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A Study of Temperature Rise in the Pulp Chamber during Composite Polymerization with Different Light-curing Units

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Abstract

Aim: The study compared pulp temperature rise during polymerization of resin-based composites (RBCs) using halogen and LED light-curing units (LCUs).

Methods and Materials: A total of 32 teeth extracted from patients aged 11-18 years were used in the study. Thermocouples placed on the roof of the pulp chamber using a novel 'split-tooth' method. In Group 1 a halogen LCU with a light intensity of 450 $mWcm^{-2}$ was used and in Group 2, an LED LCU with a light intensity of 1100 $mWcm^{-2}$ was used. The teeth were placed in a water bath with the temperature regulated until both the pulp temperature and the ambient temperature were stable at 37ºC. Continuous temperature records were made via a data logger and computer. The increase in temperature from baseline to maximum was calculated for each specimen during the curing of both the bonding agent and the RBC.

Results: The rise in pulp temperature was significantly higher with the LED LCU than with the halogen LCU for bonding and RBC curing ($p<0.05$). The major rise in temperature occured during the curing of the bonding agent. During the curing of the RBC, rises were smaller.

Conclusions: Curing of bonding agents should be done with low intensity light and high intensity used only for curing RBC regardless of whether LED or halogen LCUs are used.

Keywords: Pulp temperature rise, curing units, thermocouples

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Introduction

As a low-compliance system, pulp tissue is vulnerable to temperature changes. However, the extent of thermal trauma tolerated by the dental pulp is unknown. Studies have shown biological trauma, such as pulp cell death, results when pulp temperature increases are in excess of 5.5°C[1] as well as an increase in LTB4 synthesis, when the temperature rises above 39°C.[2] However, other sources suggest a low susceptibility of cells to heat which does not appear to be a major factor in cellular injury at least in the short term.[3] There have been numerous studies reporting one of the possible sources of temperature rise is heat generated during polymerization of resin-based materials with various light curing units (LCUs).[4-9] Some authors have reported temperature increases above 5.5ºC during this procedure.[10-12]

There are three groups of factors influencing intrapulpal temperature changes as follows:

- LCU-related factors including wavelength, irradiance and curing time.
- Resin-based composite (RBC0-related factors including shade, and filler content, among others.
- Tooth-related factors including remaining dentin thickness (RDT) and quality as well as the condition of the pulp and its repair potential.

With the evolution of LCUs, different factors that may influence the temperature of the dental pulp have been recognized. Some authors have suggested there is less temperature rise associated with a narrower spectrum of light emitted from an LCU. Hannig and Bott have found light intensity also has a substantial impact on pulp temperature.[10] In contrast, plasma lights with two to four times greater irradiance produced a comparable and insignificant temperature rise compared to halogen and light emitting diode (LED) LCUs.[9] Time is also a factor to consider. Knezevic reported the highest temperature rise occurs during the first 20 seconds of illumination.[12] Extension of illumination results in the pulp temperature reaching a plateau but increases the total heat of the tooth. This may be the case when darker shades are polymerized with halogen LCUs due to the reduced light transmittance thorough darker shades although this may not be a problem when LED units are used.[6]

Some authors have investigated the effect of polymerization modes by various LCUs on pulp temperature rise in correlation with the RDT of 1 mm, 2 mm and 3 mm.[9,14] Both studies have reported an inverse proportion of these two parameters i.e. temperature decrease in the pulp chamber with the increase in thickness of remaining dentin.

The primary purpose of this study was to compare the temperature rise in the pulp chamber after polymerization of resin based composites with halogen and LED lights and at the same time examine any potential correlation between temperature rise and RDT.

Previous studies recording temperature changes within the pulp after various clinical procedures have used thermocouples (TC) introduced into the pulp chamber *in vitro* via the root canal.[9,10] The location of the TC was verified radiographically. The disadvantage of this method is the TC could not be located precisely in any one position. The split tooth technique, described below, was devised to allow the precise location of a TC within the pulp chamber directly beneath the roof of the pulp chamber.

