

Modern High Powered Led Curing Lights and Their Effect on Pulp Chamber Temperature of Bulk and Incrementally Cured Composite Resin

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Abstract - Pulpal temperature changes induced by modern high powered light emitting diodes (LEDs) are of concern when used to cure composite resins. This study showed an increase in pulp chamber temperature with an increase in power density for all light cure units (LCU) when used to bulk cure composite resin. Amongst the three LEDs tested, the Elipar Freelight-2 recorded the highest temperature changes. Bulk curing recorded a significantly larger rise in pulp chamber temperature change than incrementally cured resin for all light types except for the Smartlight™PS. Both the high powered LED and the conventional curing units can generate heat. Though this temperature rise may not be sufficient to cause irreversible pulpal damage, it would be safer to incrementally cure resins.

KEY WORDS: Light curing; pulpal heat; LED; halogen; composite resin; bulk curing; incremental curing.

INTRODUCTION

For many years thermal damage to the pulp has been a matter of concern in dentistry. Cavity preparation, polymerization of linings and restorative resin materials and curing lights, are all potential sources of temperature rise at the cavity wall and as such must be regarded as having the ability to produce an increase in the intra-pulpal temperature^{1,2}. Zach *et al.* reported that pulp temperature increases of 5.5°C and 11.1°C (in Macaca Rhesus monkeys) could cause irreversible pulpitis in 15% to 60% of cases respectively³. It was also shown that even a small rise in pulpal temperature, irrespective of its method of induction, does produce histological evidence of pulpitis of varying severity in animals³. Tjan *et al.* reported that certain restorative procedures have the ability to cause an increase in intra-pulpal temperature that may exceed 5.5°C; especially if the procedures are carried out incorrectly⁴. Preparation of full crowns with air cooled high speed instruments can generate an average temperature increase of 8.8°C, while the fabrication of direct provisional crowns with methyl-methacrylate resins can cause an increase ranging from 8.2°C to 19.1°C⁴.

The exothermic reaction of the composite together with the radiant energy output from the light source may produce a substantial temperature rise (up to 40°C) within the composite resin⁵⁻⁸. Masutani *et al.* reported that polymerization of resin had a greater influence upon the temperature rise during curing than the light source⁹. Smail *et al.* however reported that light activation unit could also contribute

substantially to heat during polymerization¹⁰. Temperature rise caused by the light curing unit (LCU) at the cavity wall, depends mainly upon the exposure time^{6,7} and the characteristic of the light source^{9,11-13}. Furthermore, the shade of the restorative resin, the degree of porosity in the material, the initial resin temperature, and the material thickness may all have an influence on the temperature rise^{6,14}. Thermal transfer to the pulp also varies with the type of LCU used^{15,16}. Tarle *et al.* reported that more energy does not necessarily lead to higher thermal effects and intra-pulpal temperature rise may be dependant on the type of light source¹⁷.

It was reported that light output from the units outside the effective curing range (wavelength) could significantly add to the heat production¹⁸. Furthermore, the light-emitting tip placed at close proximity to the pulpal floor during the curing cycle may elevate the intra-pulpal temperature and or dehydrate the pulp¹². This information shows that if a curing light is not used correctly it can lead to intra pulpal temperature increases even if it is a low output curing light. Heat generated by LCUs can be detrimental to the health of the pulp, but the increased need for aesthetic restorations has led to the continued use of these lights and an increased demand for high power density LCUs with shorter exposure times. This demand has led to curing lights evolving from the low output LCUs to the high output units including the Light Emitting Diodes (LEDs). Most of the currently available LED curing units belong to either the 2nd or 3rd generation¹⁹, however a review of the present literature does not provide a clear definition on what power densities constitutes a high or low powered LCU. Earlier conventional lights and LEDs had a power density of 400mW/cm². Wiggins *et al.* reported that older versions of LED LCU had Power densities up to 400mW/cm², while the present day high powered LED lights were in the 1,000 mW/cm² range²⁰. The inventors of the LED curing units claim that even though these lights are high output lights they do not generate heat¹⁸. However, re-

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cently it was reported that the UltraLume 5, which is a high power density LED curing light, caused an intra-pulpal temperature increase of about 5.7°C when used to cure composite in a Class II cavity preparation with an axial wall depth of 2.5mm²¹. Guiraldo *et al.*²² reported that intra-pulpal temperature may be affected by the type of composite placement technique. Incremental placement techniques have been advocated over bulk fill techniques by a number of authors to reduce total polymerization shrinkage^{23,24}, with an initial thickness of 1mm advocated to achieve close adaptation to the cavity walls^{25,26}.

