J Clin Periodontol 2004; 31: 370–375 doi: 10.1111/j.1600-051X.2004.00491.x

Journal of Clinical Periodontology

Thermal imaging of ultrasonic scaler tips during tooth instrumentation

Simon C. Lea, Gabriel Landini and A. Damien Walmsley

School of Dentistry, The University of Birmingham, St Chad's Queensway, Birmingham B4 6NN, UK

Lea SC, Landini G, Walmsley AD: Thermal imaging of ultrasonic scaler tips during tooth instrumentation. J Clin Periodontol 2004; 31: 370–375. doi: 10.1111/j.1600-051X.2004.00491.x. © Blackwell Munksgaard, 2004.

Abstract

Objectives: During ultrasonic scaling procedures, contact of the scaler tip with the tooth surface will produce frictional heating. The aim of this study was to assess this heat generation using an Agema 900 thermal imaging system.

Materials and Methods: Both the Cavitron sustained performance system (SPS) with TFI-3 tip and the Mini Piezon with P-tip were tested. Handpieces were fixed with their sides facing the thermal camera and thermal image sequences or ''movies'' created. Measurements were performed with tips under loads of 25, 50 and 100 g, at water flow rates of 10, 20 and 40 ml/min and low, medium and high generator power settings. A measurement point was superimposed on the resulting thermal images at the tip/tooth contact site and the temperature variation with time recorded.

Results: All combinations of instrumentation produced an increase in temperature. An increase in temperature was generally observed with increasing load (for given power/water), power setting (for given load/water) and a decrease in water flow rate (for given load/power).

Conclusion: Heat generation is minimised by using low/medium power settings and light contact. Care must be taken to ensure adequate water is present at the site of instrumentation to prevent patient discomfort due to excessive heating.

Key words: heating; periodontology; thermal imaging; thermal tooth damage; ultrasonics.

Ultrasonic scaler systems are commonly used for the debridement of tooth and root surfaces. The primary cleaning mechanism of these devices is the mechanical chipping action of the scaler tip when it traverses the tooth surface. During dental ultrasonic scaling procedures, heat is generated due to friction between the tooth and the oscillating tip.

Fundamental laws of friction

The fundamental laws of solid friction were first formulated by Leonardo da Vinci (1452–1519) and were subsequently formalised by Coulomb (1736–1806) (Dhinojwala et al. 1996). Frictional force, F, is given by the product of a material parameter (coefficient of friction, μ) and the normal force, N, i.e.

$$F = \mu N$$

Frictional force is independent of the relative sliding speed between the two surfaces (McMillan 1997), though deviations can occur at very large velocities (Elmer 1997). Although dental scaler tips operate at high frequencies (25–30 kHz), the speeds of the tips are small (generally less than 10 m/s) and will not affect the frictional force. Frictional force is also independent (at given load) of the macroscopic contact area (McMillan 1997). Therefore, when the scaler tip is pressed against the tooth surface (for given load), the area of tip in contact with the tooth will not affect the frictional force or the heat generated.

Temperature regulation during scaling procedures

To minimise heating during ultrasonic scaling, water is sprayed onto the site of instrumentation. Excessive heat production will occur if either the water flow rate over the tip is insufficient or an aerosol is produced. In the latter situation water is thrown off the scaler tip as a fine mist leading to inadequate cooling of the tip. If the resulting increase in temperature is large enough, damage may be caused to the tooth.

Temperature measurements may be made by two methods: thermocouples or thermal imaging. Several studies have used thermocouples to determine the temperature rises that occur (in vitro) while using high-speed dental instruments for cavity preparation (Walsh & Symmons 1972, Laur et al. 1990, Cavalcanti & Rode 2002), bone drilling (Iyer et al. 1997a, b) and post-space preparation (Saunders & Saunders 1989).

Few studies have investigated heat generation caused by sonic and ultrasonic scaling instruments (Walmsley & Williams 1986, Kocher & Plagmann 1996, Nicoll & Peters 1998). In these investigations, temperature increases were measured within the teeth (in vitro) using thermocouples. However, ultrasonic scalers generate heat at the surface of the tooth and it is unclear what temperatures are produced at the tooth surface.

