doi:10.1111/j.1365-2591.2008.01508.x

Effect of simulated pulpal microcirculation on intrapulpal temperature changes following application of heat on tooth surfaces

K. Kodonas, C. Gogos & D. Tziafas

Department of Endodontology, School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract

Kodonas K, Gogos C, Tziafas D. Effect of simulated pulpal microcirculation on intrapulpal temperature changes following application of heat on tooth surfaces. *International Endodontic Journal*, **42**, 247–252, 2009.

Aim To evaluate *ex vivo* whether a simulated pulpal microcirculation inside a pulp chamber influenced intrapulpal temperature rise following application of heat on tooth surfaces.

Methodology An *ex vivo* model that allowed the circulation of 37 °C warm water inside the pulp chamber of an extracted human tooth was designed. The experimental model resembled pulpal microcirculation. After application of specific thermal stimuli for 30 s to the external surface of 15 maxillary central incisors, lateral incisors and canines, temperature changes were measured in the pulp chamber. The Greenhouse–Geisser and Bonferroni tests were used for analysis of the data. The level of significance was set at 0.05.

Results Significant differences were found in all three groups of teeth between temperature measurements with or without intrapulpal water flow. Additionally, temperature changes resulting from the application of different stimuli to the group of lateral incisors were significantly greater compared with the other groups of teeth ($P < 0.05$).

Conclusions The importance of the cooling effect of simulated pulp microcirculation in the thermal behaviour of the dentine was established. Thickness of tooth tissue influenced significantly pulp temperature rise *ex vivo*.

Keywords: dentine pulp complex, pulp microcirculation, thermal stimuli.

Received 16 April 2008; accepted 16 October 2008

Introduction

Potential thermal injury to the dentine pulp complex by various operative procedures has been a matter of concern for many years (Zach 1972). It is well accepted, in general terms, that the production of heat is the most severe stress produced in the pulp by a variety of operative procedures (Mjör & Ferrari 2002). Cutting dentine with a rotating bur or stone produces a considerable amount of frictional heat (Bhaskar & Lilly 1965). Heat is also generated and transferred to the dentine pulp complex during setting (Hannig & Bott 1999, Weerakoon *et al.* 2002, Saitoh *et al.* 2004) or polishing of restorative materials (Briseño *et al.* 1995), during bleaching processes (Cohen 1979, Eldeniz *et al.* 2005), or by the use of light-curing units (Hussey *et al.* 1995, Shortall & Harrington 1998, Asmussen & Peutzfeldt 2005) or lasers.

The potentially damaging effect of pulp temperature increase during restorative treatment has been investigated by various laboratory (Goodis *et al.* 1997, Uhl *et al.* 2006) and *in vivo* studies (Lisanti & Zander 1952, Zach & Cohen 1965, Goodis *et al.* 1988, Laurell *et al.* 1995, Cobb *et al.* 2000). However, the role of the pulp microcirculation as a cooling agent in the thermal behaviour of the dentine pulp complex has not been

Correspondence: K. Kodonas, Department of Endodontology, School of Dentistry, Aristotle University of Thessaloniki, GR–54124 Thessaloniki, Greece (Tel./fax: +30 2310 999 459; e-mail: kkodonas@dent.auth.gr).

evaluated (McKee 1993, Kreisler *et al.* 2002, Oelgiesser *et al.* 2003).

The aim of this study was to evaluate in a new *ex vivo* model, whether water circulation inside a pulp chamber influenced intrapulpal temperature rise.

Material and methods

A total of 15 extracted intact human maxillary teeth, five central incisors, five lateral incisors and five canines were used. The dimensions of the pulp chambers were evaluated with digital radiographs from both the bucco-lingual and mesio-distal aspects of the teeth by using the distance measurement feature of the digital x-ray software (Vixwin 2000, Gendex, Italy).