The object of the pilot study was to assess whether split tooth technique gave comparable readings with intact teeth.

Methods and Materials

The Pilot Study

Twelve non-carious intact molars extracted during the course of orthodontic treatment of patients 12-23 years were used in the pilot study. Patients were informed of the nature of the study and consented to the use of the teeth. The teeth were cleaned, stored for no longer than 24 hours in 0.02% thymol and allocated to one of two groups as follows:

Group I (Intact Teeth): Pulp residues were removed via the root after root section and a K-type TC introduced into the pulp chamber according to a method previously described.[10] (Figure 1) The position of the TC was then verified radiographically from two directions.

Figure 1. Intact tooth with thermocouple introduced via root canal.

Group II (Split Teeth): Teeth were sectioned 1 mm off-center, along the mesio-distal plane using an Isomet saw (Isomet®, Buehler, Lake Bluff, IL, USA) running at 800 rpm. Residual pulp tissue was removed and the TC introduced into the larger tooth section in a position similar to those verified radiographically in Group I and held in position with Loctite® Super glue (Henkels Consumer Adhesives, Winsford, Cheshire, UK). The position of the TC was verified visually. The two sections were then bonded together using Araldite® adhesive (Bostik Findlay, Staffordshire, UK).

The pulp chambers in both groups were filled with ECG gel (CamCare, Ely, Cambridgeshire, UK) by injection via the other root canal not used by the TC. When no more gel could be injected the root ends were sealed with Araldite®. Radiographs were then taken of the teeth from two directions as in Group 1.

The TCs were then connected to a data logger (Measurement Computing Corporation, Norton, MA, USA) and Tracer DAQ software (Measurement Computing Corporation, Norton, MA, USA). Teeth in both groups were thermocycled between baths held at 55ºC and 5ºC with a dwell time of 20 seconds. Transport time between baths was 20 seconds and the ambient temperature was 23ºC and humidity 45±1°C. Continuous measurements of temperature were made at 1 second intervals. These results were obtained to verify the integrity of the Araldite seal under thermal stress. The mean temperature recorded from both groups during immersion in hot and cold bath were statistically analyzed using nonparametric (Mann Whitney) test at a 95% confidence level.

The second part of the pilot study was undertaken to assess light transmission through dentin in intact teeth and compare the results with light transmission through the 'split teeth'.

Occlusal reduction into dentin was undertaken in teeth in both Groups 1 and 2 using an Isomet saw. Using the previously obtained radiographs the degree of reduction resulted in the remaining dentin thickness in both groups being approximately 2 mm. The teeth were then irradiated with a conventional halogen LCU (Prismetics Lite II®, Dentsply Detrey, Konstanz, Germany) at a light intensity of 450 $mWcm^{-2}$ for 20 seconds and continuous measurements of temperature rise taken via the data logger as described.

The Main Study

Thirty-two non-carious permanent molars extracted for orthodontic reasons and stored in 0.02% thymol for not more than four months were selected for the study. Informed consent was gained for the use of these teeth for research purposes. The age range of patients was 11-18 years.

Prior to the study, the teeth were cleaned of all superficial debris using an ultrasonic scaler. For the duration of the experiment the teeth were kept in distilled water in a temperature controlled environment at 37ºC to ensure adequate hydration of the dental tissues. To facilitate cavity preparation, sectioning and image analysis the roots of the teeth were embedded up to the cemento-enamel junction in resin, 14 mm x 14 mm x 7 mm. Standard cavity preparation and placement of TCs was prepared in the following manner: (Figure 2)

Figure 2A. The apices of the roots were cut off and the tooth embedded in clear acrylic up to the cementoenamel junction.

Figure 2B. A diamond bur in a high speed hand piece with water spray was used to reduce the cusps to create a flat occlusal plane.