Thermal imaging has been shown to be a useful method for analysing patterns of temperature change, which can help locate areas of maximum heat production (McCullagh et al. 2000). Crandell & Hill (1966) first used thermal imaging for dental research purposes, as a diagnostic aid for periapical abscesses. Since this time, thermal imaging technology has improved and found application in periodontology, for studying the thermodynamic behaviour of human gingiva (Mörmann et al. 1985, Barnett et al. 1989), as well as several other dental disciplines (Biagioni et al. 1996, Hussey et al. 1997, McCullagh et al. 1997, Benington et al. 2002).

The aim of this investigation was to analyse the temperature rise at the tooth surface, in vitro, caused by ultrasonic scalers under varying conditions of contact load, generator power setting and water flow rate, using an Agema 900 thermal imaging system (EPSRC Engineering Instrument Pool, Rutherford Appleton Laboratory, Didcot, UK).

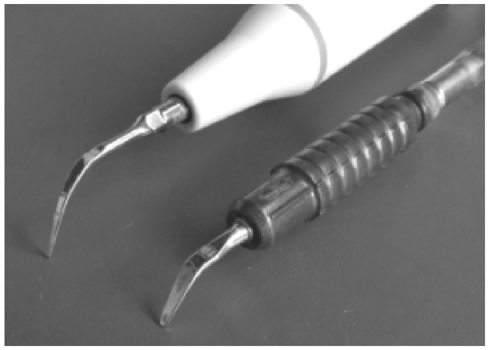

Fig. 1. The scaler tips used in this investigation including (left) a P-style piezoelectric tip and (right) a TFI-3 magnetostrictive tip.

Materials and Methods

Principles of thermal imaging

Friction between the oscillating scaler tip and the tooth surface causes an increase in temperature at the treatment site. This temperature rise excites the atoms within the tooth structure and the metallic tip. Those electrons in a lower energy orbital of an atom undergo a transition to a higher energy orbital. When the atom tries to return to its ground state it releases energy as a photon with a specific wavelength. Heat causes atoms to emit photons in the infrared region of the electromagnetic spectrum. It is possible to detect the infrared radiation emitted by an object using a phased array of detector elements. The energy carried by the photons may be converted into electrical signals, which are sent to a signal-processing unit from where an image is created, known as a thermogram. A colour-graduated scale can be used to conveniently indicate the intensity of the infrared emission (and hence the temperature) at the treatment site.

The thermal imaging system used in this study was the Agema 900, which detects thermal IR radiation between wavelengths 8 and 12 μm. The system is cryogenically cooled and has a temperature range of -30°C to $+1500^{\circ}$C with a sensitivity of 0.08°C at $+30^{\circ}$C (EPSRC Engineering Instrument Pool, Brief Technical Guide, 2002). Up to 25 frames/s may be captured (real time) using 10° or 20° field of view lenses. The Agema 900 also has a purpose-built computer and operates the Erika thermal analysis software package (EPSRC Engineering Instrument Pool, Brief Technical Guide, 2002).

Selection of scaler systems

As a scaler tip moves across the surface of a tooth, some of the tip's kinetic energy (KE) is converted into thermal energy, due to the frictional force between the scaler tip and the tooth. Since frictional force is independent of relative sliding speed (McMillan 1997), the speed of the scaler tip (determined by the generator power setting and the design of the tip) as it traverses the tooth surface will not, theoretically, affect the detected temperature rise. However, scaler tips oscillate back and forth and, with each pass over the surface of the tooth, some KE is converted into thermal energy. The more often the tip traverses the tooth surface per unit time, the more often the conversion of KE to thermal energy and therefore the greater the rise in temperature. Hence, the detected temperature rise will be affected by the frequency of the scaling tip system utilised. Therefore, when comparing ultrasonic generators made by different manufacturers they should operate at similar frequencies. This enables meaningful comparisons of the effects of load, generator power setting and water flow rate on the heat generated.