Access was made into the pulp chambers from the lingual aspect of the teeth so that a thermocouple wire (Pico technology, Cambridge, UK) could be inserted. The contact of this internal thermocouple with the buccal circumpulpal dentine inside the pulp chamber was confirmed with digital radiographs. The root portions were sectioned with a slow speed diamond saw approximately 2 mm below the cemento-enamel junction. A 10-mm-long 25-gauge needle was inserted through the root canal into the pulp chamber (Fig. 1). Before temperature measurements were made, the position of the internal thermocouple was verified with digital radiographs and corrected as needed.

This *ex vivo* model allowed the circulation of distilled water (37 °C) at two possible rates of flow: 1 and 0.5 mL min^{-1} inside the pulp chamber through the needle, thus mimicking pulp microcirculation. The use of two different water flow rates was supposed, in theory, to simulate different conditions of pulp tissue vascular response to external stimuli. However, pilot experiments using a flow rate of 0.5 mL min^{-1} led to discontinuous water flow inside the pulp chamber. Consequently, all measurements were taken using a water flow of 1 mL min^{-1}. The water circulation was ensured by a pressurized water tank.

A second thermocouple was placed in contact with the external surface on the mesio-buccal aspect of the tooth, and a third in contact with the palatal surface of the tooth. The thermocouple wires were connected to a data logger (TC-08 Thermocouple Data Logger; Pico technology) (Fig. 1). Temperature recordings were monitored and transferred in real time to a personal computer.

Intrapulpal temperature rises were induced by applying a specially modified and rheostat controlled thermode tip to the external surface of the teeth. The thermode tip was made slightly concave so as to conform as closely as possible to the enamel surfaces. Application time was set at 30 s and the application site was the centre of the buccal aspect of each tooth. The thermode tip reached a temperature of 100 or 200 °C.

Temperature changes on the tooth surfaces were recorded automatically every second until the pulp temperature returned to 37 °C. The thermocouple temperature rating was from −70 to +350 °C. For each tooth, temperature variation was determined as the increase from 37 °C to the highest temperature recorded after the application of external stimulus. Four measurements per tooth were performed using:

- a stimulus of 100 °C with intrapulpal water flow at a rate of 1 mL min^{-1},
- a stimulus of 200 °C with intrapulpal water flow at a rate of 1 mL min^{-1},
- a stimulus of 100 °C without water flow,
- a stimulus of 200 °C without water flow.

In order to examine reproducibility, each measurement was repeated four times. All teeth failing to produce repeated measurements were replaced. Greenhouse–Geisser and Bonferroni tests (SPSS, version 12,

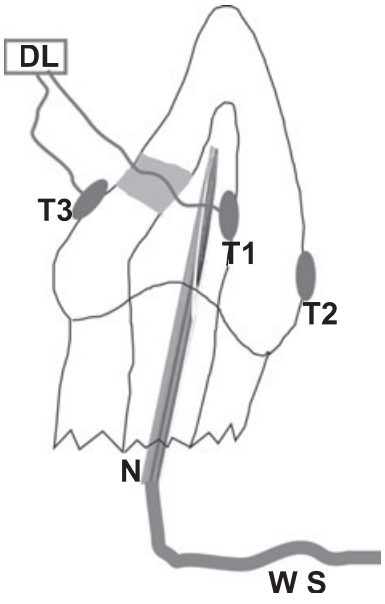

Figure 1 Figure showing the position of the needle and the thermocouple wires on the tooth surfaces. Water supply (WS), internal thermocouple (T1), second thermocouple placed in contact with the mesio-buccal aspect of the tooth (T2), third thermocouple placed in contact with the palatal surface of the tooth (T3), needle (N), data logger (DL).