Figure 2C. Using the same diamond bur a preliminary cavity was cut into dentin but not extending more than 1.5 mm from the occlusal plane. A Class 1 large Cerana diamond bur (Nordiska Dental, Angelholm, Sweden), dimensions: height 3 mm; top diameter 4 mm; bottom diameter 3 mm), normally used to prepare standardized cavities for ceramic inserts was used to enlarge the initial cavity. At this stage, the depth of the cavity was under prepared.

Figure 2D. The teeth were then sectioned through the prepared cavity, off-centre, along the mesio-distal plane using a slow speed saw (Isomet®, Buehler, Lake Bluff, IL, USA). All remaining remnants of pulp tissue were removed by washing the cavity with 5% sodium hypochlorite and flushing with distilled water.

Figure 2E. The Cerana bur was then used to create a standard cavity with a RDT of approximately 0.5 mm. The depth of the cavity was then standardized to be 2 mm deep through reduction of the flat occlusal plane in all cases.

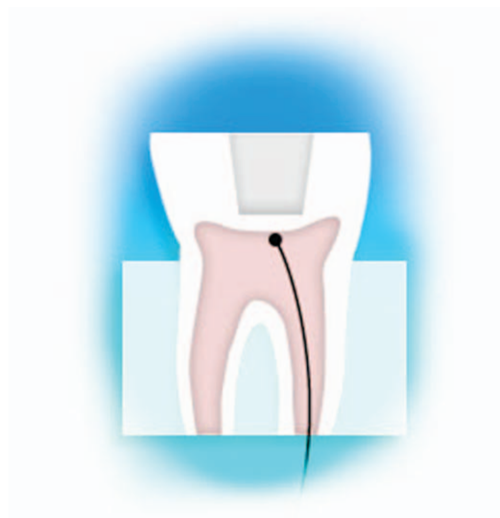

Figure 2F. Using an image analysis system (Olympus Camedia and SZ-CTV Olympus, Tokyo, Japan) both sections of each tooth were photographed and the average RDT was calculated and recorded from five randomly selected sites. Using a tungsten carbide bur one root was prepared to receive the leads of the TC and the TC head fixed in position with Loctite® Super glue (Henkels Consumer Adhesives, Winsford, Cheshire, UK) to the dentin of the roof exactly in the midline of the cavity in the larger of the two sections. The pulp chamber was filled with ECG gel. The two sections were then carefully glued together using Araldite®.

Figure 2. The split tooth technique for preparing standard cavities and placement of thermocouples.

The teeth were then randomly allocated to two test groups as follows:

Group 1: Conventional halogen LCU (Prismetics Lite II®, Dentsply Detrey, Konstanz, Germany)
- Light intensity 450 $mWcm^{-2}$
- Curing times: bonding agent 10 seconds: RBC 20 seconds

Group 2: LED high intensity LCU (Bluephase®, Ivoclar Vivadent, Schaan, Lichtenstein)
- Light intensity 1100 $mWcm^{-2}$.
- Curing times: bonding agent 10 seconds; RBC 20 seconds

The intensity of the halogen light curing units was monitored before commencing the study and frequently during the study with a radiometer, (Model 100 Curing Radiometer, Kerr Corporation, Danbury, CT, USA) and the light intensity of the LED unit was similarly monitored through its own integrated photometer.

The ambient tooth temperature was recorded by a second TC attached externally, midway along the clinical crown. The tooth now had two TCs, one recording pulp temperature and the second recording ambient temperature. TCs were connected via a data logger (Measurement Computing Corporation, Norton, MA, USA) to a computer and temperature was recorded using a software package, Tracer DAQ (Measurement Computing Corporation, Norton, MA, USA). (Figure 3)

All teeth were placed in Oasis (flower display sponge) in a water bath with the temperature regulated until both the pulp temperature and the ambient temperature were stable at 37ºC±1°C. All subsequent cavity filling and temperature recording was done with the teeth in the water bath maintained at 37°C±1°C.

