of 47°C.
It is at present unclear what mechanisms may be operational for ultrasonic energy transfer into irrigation solutions, with the result of heat generation as well as development of streaming and cavitation. Moreover, it is unclear if the files that generated the least temperature increase in the present study would transfer most energy into the streaming patterns and thus may be more effective for canal disinfection.

In conclusion, the present study demonstrated that passive ultrasonic irrigation after syringe deposition is associated with raised irrigation solution temperatures. More research is needed to demonstrate which of the effects of ultrasonic activation is responsible for increased irrigation efficacy.
Figures and Tables

Fig. 1: Test specimens were constructed by placing three thermocouples flush with the inner root canal wall into openings drilled through dentin (A) that were placed in a 37°C warm water bath. When irrigant at 20°C was deposited into the root canal, temperatures dropped and over about 35s approached baseline temperatures (B).

Fig. 2: Temperature changes over time with passive ultrasonic irrigation with continuous flow (PUI-CF, A) and syringe delivery (PUI-SD, B). Data was averaged from 15 measurements and normalized in relation to the time point of irrigant delivery.
TABLE 1: Mean temperature changes relative to baseline (in °C, ±S.D.) showed biphasic responses with an initial drop and then an increase (n=15 each). Data was recorded continuously during irrigation with ultrasonics with various inserts. The deepest drop and greatest increase are marked. Passive ultrasonic activation of irrigant was either with continuous flow (PUI-CF) or syringe delivery (PUI-SD).
References

### Continuous flow of irrigation solution

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### Irrigation solution deposited with syringe

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