The ultrasound generators selected for this study were the Cavitron SPS (Dentsply, York, PA, USA), 30 kHz magnetostrictive generator and the Mini Piezon, 30 kHz piezoelectric generator. A TFI-3 style scaler insert (Dentsply, York, PA, USA) was used with the Cavitron SPS generator and with the Mini Piezon (Electro-Medical Systems, Switzerland) 30 kHz piezoelectric generator a P-Tip (Electro-Medical Systems, Switzerland) was chosen (Fig. 1). A 10-point graduated scale was positioned over the original Cavitron SPS power control dial to enable accurate and reproducible power settings to be selected. This was not necessary for the Mini Piezon generator, which has button controls for power output, rather than a dial. Water flow rates of 10, 20 and 40ml/min were measured and used throughout the course of the experiment.

Experimental

One of the generators was selected and its corresponding insert placed within the scaler handpiece. The scaler was held in place, using a clamp, with the side of the tip and handpiece facing the thermal camera. The scaler tip was contacted against the surface of a tooth, which itself was fixed to a mount on a Model 31 (1000 g) load cell (Sensotec, Columbus, OH, USA) connected to an E725 microprocessor transducer indicator/controller. The load cell enabled contact loads of 25 ± 1, 50 ± 1 and 100 ± 1 g to be used.

For each of the loads, thermal ''movies'' or image sequences were then taken, at a rate of 1 frame/s, over a period of 70 s. For the first 10 s, no power was supplied to the scaler handpiece. This enabled the ambient background temperature of the experimental set-up to be determined. For the following 60 s, power was supplied to the scaler handpiece, using a low, medium or high generator power setting (corresponding to power setting marks 2, 5 or 9, respectively). For each power and load combination, thermal sequences were obtained using water flow rates of 10, 20 and 40 ml/min. After instrumentation, all power to the handpiece was stopped and the apparatus allowed time to cool. Thermal ''movies'' were taken for all tip/tooth contact load, water flow rate and generator power-setting combinations.

A measurement point was located on the images of the resulting thermal sequences, at the point where tip/tooth contact occurred. The sequences were reviewed frame by frame at the point of interest and the temperature variation as a function of time was recorded.

