Temperature rise of the post and on the root surface during ultrasonic post removal

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Abstract

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Aim To determine the temperature rise on the root surface caused by ultrasonic post removal using different devices and techniques in a laboratory setting.

Methodology Two ultrasonic devices, one piezoelectrical (Pi) and one magnetostrictive (Ma), were investigated. A serrated titanium post was placed into the distal root canal of a human mandibular first molar. Four coolant parameters were utilized: no air, no water, no evacuation (NN), air only with high-speed evacuation (A), 15 mL min^{-1} water coolant with high-speed evacuation (W15) and 30 mL min^{-1} water coolant with high-speed evacuation (W30). Five simulated post removals were measured at two locations, the post (P) and the root (R), for each coolant parameter. Temperature rise was measured at 30, 60, 90 and 120 s intervals using calibrated infrared thermography ($n = 80$). Temperatures were recorded at 45 ms intervals. Data were analysed using repeated measures ANOVA with the Scheffe *post hoc* test ($P \leq 0.05$).

Results The overall mean pooled effect showed that temperature rise for P = 20.1 ± 27.9 °C and R = 10.9 ± 7.9 °C were significantly different. Significant differences in temperature rise were: Pi > Ma, P > R, NN > A = W15 = W30 however, A > W30.

Conclusions There were significant differences in temperature rise as a function of ultrasonic device, location on the tooth and cooling method utilized for post removal.

Keywords: post removal, root, temperature, ultrasound.

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Introduction

Ultrasonic devices might be used for intraradicular post removal. Clinicians utilize a range of techniques, including no coolant, to improve visibility and air/water coolant to remove debris (Cohen & Burns 2001). One concern with these devices is the heat that they generate, which could penetrate into periradicular tissues and cause damage (Atrizadeh *et al.* 1971).

The ultrasonic energy utilized in endodontic devices is generated by one of two types of ultrasonic transducers that convert one form of energy into another. Piezoelectrical (Pi) transducers produce ultrasonic energy by transforming electricity into ultrasonic vibrations. Crystals within the transducer (usually made of quartz) are vibrated by the electricity flowing through them. By applying an alternating electrical field across the crystals, the quartz is compressed and released producing vibration of the tip. Magnetostrictive (Ma) transducers use ferromagnetic materials and certain nonmetals called ferrites. A change in dimension occurs when a rod or bar of this material is subjected to an alternating magnetic field producing vibration of the tip. Pi and Ma devices also produce noise and heat.

Research has focused on the efficiency of different ultrasonic devices by measuring the time and force required to achieve post removal. Dixon *et al.* (2002) compared the time required to remove a 16 mm No. 5 (0.050 in) Para-post cemented with zinc phosphate

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cement using the Piezo-Ultrasonic (Spartan USA, Fenton, MO, USA) and the Enac OE-50 (Osada Inc., Los Angeles, CA, USA) at their highest intensities. The results showed that both devices were effective with typical post removal times of <2 min. Other studies have also used the time required to achieve post removal as a dependent variable to determine the effectiveness of different ultrasonic devices (Buoncristiani *et al.* 1994, Altshul *et al.* 1997, Smith 2001, Garrido *et al.* 2003). These studies examined the effects of varying power settings and treatment times for removing posts but they did not evaluate factors such as applied force and temperature rise in adjacent tissues.

Satterthwaite *et al.* (2003) investigated temperature rise of the root surface during ultrasonic instrumentation of ceramic and stainless steel posts and found an inverse relationship between temperature rise and remaining dentine thickness. Cameron (1988) used thermocouples to measure the temperature rise on the external and internal root canal wall during cleaning and shaping of the root canal with ultrasonic instrumentation using continuous 30 mL water min^{-1} irrigation. Continuous water flow caused the external temperature to fall from 37 to 32 °C. Results using water coolant intermittently showed a temperature peak of 45 °C internally and 40 °C externally. The thickness of the root canal wall affected the rate of temperature rise, but not the final temperature.