As LED technology is well set to shape the next generation of curing lights, it is appropriate to further investigate and compare them with the standard curing methods. This study used a single tooth model to measure intra-pulpal temperature changes during bulk and incremental packing of composite resin using three high powered LEDs and a conventional halogen curing unit. This single tooth model would avoid variability associated with use of multiple teeth.

MATERIALS AND METHODS

A recently extracted impacted third molar with completely formed root apex was cleared of debris and soft tissue and stored for 24 hours in distilled water containing 1% thymol (Merk, Darmstadt, Germany). The tooth was collected following human ethical approval and informed consent from the patient. To ensure standardisation of the results, a single tooth model was used for this study. The roots were resected a few millimetre below the Cemento-enamel Junction (CEJ) with a straight hand piece using a tapered bur (ISO 807104, Komet, Besigheim, Germany) and pulp tissue was removed with an excavator and endodontic files (Maillefer, Ballaigues, Switzerland). A standard Class I cavity (3mm x 3mm wide) was prepared on the occlusal surface with a depth of 4mm and remaining dentine thickness (RDT) of 1mm. The RDT was measured both radiographically and with a Boley gauge (Wright Health Group, Scotland). The cavity was prepared with a straight hand piece and a carbide fissure bur (500 104 237 006 027). The cavity walls were smoothed with a tapered fissure bur (Shofu™ 173/015) to produce a slight incline on walls with no undercuts. The occlusal surface was then ground with an Impitech grinder polisher (P20V001, IMP Innovative MET product cc, Boksburg SA) to reduce the cavity depth to 2mm.

An experimental model based on the one used by Hanning and Bott¹⁶ was constructed for this experiment with a few modifications. A hole was drilled into the tooth just below the CEJ to allow access for the thermocouple into the pulp chamber (Fig.1). The tooth was then adapted into a hole prepared on the lid of a 50ml cylindrical sample bottle and secured using cyanoacrylate glue. The lid with the tooth attached was then placed back in the sample bottle. The bottom of the sample bottle was cut off to allow free circulation of water around the root of the tooth. The final set up had the crown and thermocouple floating above water and the root of the tooth submerged. A K-type thermocouple (Lutron, Electro-tech, Wynburg, SA) was positioned on the mesial side of the pulp just underneath the cavity preparation (Fig.2). The thermocouple maintained immediate contact with the dentine by means of a thin

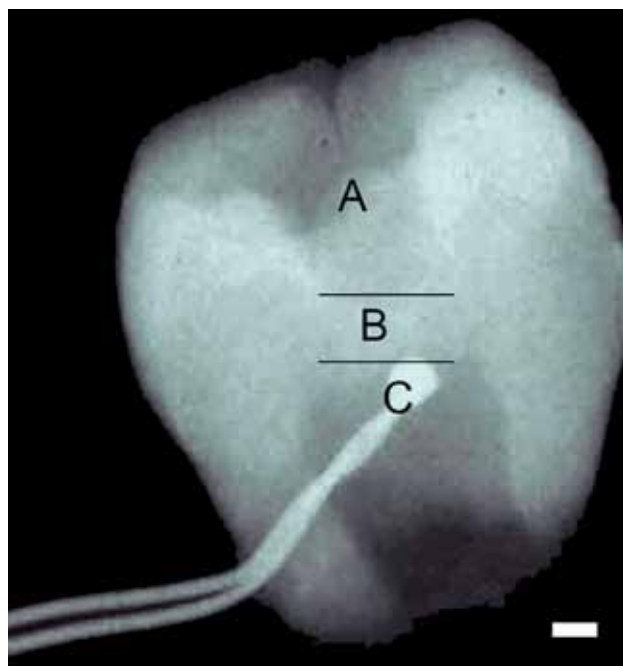


Figure 1.

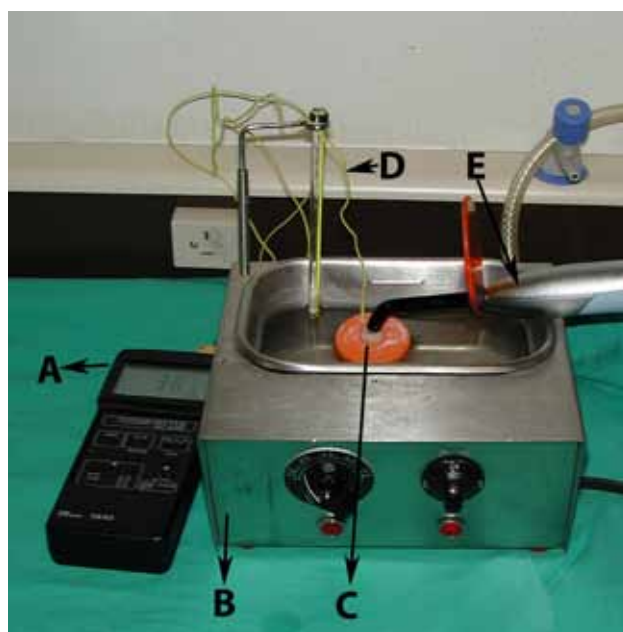


Figure 2.