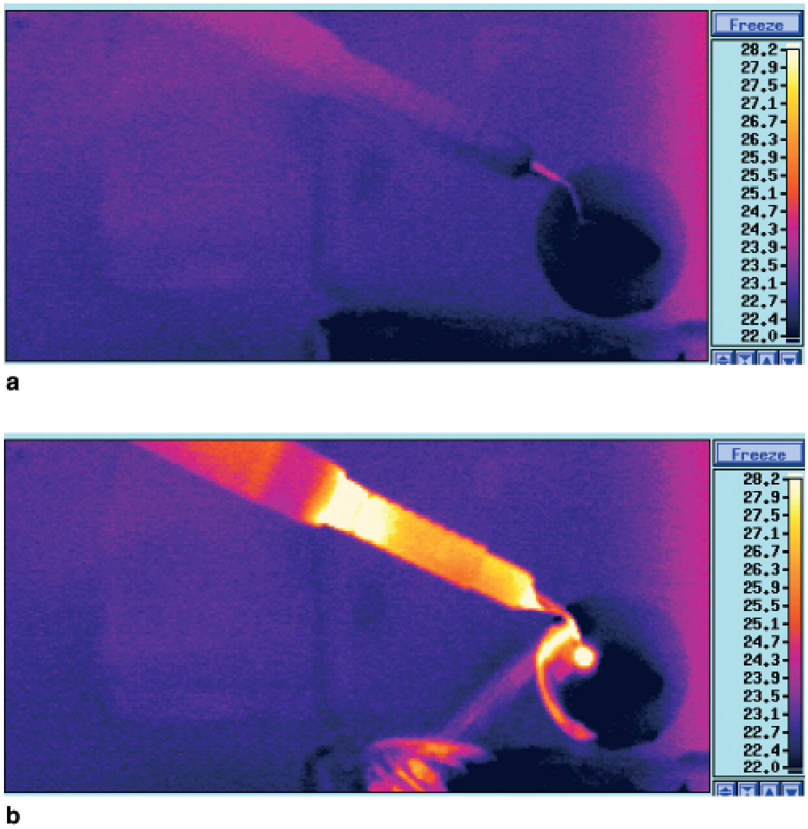

Fig. 2. Typical thermal images obtained using the Agema 900 Thermal Imaging System, for the SPS (a) during the first 10 s of data acquisition with no power supplied to the instrument and (b) after approximately 40 s of instrumentation. The colour-graduated scale to the right of the image gives an indication of the temperatures detected. A hotspot is observed at the tip/tooth contact site. An increase in temperature is also seen for the scaler insert, especially where the insert fits into the handpiece.

Results

Typical images obtained using the Agema 900 thermal imaging system, for both the magnetostrictive and piezoelectric scaling system, are shown in Figs. 2 and 3, respectively. A measurement point was positioned at the site of tip/tooth contact and the temperature recorded in successive 1-s intervals. Graphs of temperature increasing with respect to time were created to observe the effects of generator power setting, water flow rate and tip/tooth contact load, on the heat generated during ultrasonic instrumentation of tooth surfaces (Figs. 4–6). Data for the maximum temperature increase for each generator power, water flow rate and load combination were also recorded.

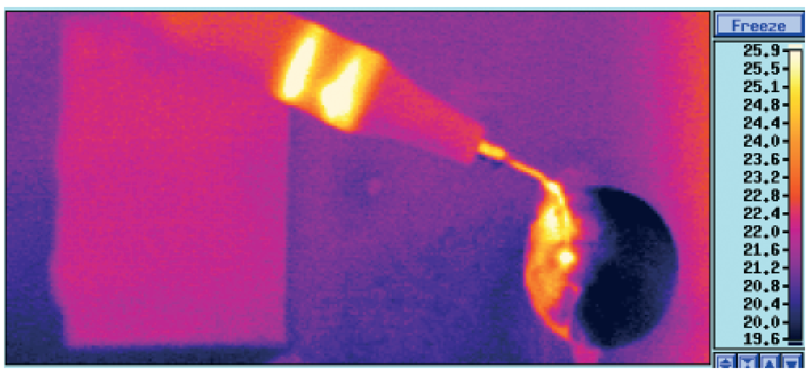

Fig. 3. A typical thermal image obtained using the Agema 900 Thermal Imaging System, for the Mini Piezon, after approximately 40 s of instrumentation. A hotspot is observed at the tip/tooth contact site and an increase in temperature is also seen for the scaler handpiece where the piezoelectric crystal is located.

With no power supplied by the generator (0–10 s) there is no scaler tip oscillation and so the recorded temperature is an indication of the ambient room temperature. For the following 60 s power was supplied and an increase in temperature was detected by the thermal imaging system for both generators, irrespective of instrumentation conditions. The mean background temperature (for each thermal sequence) was determined from the first 10 s of data. This value was then subtracted from all the data in that thermal sequence, enabling the increase in temperature, from room temperature, to be observed (Figs. 4–6). Therefore, to determine the absolute temperature increase, the background room temperature of 20°C should be added.