AdheSE™ bonding agent (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the cavities

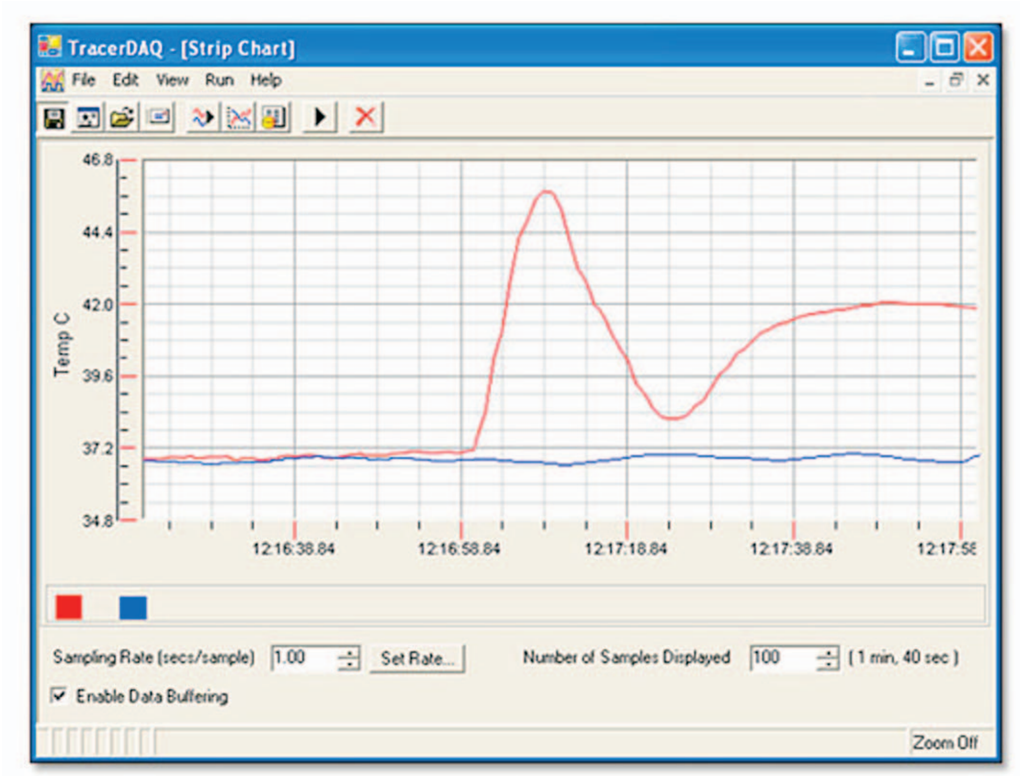

Figure 3. Tracer DAQ original image of temperature values in the pulp chamber and the ambient temperature.

along with a microscope slide placed immediately on the flat occlusal plane of the tooth to insure the distance between the light source and the cavity was standardized and cured according to the manufacturer's instructions. Immediately after curing the bonding agent the cavity was bulk-filled with TetricEvo Ceram™ RBC, (Shade A3, Lot Number J17761, Ivoclar Vivadent, Schaan, Liechtenstein) and cured through the microscope slide according to the manufacturer's instructions.

The increase in temperature from baseline to maximum was calculated for each specimen.

Results

The Pilot Study

The Mann-Whitney test showed the temperature changes between Groups 1 and 2 were not significantly different for either hot (p=0.9587) or cold baths (p=0.9941). (Table 1)

The Mann-Whitney test also showed the temperature changes during irradiation with the halogen LCU between Groups 1 and 2 were not significantly different (p=0.8182). (Table 2)

The Main Study

The mean and standard deviation RDT values for both groups are presented in Table 3.

Results of temperature rise are given in Tables 4 and 5, and the correlation between temperature rise and RDT is given in Table 6.