Table 1 Greenhouse–Geisser test indicated no statistically significant differences ($P > 0.05$) between repeated measurements made on a specific tooth (stimulus × tooth, $P = 0.699$), with specific conditions of water flow (stimulus × water, $P = 0.25$), using a specific stimulus (stimulus × intension, $P = 0.505$)

Source	Type III sum of squares	df	Mean square	*F*	Sig.
sti × tooth	40.073	3.911	10.246	0.545	0.699
sti × water	51.637	1.956	26.405	1.405	0.25
sti × inten	25.03	1.956	12.799	0.681	0.505

Chicago, IL, USA) were used for analysis of the data. The elected level of significance was set at 0.05.

Results

Statistical analysis indicated no significant differences ($P > 0.05$) between repeated measurements made in a specific type of tooth, under the same conditions of water flow inside the pulp chamber, and using the same stimulus (Table 1).

Statistical analysis revealed that temperature changes were significantly influenced ($P < 0.05$) by all three factors evaluated in the present study: the type of tooth, water flow and stimulus (Figs 2 and 3).

Average temperature changes resulting from the application of different stimuli to the three groups of teeth are summarized in Table 2. In more detail:

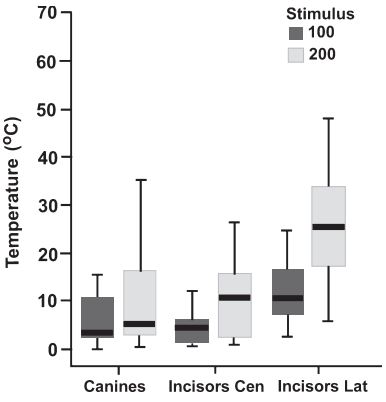

Figure 2 Boxplot indicating statistically significant differences of temperature changes to the group of lateral incisors ($P < 0.05$). The first two boxplots represent temperature changes to the group of canines, the next two to the group of central incisors and the last two represent temperature changes to the group of lateral incisors.

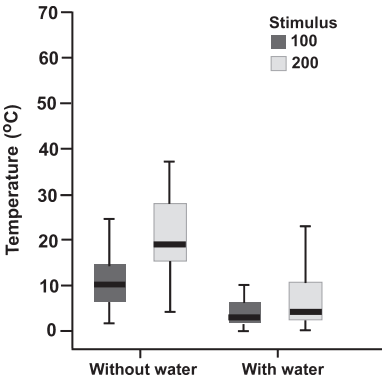

Figure 3 Boxplot indicating statistically significant differences between temperature changes induced with or without intrapulpal water flow ($P < 0.05$). The first two boxplots represent temperature changes induced without the use of water flow inside pulp chamber and the next two represent temperature changes induced with the use of water flow.

Table 2 Average temperature changes resulting from the application of different stimuli to the three groups of teeth

		Stimuli							
		Without water (°C)				With water (°C)			
		100 °C		200 °C		100 °C		200 °C	
Teeth	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Canines	20	9.6	4.2	15.7	8.1	2.3	1.2	2.7	1.5
Central incisors	20	6.5	2.6	16.4	4.9	2.2	2.0	3.9	3.7
Lateral incisors	20	18.8	9.6	37.5	15.9	8.5	4.7	17.7	10.7

Canine teeth: the average temperature rise within the pulp chambers, without water flow, was 9.6 °C using a stimulus of 100 and 15.7 °C with 200 °C. With the cooling effect of a water flow inside pulp chamber, the average temperature rise was 2.3 and 2.7 °C using the same stimuli.

Central incisor teeth: The average temperature rises resulting from exposure to stimuli of 100 and 200 °C was 6.5 and 16.4 °C respectively, without water flow. A small temperature increase within the pulp chambers, 2.2 °C under 100 °C, and 3.9 °C under 200 °C, occurred when water flow was used.

Lateral incisor teeth: Temperature increases of 18.8 and 37.5 °C without water flow were recorded; while with water flow the corresponding temperature rise inside the pulp chambers were 8.5 and 17.7 °C.