More recently, Trenter & Walmsley (2003) reviewed the hazards associated with using an ultrasonic dental scaler, including thermal hazards to the periodontal tissues. Their review showed that ultrasonic scaling with irrigation causes no significant injury to the periodontal ligament, alveolar bone or the gingival but histological examination immediately after ultrasonic scaling showed some superficial tissue coagulation. Trenter & Walmsley (2003) suggested that in order to eliminate thermal damage, ultrasonic scalers should not be used if the irrigant water flow is below 20 mL min^{-1}. Nicoll & Peters (1998) used thermocouples and dentine/cementum root slabs cut to various thicknesses to determine the temperature rise produced by Ma ultrasonic scalers. Dentine temperature increased both with decreasing slab thickness and with increasing duration of instrumentation. Only scaling without irrigation produced a rise in dentine temperature from baseline to a level reported as deleterious to periodontal tissues. Eriksson & Albrektsson (1983) reported that a 10 °C temperature rise led to thermal damage to periodontal tissues in rabbits. They believed that the threshold for human periodontal tissues would be similar. Studies using ultrasonic devices for endodontics and periodontal scaling have been completed (Kocher & Plagmann 1996, Verez-Fraguela *et al.* 2000), Satterthwaite *et al.* (2003) noted the lack of data of temperature rise on the external portion of the root and the need for investigation of differing volumes of water coolant during post removal.

The purpose of this study was to determine the temperature rise on the external root surface caused by ultrasonic post removal using different devices and coolant regimens.

Materials and methods

Two ultrasonic devices were compared using four different coolant regimens. The first device, the Mini-Endo II (Sybron Dental, Orange, CA, USA) generated ultrasonic energy through a Pi transducer. The second device, the Cavitron (Dentsply, York, PA, USA) generated ultrasonic energy through a Ma transducer. The four regimens were: no air coolant, no water coolant, no evacuation (NN), air coolant only with high-speed evacuation (A), 15 mL min^{-1} water coolant with high-speed evacuation (W15) and 30 mL min^{-1} water coolant with high-speed evacuation (W30) (Table 1).

An air/water pressure regulator (Micro-cart; A-Dec, Newburg, OR, USA) was attached to each ultrasonic device to control the coolant. The water temperature was constant at 18 °C.

A Flexi-Post No. 2 (Essential Dental Systems, New York, NY, USA) was threaded and cemented with glass–ionomer cement into the distal root canal of a human mandibular first molar, with a length of 10 mm. The active threaded post was used to simulate the worst case scenario of post removal and so that it would remain stationary during temperature measurements. A single post and root was utilized to eliminate the variable of remaining dentine thickness and enable a direct comparison of heat effects as a function of the device and cooling regimen. To determine the temperature at the interface of the post and root, the crown

Table 1 Treatment condition as a function of air, water and evacuation cooling

Treatment condition	Air	Water	Evacuation
NN	None	None	None
A	15 psi	None	High-speed
W15	15 psi	15 mL min^{-1}	High-speed
W30	15 psi	30 mL min^{-1}	High-speed

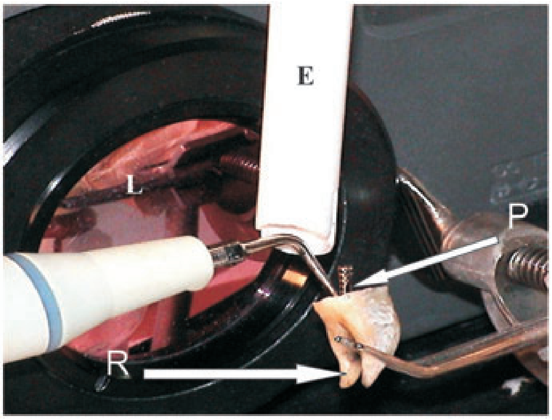

Figure 1 Experimental setup showing the ultrasonic handpiece, high volume evacuation (E), the lens of the infrared camera (L) and the tooth with post. Temperature measurements were taken at the post–tooth interface (P) and at the apical root surface (R).

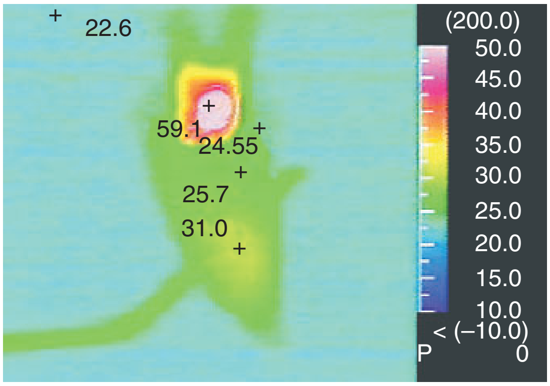

Figure 2 Infrared camera image showing temperature scale on the right, a baseline temperature of 22.6 °C with a temperature of 59.1 °C at the tooth–post interface and 31 °C at the surface of the root during piezoelectric post removal with coolant parameter air only (treatment condition A).

was removed at the level of the cemento-enamel junction. The removal of the crown also eliminated the possibility of heat dissipating into the crown.