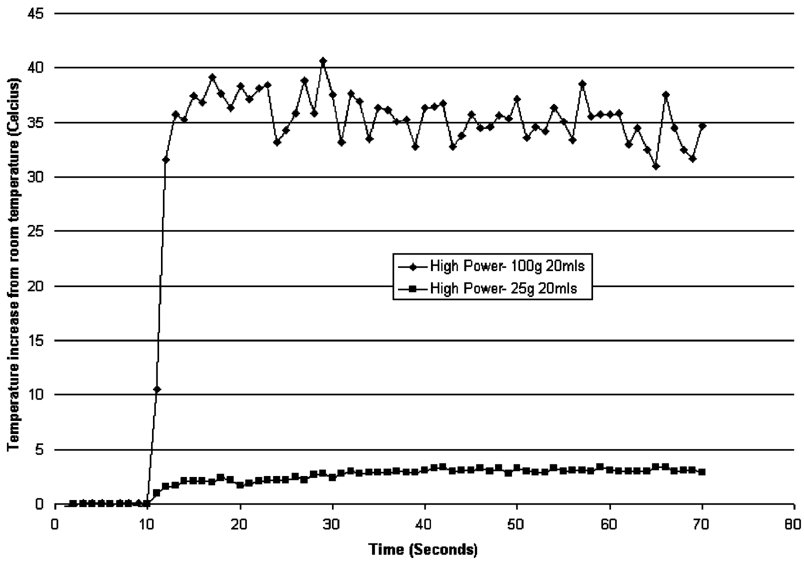

Fig. 4. Graphs of increase in temperature with time for the Mini Piezon scaling system, demonstrating the effect of contact load on temperature. The mean background temperature was calculated and subtracted from all data, enabling the increase in temperature, from room temperature, to be observed. Instrumentation conditions are high generator power setting and 20 ml/min water flow rate with loads of 25 g, 50 g and 100 g.

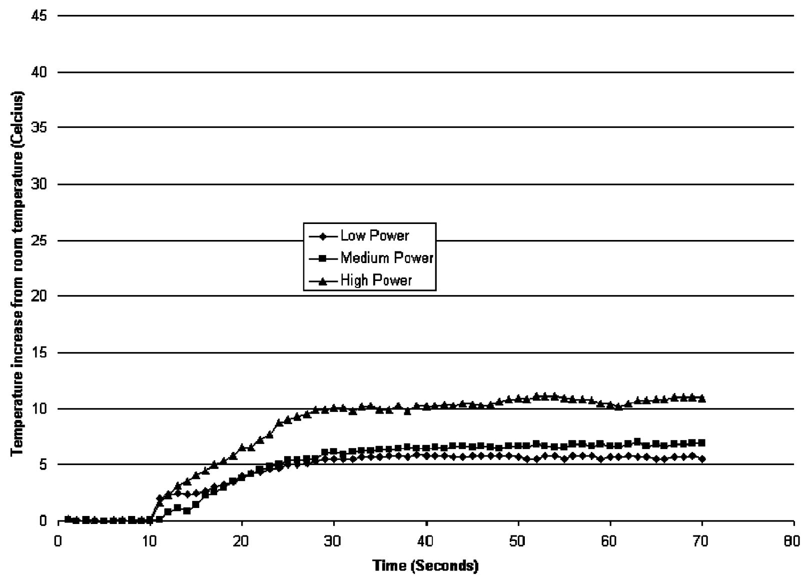

Fig. 5. Graphs of increase in temperature with time for the SPS scaling system, demonstrating the effect of generator power setting on temperature. Instrumentation conditions are 100 g load and 40 ml/min water flow rate with generator power settings of low, medium and high.

Data obtained for both scaler systems showed that an increase in load (for set water flow rate/generator power setting) and generator power setting (for set load/water flow rate) generally corresponded to an increase in detected temperature (Figs. 4 and 5). It was also observed that an increase in water flow rate over the scaler tip (for set conditions of load/generator power setting) generally lead to a reduction in the maximum temperature attained (Fig. 6a–c) for both scaler systems.

Discussion

During normal operation, dental scaler tips have a continuous stream of water flowing over them. As well as potentially assisting in the cleaning process (through the generation of cavitation and acoustic streaming forces), this flow of water helps to regulate the heat generated at the tip / tooth interface. This is primarily achieved via the constant removal of the frictional heat through forced convection (Eastop & McConkey 1993). As the water flows over the surface of the tooth the heat generated, due to the friction between the scaler tip and the tooth, is conducted into the water and carried away by the bulk fluid movement.

An increase in water flow rate reduced the maximum heat generated at the tip/tooth contact point (Fig. 6a–c). This effect was most readily observed when loads of 100 g were used with high generator power settings (Fig. 6c).