Discussion

In the present study teeth extracted from consenting patients, age range 11 to 23 years, were used. The microanatomy and pathology of these teeth may not fully reflect clinical conditions, such as the affect of caries, tertiary dentine formation, and sclerosis, found in adult teeth. However, they would reflect the worse case scenario in terms of greater thermal conductivity through these teeth than in older diseased teeth.

The pilot study was undertaken to assess the effect of using a split tooth versus an intact tooth to study temperature rises within the pulp. There was no significant difference between data obtained from intact and split teeth in terms of heat and light transmission. Most previous studies used intact teeth and introduced TCs via a root

Table 1. Temperatures variations in the pulp chamber in hot and cold bath in intact VS split teeth.

Parameter	Group 1 (Intact Teeth)		Group 2 (Split Teeth)	
	Hot	Cold	Hot	Cold
Median (ºC)	38.06	16.00	38.15	16.17
Maximum (ºC))	41.99	20.00	41.5	19.58
Minimum (ºC)	35.33	15.00	35.78	15.39
Mean (ºC)	38.53	17.17	36.48	17.09
SD (ºC)	2.00	1.90	1.98	1.74
Lower 95% CI	37.787	16.457	37.742	16.441
Upper 95% CI	39.224	17.876	39.224	17.742

Table 2. Temperature variations in pulp chamber during halogen light irradiation.

Parameter	Group 1 (Intact Teeth)	Group 2 (Split Teeth)
Median (ºC)	1.98	1.98
Maximum (ºC))	2.15	2.14
Minimum (ºC)	1.77	1.66
Mean (ºC)	1.97	1.94
SD (ºC)	0.14	0.20
Lower 95% CI	1.826	1.733
Upper 95% CI	2.124	2.151

Table 3. Mean RDT and standard deviation values.

	Group 1: RDT	Group 2: RDT
Mean RDT (mm)	1.003	1.125
SD (mm)	0.202	0.229
Sample size	16	16
Standard error of mean (SEM)	0.05	0.06
Lower 95% confidence limit	0.8952	1.003
Upper 95% confidence limit	1.110	1.247

Table 4. Mean temperature rise, standard deviation, and confidence limits.

	Halogen LCU		LED LCU	
	Bond	RBC	Bond	RBC
Sample size	16	16	16	16
Mean temp. (ºC)	2.969	1.958	5.980	4.085
Standard deviation	0.977	0.908	2.245	1.587
Lower 95% CL	2.449	1.474	4.785	3.239
Upper 95% CL	3.490	2.441	7.176	4.930

Table 5. Mean temperature rises for the different LCUs.

	P value	Significant / Not Significant
Hal Bond vs Hal RBC	0.0099	S
LED Bond vs LED RBC	0.0151	S
Hal Bond vs LED Bond	0.0001	S
Hal RBC vs LED RBC	0.0003	S

Table 6. Correlation between remaining dentin thickness and temperature rise.

	R value	95% Confidence Level	Two-tailed P Value	
RDT vs Hal Bond	-0.2235	-0.6568 to 0.3207	0.4053	ns
RDT vs Hal RBC	-0.0383	-0.5357 to 0.4789	0.8881	ns
RDT vs LED Bond	-0.0928	-0.5736 to 0.4356	0.7325	ns
RDT vs LED RBC	-0.2047	-0.6545 to 0.3383	0.4469	ns

canal. The position of the TC was then determined by a radiograph. However, it is almost impossible to accurately position a TC in a reproducible and controlled manner using this method. The split tooth method allows TCs to be placed directly beneath the center of the roof of the pulp chamber in a location normally occupied by the odontoblast layer. The odontoblasts (post-mitotic cells) are the cells most likely to be vulnerable to temperature rises. By locating the TC in the same position in each tooth standardization is achieved. This was not previously obtainable using the intact tooth method. Moreover, this method allows a standardization of the thickness of dentin between the cavity floor and the pulp chamber as well as a standardized cavity size and, subsequently, a standardized volume of RBC.