A further difference was noticed between measurements made with and without intrapulpal water flow. The return time of pulp temperature to the baseline was

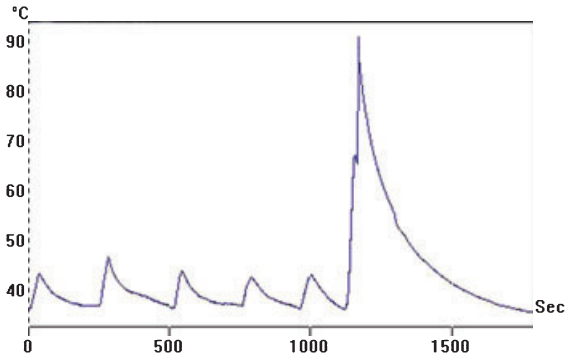

Figure 4 This diagram shows the internal thermoelement sampling after the use of six repeated stimuli of 200 °C on the external surface of a lateral incisor. The last temperature rise is induced without the use of water flow inside pulp chamber. It is obvious that there is a higher intrapulpal temperature rise with a long-lasting effect also.

significantly longer ($P < 0.05$) in all groups of teeth without intrapulpal water flow (Fig. 4).

Discussion

The present study introduces a new *ex vivo* experimental method to determine the role of pulp microcirculation in the thermal behaviour of the dentine pulp complex during application of various external thermal stimuli.

Pulp temperature rise depends on many factors, *in vivo*. The intensity and duration of the applied thermal stimulus seems to be the most crucial. In this study the outer stimulus was standardized, since the thermode tip used reached specific temperatures of 100 and 200 °C. It has been shown that this kind of stimulus is clinically relevant; during cavity preparation without proper water flow from the handpiece a temperature of 240 °C is generated (Lloyd *et al.* 1978). However, water cooling is normally used in operative procedures and consequently the induction of such thermal stimuli to the dentine pulp complex is avoided. Nevertheless, this *ex vivo* study highlights the effect of water flow within the pulp chamber on the intrapulpal temperature rise induced by specific and standardized thermal stimuli. However, actual temperature values recorded do not necessarily replicate *in vivo* conditions.

Intrapulpal temperature rise during various restorative procedures has been studied in experimental studies during the last decade (Cobb *et al.* 2000, Eldeniz *et al.* 2005). However, heat distribution in teeth with pulp microcirculation simulation has not been evaluated. Previous laboratory studies, (Hannig & Bott 1999, Cobb *et al.* 2000, Eldeniz *et al.* 2005) used pulp chambers filled with water at 37 °C. Obviously, the lack of flow diminishes the possibilities for heat dissipation by these means.

Pulpal blood flow has been estimated in intact teeth and found to be 40 mL min^{-1} 100 g of tissue (Meyer 1993, Matthews & Andrew 1995). In the present study, pulp microcirculation was simulated by constant water flow at 37 °C inside the pulp chamber through a 10-mm-long 25-gauge needle, at a rate of 1 mL min^{-1}. This flow rate exceeds the pulp blood flow rate of intact teeth; however there is an increase in blood perfusion when the dentine pulp complex is stimulated. Specifically, it has been documented that external stimuli such as grinding dentine, ultrasonic stimulation or percussion of the teeth induce immediate vascular responses in the dental pulp and particularly an instant increase in blood flow (Olgart *et al.* 1991). Considering the complexity of parameters determining the nature of outer stimuli applied to the dentine pulp complex (type of stimuli, remaining dentine thickness or pulp capability to respond) it is obvious that the vascular response of pulp tissue to external stimuli varies according to the parameters mentioned above.

In addition, using lower water flow rates would be an inadequate simulation of pulp blood flow. During the preliminary tests for this study, using a rate of 0.5 mL min^{-1} led to procedural errors due to a discontinuous water flow inside the pulp chamber. This is logical considering that water perfusion *ex vivo* is not supported by a complex microvasculature consisting of many arterioles and venules with many anastomoses. However, this new model of simulated pulp circulation corresponds more closely with clinical conditions than alternatives where the lack of flow diminishes any possibility of heat dissipation.