An increase in generator power setting generally corresponds to an increase in scaler tip displacement amplitude (Lea et al. 2003) and tip velocity. Frictional force depends only on the normal contact force and is independent of the relative sliding speed between the two surfaces. Therefore, any increase in tip velocity as it traverses the tip surface, due to an increase in generator power setting, should not affect the frictional force.

However, the data obtained show that an increase in generator power setting often leads to an increase in heat generation (Fig. 5). At lower power settings, scaler tip displacement amplitude is relatively small and the water flows down the length of the tip, to the treatment site, regulating heat generation as described previously. At higher power settings, the water tends to be thrown off as aerosol before it reaches the working end of the tip (Lea et al. 2002) and so provides no heat regulation.

Frictional force is directly proportional to the load perpendicular to the tooth surface, due to the contact of the moving scaler tip. Therefore, when greater tip contact loads are applied the frictional force will increase, causing an increase in the heat generated and detected.

For both scaler systems an increase in contact load generally corresponded to an increase in heat generation and, at high power settings, caused particularly large increases in the temperature measured (Fig. 4).

Data for the Mini Piezon show that the largest temperature increases (greater than 25°C) occurred when instrumentation conditions of high power with 50 g load (10 and 20 ml/min water flow

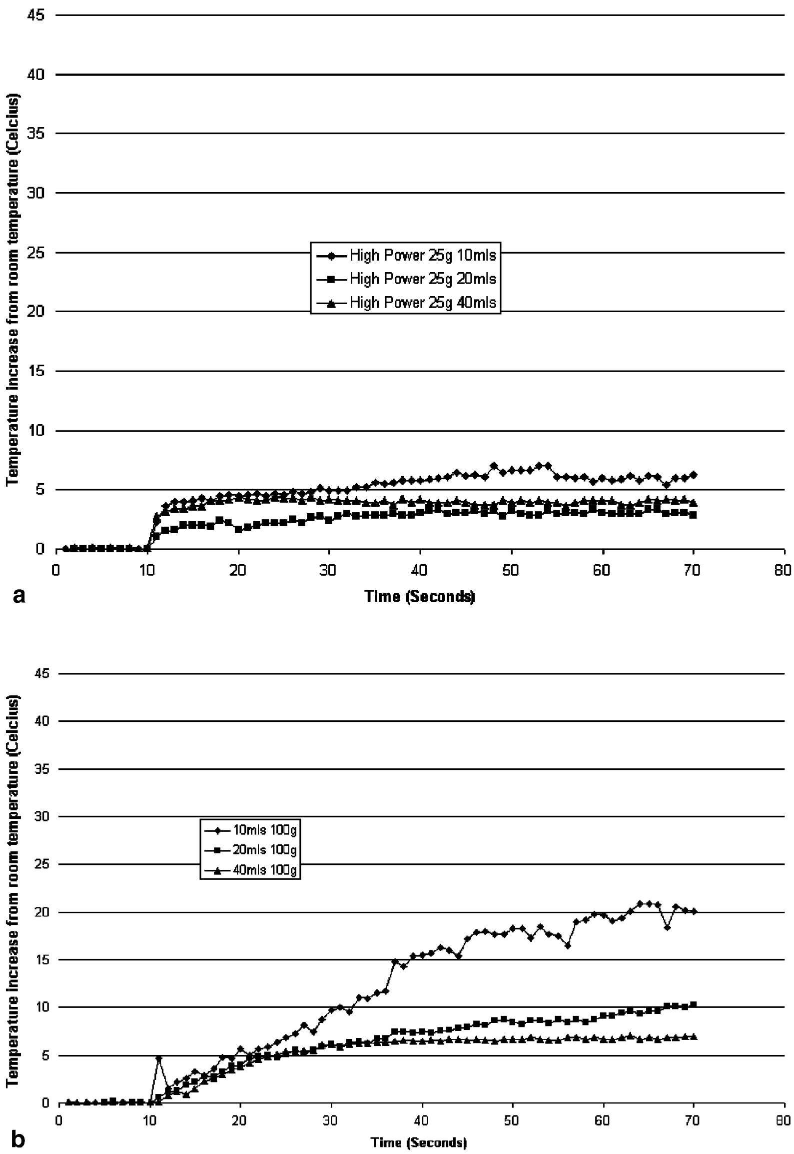

Fig. 6. Graphs of increase in temperature with time, demonstrating the effect of water flow rate on temperature. Instrumentation conditions are (a) Mini Piezon; high power/25 g load/10, 20 and 40 ml/min water, (b) SPS; medium power/100 g load/10, 20 and 40 ml/min water and (c) Mini Piezon; high power/100 g load/20 and 40 ml/min water.