Temperature rise was measured at two locations. The first location was at the coronal aspect of the post–root interface (P). The second location was at the distal root surface 3 mm from the apex of the root (R) at the terminus of the post (Fig. 1). The ultrasonic tip supplied with each device was applied to the post at the junction of the post and tooth surface for a duration of 120 s using a circumferential technique around the post. The force applied to the tooth–post interface was designed to simulate the range of force used clinically during post removal.

The experimental setup with evacuation and ultrasonic tip is illustrated in Fig. 1. The tooth was held stationary by clamping the mesial root. Temperatures were measured using an infrared camera (Model TH-5104; Mikron Infrared Inc., Oakland, NJ, USA). The camera measures temperatures by performing a scan of the field of focus every 45 ms. The accuracy of the camera was verified to within ±0.5 °C using heated water at 51 °C and cooled water at 19 °C. The infrared camera has a mercury–cadmium–tellurium linear array detector which enables the camera to detect changes in temperature. The operator distinguished changes in temperature using two different methods. First, the camera was programmed to distinguish variations in temperature by producing a different coloured image on the monitor for every 5 °C change in temperature. Secondly, numeric point values to one significant digit were displayed on the screen in °C. A measurement of room temperature was simultaneously recorded as a baseline for temperature rise. An example of an image produced by the camera is provided in Fig. 2.

Following each trial, the videotape was used to record temperatures at 30, 60, 90 and 120-s intervals. Five repetitions were recorded for each location for each cooling regimen ($n = 80$). Five repetitions were chosen based on a sample size calculation using repeated measures analysis of variance (ANOVA) design with power = 0.8, minimum detectable difference of 5 °C and SD of residuals of five for the eight treatment groups over the four time points measured. The temperature rise was calculated by taking the maximum temperature at each interval and subtracting the baseline room temperature. The temperature of the tooth–post system was allowed to return to room temperature in between repetitions. All data were obtained and recorded by a single operator. Independent variables were as follows: device type, location on the tooth and cooling regimen. The dependent variable was temperature rise. Results were analysed for statistical significance using repeated measures ANOVA with the Scheffe *post hoc* test ($P \leq 0.05$).

Results

The overall mean pooled effect for temperature rise following instrumentation with each ultrasonic device is displayed in Table 2. Temperature rises were higher for the Pi, especially with no air and no water coolant.

Table 2 Temperature rise as a function of ultrasonic device

Device	Temperature rise (°C) ± 1 SD
Piezoelectric	20.1 ± 27.9
Magnetostrictive	10.9 ± 7.9

Table 3 Temperature rise as a function of ultrasonic device and location

Device/location	Temperature rise (°C) ± 1 SD
Piezoelectric/post	27.9 ± 34.2
Piezoelectric/root	12.3 ± 16.6
Magnetostrictive/post	13.9 ± 8.9
Magnetostrictive/root	7.9 ± 5.3

Table 3 shows the temperature rise as a function of device type and distinguishes between the locations on the tooth. As expected, the temperature at the post–tooth interface was higher than at the surface of the root. The post–tooth interface and root surface heat profiles were uniform and followed the outline of the tooth and we did not visualize any change in heat profile at the slight concavity of the mesial aspect of the distal root used in the study. Figures 3 and 4 show temperature rise as a function of device, location and cooling regimen. Temperature rise was inversely proportional to air and water coolant. Statistically significant differences were found for temperature rise at the post location using the Pi device where NN > A = W15 = W30. There were no statistically significant differences in temperature rise at the post location using the Ma device where NN = A = W15 = W30. At the root, results for the Pi device were NN > A = W15 = W30. At the root, results for the Ma device were NN = A = W15 > W30. The mean pooled results were significantly different between device type (Pi > Ma) and location on the tooth (P > R). Statistical significance regarding temperature rise between cooling regimens was as follows: NN > A, A = W15, W15 = W30 and A > W30 for both devices tested. Temperature rise as a function of time and location is listed in Table 4. Overall, the majority of the temperature rise at the post occurred within the first 30 s whereas the temperature rise at the root surface continued to rise up to 90 s.