In the present study, water flow inside the pulp chamber proved to be a major factor influencing pulp temperature rise *ex vivo*. The differences between measurements made with and without water flow indicate the potential influence of blood microcirculation in cooling the dentine pulp complex (Raab 1992, Hannig & Bott 1999).

Investigators have expressed concerns about the effects of heat produced during various clinical procedures on vital pulp (Hannig & Bott 1999). Irreversible pulp damage has been correlated with intrapulpal temperature rises of 5–10 °C (Zach & Cohen 1965). The present study suggests that the temperature rises produced can range from 8.5 to 17.7 °C, under normal

conditions of water flow inside pulp chamber when external stimuli of 100 and 200 °C are applied. These results demonstrate that teeth with thinner dentine walls, such as lateral incisors, are susceptible to pulp damage if subjected to the specific stimuli used in this experiment.

Nevertheless, the measurements from the present study can not be applied to the thermal behaviour of the dentine pulp complex *in vivo*. Although the experimental design of this study took into consideration heat conduction due to the effect of pulpal microcirculation, fluid motion in dentinal tubules, or pulpal blood flow changes due to stimulation of the pulpal nervous system could not be replicated (Raab & Muller 1989, Raab 1992). However, the absence of the surrounding periodontal tissues did not appear to significantly affect the results since the low thermal conductivity of the dentinal walls of the tooth prevent heat dissipation through conduction (Lisanti & Zander 1950, Soyenkoff & Okun 1958, Heithersay & Braennstroem 1963, Brown *et al.* 1970).

Conclusion

Simulation of pulpal microcirculation, *ex vivo*, significantly influenced temperature rise in the pulp chamber. Dental tissue thickness was a major factor influencing intrapulpal temperature rise.

References

Asmussen E, Peutzfeldt A (2005) Temperature rise induced by some light emitting diode and quartz-tungsten-halogen curing units. *European Journal of Oral Sciences* **113**, 96–8.

Bhaskar SN, Lilly GE (1965) Intrapulpal temperature during cavity preparation. *Journal of Dental Research* **44**, 644–7.

Briseño B, Ernst CP, Willershausen-Zönnchen B (1995) Rise in pulp temperature during finishing and polishing of resin composite restorations: an in vitro study. *Quintessence International* **26**, 361–5.

Brown WS, Dewey WA, Jacobs HR (1970) Thermal properties of teeth. *Journal of Dental Research* **49**, 752–5.

Cobb DS, Dederich DN, Gardner TV (2000) In vitro temperature change at the dentin/pulpal interface by using conventional visible light versus argon laser. *Lasers in Surgery and Medicine* **26**, 386–97.

Cohen SC (1979) Human pulpal response to bleaching procedures on vital teeth. *Journal of Endodontics* **5**, 134–8.

Eldeniz AU, Usumez A, Usumez S, Ozturk N (2005) Pulpal temperature rise during light-activated bleaching. *Journal of Biomedical Materials Research. Part B, Applied Biomaterials* **72**, 254–9.

Goodis HE, Schein B, Stauffer P (1988) Temperature changes measured in vivo at the dentinoenamel junction and pulpodentin junction during cavity preparation in the Macaca fascicularis monkey. *Journal of Endodontics* **14**, 336–9.

Goodis HE, White JM, Marshall GW Jr *et al.* (1997) Effects of Nd: and Ho:yttrium-aluminium-garnet lasers on human dentine fluid flow and dental pulp-chamber temperature in vitro. *Archives of Oral Biology* **42**, 845–54.

Hannig M, Bott B (1999) In-vitro pulp chamber temperature rise during composite resin polymerization with various light-curing sources. *Dental Materials* **15**, 275–81.

Heithersay GS, Braennstroem M (1963) Observations on heat-transmission experiments with dentin. 1. Laboratory Study. *Journal of Dental Research* **42**, 1140–5.