The split tooth technique also allowed the identification of pulp exposures during standardized cavity preparation. In the present study the pulps of two teeth were exposed and eliminated from the experiment. The split tooth technique was, therefore, adopted for the main study.

In an attempt to reduce clinical working time and reach a more effective depth of cure, most manufacturers have introduced LCUs approaching an irradiance of 1000 mW/cm^2. Early reports suggest LED LCUs are less harmful to the pulp, but general dental practitioners should be cautious in interpreting these early studies because LCUs of lower irradiance (usually in the range of 400 mW/cm^2) were tested. The LED light tested in the current study was 1000 mW/cm^2, and the mean temperature rise during bonding with LED was in excess of the 5.5ºC. This temperature is normally considered sufficient to cause pulp cell damage. Even though dentin has a low thermal conductivity, the potential for pulp damage is greater as the number of dentin tubules increases per unit area in deep cavity preparations.[16]

The results of the present study should serve to caution clinicians against excessively long bonding times when using LED lights at 1000 mW/cm^2. If LCUs have a low irradiance mode, it should be used for bonding and the high irradiance mode of 1000 mW/cm^2 should be restricted to curing RBCs.

In both groups there was a significant difference in the temperature rise during bonding compared to the curing of RBCs. In all cases temperatures fell immediately after the curing procedure. It is not surprising to find pulp temperatures were lower during RBC curing which can be attributed to the thermal insulation offered by the material itself.

There was no significant correlation between RDTs and temperature rise in either groups or subgroups which could be attributed to the small standard deviation in RDT. In the present study there was no correlation between RDTs and temperature changes with either of the two units for dentin bond or RBC curing. This was most likely due to the favorable thermal insulating effect of dentin and the relatively small differences in recorded thicknesses.

Manufacturers of RBCs recommend a curing time of 40 seconds for halogen lights operating at 400-500 mW/cm^2 and 20 seconds for the newer high powered halogen and LED light

operating at over 1000 mW/cm^2. For this reason, a conventional halogen light operating at 450 mW/cm^2 was compared with a newer LED light operating at 1000 mW/cm^2. There was always a significant higher temperature rise with the LED unit compared to the halogen unit when both the dentin bonding agent and the RBC were cured. These results are in agreement with the overall conclusions of Hannig and Bott[10] but in conflict with the findings of Yazici and Knezevic.[9,12]

The first two quoted studies compared halogen units with plasma lights, the third halogen versus LED lights. Hannig and Bott concluded the potential risk for heat induced pulpal injury is increased with high energy out-put light sources as compared to low energy out put LCUs.[8] Knezevic suggested the results were due to the narrower spectrum of the LED lights. However, it should be noted the irradiance of the LEDs were only 50 mW/cm^2 in the first 10 seconds and 150 mW/cm^2 in the subsequent 30 seconds in that study. In addition the halogen units used in their study were operating at 750 and 800 mW/cm^2.[12] Therefore, the light intensity and not the type of unit is most important in the production of heat. However, other factors such as duration of exposure and spectral distribution are also important factors as well.

A critical factor in reducing thermal transfer to the pulp tissue is the low thermal conductivity of dentin.[17] There is a an increase in pulpal trauma from heat production as the thickness of the remaining dentin decreases.[9,14,17-19]

The effect of blood flow throw pulp tissue as a mechanism for heat dissipation must also be considered. In the present study water did not circulate in the water bath and, therefore, heat would not be dissipated as it would in vital tissue. The temperature rise recorded may, therefore, be higher than in *in vivo* conditions.

Conclusion

The major rise in pulp temperature is during the curing of a dentin bonding agent. During the curing of the RBC, rises are smaller. Curing of dentin bonding agents should be done with low intensity light settings and, subsequently, the high intensity mode of an LCU should only be used only for RBC curing whether or not halogen or LED units are used in order to avoid pulp cell damage. Most manufacturers now supply units with low power modes to address this issue.

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