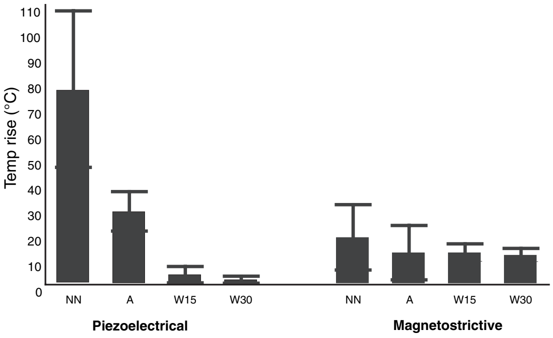

Figure 3 Temperature rise at the post as a function of ultrasonic device and cooling regimen.

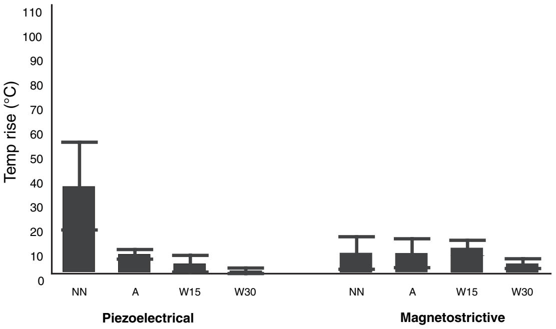

Figure 4 Temperature rise at the root as a function of ultrasonic device and cooling regimen.

Table 4 Mean temperature rise (°C) as a function of location and time interval

	30 s	60 s	90 s	120 s
Post	23.8 ± 31.0	29.6 ± 35.8	31.0 ± 36.5	27.1 ± 35.3
Root	6.7 ± 7.8	12.0 ± 15.3	14.8 ± 18.9	15.6 ± 20.9

Discussion

The ultrasonic devices used in this study were selected to compare the differences in the temperature rise using different ultrasonic transducers. The four cooling regimens used in this study were selected to include common cooling techniques currently used by many practitioners. The NN parameter was selected as this technique provides the best visualization for the clinician, although with the highest temperature rise. Temperature rise at both the crown and the root was measured in order to determine the amount of heat conducted down the post to the root. The distal root of the mandibular molar was chosen as this represents a common site of post placement. The temperature rise at the distal surface of the root was measured to facilitate imaging with the infrared camera. The 120 s duration of instrumentation was chosen to simulate a clinical setting in which the progress of post removal would be verified periodically and some form of coolant and evacuation applied to wash the area.

Heat is produced from ultrasonic devices through three different mechanisms. First, via friction created between the titanium post and the ultrasonic tip. Secondly, via the temperature of the coolant flowing through the handpiece. Thirdly, via acoustic energy absorption of ultrasound transmitted to the tooth (Bergeron *et al.* 2001).

The Pi transducer caused a significantly greater temperature rise than the Ma transducer when the NN cooling regimen was used. However, the Ma device produced a higher temperature using the W15 and W30 parameters at both the crown and the root than the Pi device. Although the post–tooth system was allowed to cool to room temperature between repetitions, the heat produced and retained within the transducer most likely explains the above observation caused by the water coolant flowing through the handpiece. The increased temperature of the water coolant caused by the ferromagnetic rods might have contributed to the increased temperatures observed with the use of the Ma device.