Hussey DL, Biagioni PA, Lamey PJ (1995) Thermographic measurement of temperature change during resin composite polymerization in vivo. *Journal of Dentistry* **23**, 267–71.

Kreisler M, Al-Haj H, D'Hoedt B (2002) Intrapulpal temperature changes during root surface irradiation with an 809-nm GaAlAs laser. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **93**, 730–5.

Laurell KA, Carpenter W, Daugherty D, Beck M (1995) Histopathologic effects of kinetic cavity preparation for the removal of enamel and dentin. An in vivo animal study. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **80**, 214–25.

Lisanti VF, Zander HA (1950) Thermal conductivity of dentin. *Journal of Dental Research* **29**, 493–7.

Lisanti VF, Zander HA (1952) Thermal injury to normal dog teeth: in vivo measurements of pulp temperature increases and their effect on the pulp tissue. *Journal of Dental Research* **31**, 548–58.

Lloyd BA, Rich JA, Brown WS (1978) Effect of cooling techniques on temperature control and cutting rate for high-speed dental drills. *Journal of Dental Research* **57**, 675–84.

Matthews B, Andrew D (1995) Microvascular architecture and exchange in teeth. *Microcirculation* **2**, 305–13.

McKee MD (1993) Effects of CO2 laser irradiation *in vivo* on rat alveolar bone and incisor enamel, dentin, and pulp. *Journal of Dental Research* **72**, 1406–17.

Meyer MW (1993) Pulpal blood flow: use of radio-labelled microspheres. *International Endodontic Journal* **26**, 6–7.

Mjör IA, Ferrari M (2002) Pulp-dentin biology in restorative dentistry. Part 6: reactions to restorative materials, tooth-restoration interfaces, and adhesive techniques. *Quintessence International* **33**, 35–63.

Oelgiesser D, Blasbalg J, Ben-Amar A (2003) Cavity preparation by Er-YAG laser on pulpal temperature rise. *American Journal of Dentistry* **16**, 96–8.

Olgart L, Edwall L, Gazelius B (1991) Involvement of afferent nerves in pulpal blood-flow reactions in response to clinical and experimental procedures in the cat. *Archives of Oral Biology* **36**, 575–81.

Raab WH (1992) Temperature related changes in pulpal microcirculation. *Proceedings of the Finnish Dental Society* **88**(Suppl. 1), 469–79.

Raab WH, Muller H (1989) Temperature-dependent changes in the microcirculation of the dental pulp. *Deutsche Zahnarztliche Zeitschrift* **44**, 496–7.

Saitoh M, Masutani S, Kojima T, Saigoh M, Hirose H, Nishiyama M (2004) Thermal properties of dental materials–cavity liner and pulp capping agent. *Dental Materials Journal* **23**, 399–405.

Shortall AC, Harrington E (1998) Temperature rise during polymerization of light-activated resin composites. *Journal of Oral Rehabilitation* **25**, 908–13.

Soyenkoff BC, Okun JH (1958) Thermal conductivity measurements of dental tissues with the aid of thermistors. *Journal of the American Dental Association* **57**, 23–30.

Uhl A, Völpel A, Sigusch BW (2006) Influence of heat from light curing units and dental composite polymerization on cells in vitro. *Journal of Dentistry* **34**, 298–306.

Weerakoon AT, Meyers IA, Symons AL, Walsh LJ (2002) Pulpal heat changes with newly developed resin photopolymerisation systems. *Australian Endodontic Journal* **28**, 108–11.

Zach L (1972) Pulp lability and repair; effect of restorative procedures. *Oral Surgery, Oral Medicine, and Oral Pathology* **33**, 111–21.

Zach L, Cohen G (1965) Pulp response to externally applied heat. *Oral Surgery, Oral Medicine, and Oral Pathology* **19**, 515–30.