rate) and 100 g load (all water flow rates) were used. For all other operating conditions, the overall temperature increase at the tooth surface was less than 10°C. The data also show that a temperature increase of 25°C occurred for the SPS when instrumentation conditions of high power and 100 g load were used with 10ml/min water flow rate. These data indicate that high generator power settings, in conjunction with low water flow rates and large loads, should be avoided to reduce the risk of large temperature increases.

Risk of tooth damage

It was not possible to determine the pulpal temperature rise using the thermal imaging system. However, enamel and dentine are poor thermal conductors and form an effective thermal barrier, which prevents large pulpal temperature rises (Walmsley & Williams 1986). This is due to the low thermal conductivity and thermal diffusivity of both enamel and dentine (Brown et al. 1970).

Previous investigation into pulpal temperature rise (in vitro), due to heat generated during ultrasonic descaling procedures, reported a maximum pulpal temperature increase of approximately 8°C (Walmsley & Williams 1986). However, this investigation was performed under conditions of 14 g load, medium generator power setting and with a water flow rate of 20 ml/min. With greater loads of 50 and 100 g, high generator power setting and water flow rates of 10 ml/min, as utilised in this investigation, it is likely that pulpal temperatures exceeding 8°C may be reached.

Pulp temperature increases of 5.5°C and 11°C have been shown to cause irreversible pulpitis in 15% and 60% (respectively) of healthy Macaca rhesus monkey dental pulps (Zach & Cohen 1965). This would suggest that the temperature increases encountered in this study may pose a potentially serious threat to pulp vitality.

However, the temperature rises observed in this study are not truly indicative of those observed in vivo. During clinical instrumentation, the scaler tip is moved constantly over the surface of the tooth and so this prevents spot heating from occurring. Blood flow through the pulp chamber and the diffusion of heat into the surrounding bone may also reduce the anticipated pulp temperature rise (Walmsley & Williams 1986). Heat conduction relies on the presence of a temperature gradient, across a body, for heat energy to flow from the high temperature region to the low temperature region. Therefore, the heat energy at the tooth surface must be greater than body temperature (approximately 37°C) to be conducted to the pulp.

Large temperature increases may not just be potentially damaging to dental pulp. Teeth subjected to sudden temperature increases, followed by temperature decreases, may be susceptible to crack development in their enamel (Brown et al. 1970). The largest temperature rises are observed for conditions of large load, high generator power and low water flow rates and these should be avoided to reduce the risk of pulpal damage and enamel cracking.

Conclusion

Due to the non-invasive nature of the thermal imaging system, which relies only on the emission of thermal infrared radiation to operate, it may be of interest to repeat the investigation in vivo. This would facilitate the monitoring of temperature rise, on the external surface of the tooth, during ultrasonic instrumentation under standard clinical conditions. Heat generation is minimised by using light loads in conjunction with low/medium generator power settings and water flow rates of at least 20 ml/min. Care must be taken to ensure adequate water is present at the site of instrumentation to prevent patient discomfort due to excessive heating.

Acknowledgments

This work was supported by a project grant from the Engineering and Physical Science Research Council (EPSRC) of the United Kingdom (No GR/M75136). The authors also wish to thank Peter Anthony and the EPSRC Engineering Instrument Pool for the loan of the Agema 900 Thermal Imaging System.

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Address:
S. C. Lea
School of Dentistry
The University of Birmingham
St Chad's Queensway
Birmingham B4 6NN
UK
Fax: +44 0121 625 8815
E-mail: s.lea@bham.ac.uk