Repeated measure methods were used reducing the sample size estimate to five repetitions per treatment condition. This allowed for the determination of statistical differences between the two devices and four coolant regimens over time at the post and root surface. One post and root was utilized in order to limit the variability because of differences in remaining dentine thickness and root volume. By this method, it was possible to determine differences in heat produced as a function of the devices and cooling regimen. The average length of the distal root of a lower first molar is 14 mm. In the cervical region, the mesial/distal width is generally equal to the buccal/lingual width, 9 mm (Ash 1993). By comparison, the average root length for maxillary and mandibular canines is 16 mm with cervical mesial/distal width of 5.5 mm and cervical buccal/lingual diameter of 7 mm (Ash 1993). Anterior teeth with less root volume would be expected to have higher temperature rises than those that we reported and roots with larger volumes would be expected to have lower rises than those we reported. Further studies using different size roots would define the range of temperature rises that might be expected for all teeth. However, the sample size would be very large for each treatment group accounting for variation in root size, remaining dentine thickness and volume. A change in heat profile at the slight mesial concavity of the mesial aspect of the molar was expected but did not occur. The infrared images confirmed the majority of the heat diffused down through the post and into the dentine heating the root surface uniformly. It can be hypothesized that within the range of remaining dentine of the root (1–2 mm) that the temperature effects from the diffused heat were within 5 °C because no difference was visualized in the infrared thermal profile. The application of the ultrasonic device was limited to the post for 2 min to simulate a clinical application. Generally, clinicians use a device for this amount of time and then stop to inspect the area. Even 2 min was also a good time as the temperature rise reached steady state within 90 s and did not continue to increase.

Results from Eriksson & Albrektsson (1983) suggested that a temperature rise above 10 °C can cause irreversible damage to the periodontal ligament and bone. Comparisons of temperature rise between cooling regimens were made to determine what regimen cooled the tooth sufficiently to consistently remain below the 10 °C threshold. The infrared camera used to measure temperature rise in this study allowed the measurement of temperature rise to be recorded over a broad area and to a degree of accuracy that is not achievable with the traditional thermocouples used in previous studies. Thermocouples allow temperatures to be recorded at only those locations between the thermocouples where a circuit can be created. In contrast, an infrared camera allows temperatures to be recorded at a number of locations simultaneously with accuracy to one significant digit. Using infrared thermography, the area of highest temperature rise can be pinpointed and measured (McCullagh *et al.* 2002). Thermocouple accuracy can be negatively affected by a number of factors including how the thermocouple adheres to the material to be measured, alteration of the electrical circuit and specific operating temperature ranges related to thermocouple types. All of these factors are eliminated with the use of an infrared camera.

Recently, Satterthwaite *et al.* (2003) reported temperature changes from ultrasonic vibration of ceramic and stainless steel posts. The results of their study indicated temperature rises lower than those in the present report. Their study utilized morphologically similar canine teeth mounted in a mounting jig (silicone rubber) that would have increased the variability of the measurements and also reduced the temperature rise as compared with the present study. In their study, k-type thermocouples were mounted on the root surface, whereas infrared thermography was utilized in the present study. Satterthwaite *et al.* (2003)

did not report the amount of water coolant and they used longer time intervals, up to 30 min, for post removal. The differences in the results of these studies are most likely because of differences in experimental technique and materials. Both utilized the tip of the ultrasonic device in contact with the post, creating heat by friction and both studies suggest temperature rises likely to cause adverse thermal effects to adjacent tissues. In the present study, the majority of temperature rise occurred at the post–tooth interface within the first 30 s. The temperature rise continued to increase at the root surface up to 90 s before reaching a steady state. The difference in time to reach steady state at the crown and root surface is presumably because of the diffusion of heat through the tooth taking time to reach the root surface.

In summary, this study shows that failure to provide some form of water coolant during ultrasonic post removal can result in temperature rises that exceed the 10 °C threshold. The results of the present study also illustrate the need of using the minimum time to reach the treatment objective; even 15 mL min^{-1} water coolant can permit a temperature rise that exceeds the 10 °C threshold. In this study, the temperature rise never exceeded the 10 °C threshold when using 30 mL min^{-1} water coolant. The results showed no statistical significance between 15 and 30 mL min^{-1} water coolant. Nevertheless, we recommend that a minimum of 30 mL min^{-1} water coolant be used during ultrasonic post removal procedures as this regimen did not exceed the defined temperature rise threshold.

Future studies should focus on determining differences in temperature rise comparing different teeth, varying dentine and enamel thicknesses, a range of clinical techniques including a range of applied force and different coolant conditions. The intensity of the temperature rise, the frequency of the thermal insult, the size of the thermal mass and the duration of temperature rise are all important factors to be considered in determining adverse thermal effects to tissue. In a clinical setting it would be expected that the temperatures would be lower given the larger body mass for heat dissipation and blood flow of surrounding tissues. These factors are likely to have an impact in reducing the amount of heat that is actually absorbed by periodontal tissues.

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