layer of silicone oil based thermal compound (Servisol, Ambersil LTD, Bridgewater, England). The position of the thermocouple was verified radiographically (Fig.1). The complete set-up (Fig.2) was placed in a water bath ($37 \pm 1^\circ\text{C}$) and the thermocouple was connected to a digital thermometer (Lutron, model TM915, Denmark, Accuracy $\pm 0.075\%$ - 1°C).

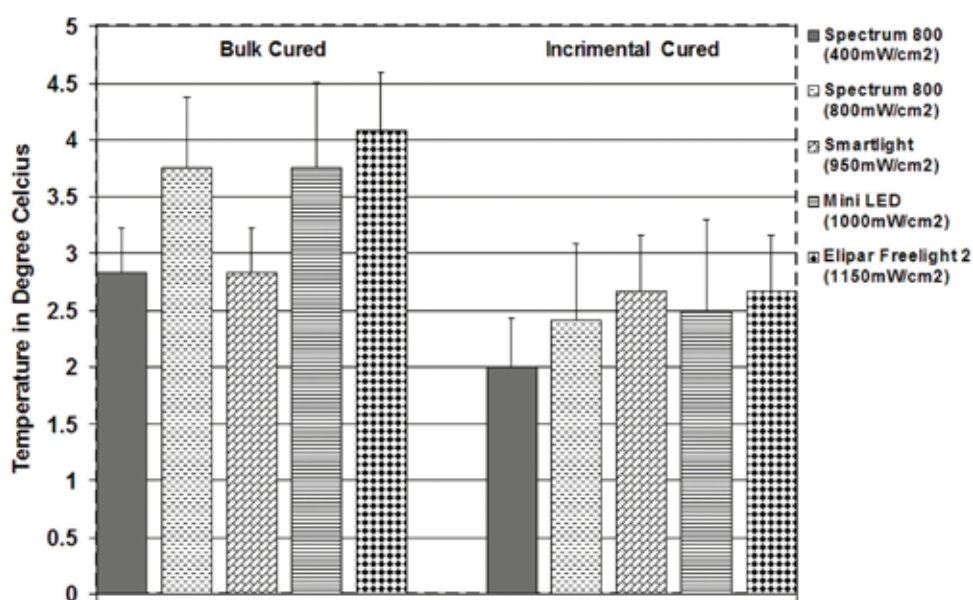
All curing units were used with a light guide tip (8mm diameter). To allow for easy removal of the polymerised resin (TPH Spectrum, Shade A1, Dentsply), without damaging or increasing the size of the cavity during each experimental cycle, the cavity was filled without etching or bonding. Three LEDs and one conventional halogen light source (control) were used for this study (Table 1).

Table 1. Showing the different standard parameters of the Light curing Units(LCU)

LCUs	Manufacturer	Type of light	Power Density (mW/cm ²)	Manufacturers quoted Wavelength (nm)	Energy Density (mW/cm ² ·sec) (KJ)
Spectrum™800	Dentsply	Halogen (Control)	400	425-580	16
Spectrum™800	Dentsply	Halogen (Control)	800	425-580	32
Smartlight™PS	Dentsply	LED	950	450-490	38
Mini-LED	Dentsply	LED	1000	420-480	40
Elipar Freelight 2	3M	LED	1150	430-480	46

Table 2: Differences in bulk and incrementally cured composite following a 40 second curing cycle are shown as follows: ns, not significant; *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$

LCUs	Bulk cured Mean temperature change °C (Standard deviation)	Incremental cured temperature change °C (Standard deviation)
Spectrum™800	2.83 (0.39)*	2(0.43)
Spectrum™800	3.75 (0.62)***	2.42(0.67)
Smartlight™PS	2.83 (0.39) ns	2.66 (0.49)
Mini-LED	3.75 (0.75)**	2.5(0.79)
Elipar Freelight 2	4.08 (0.51)***	2.6(0.49)

**Figure 3.** Intra-Pulpal temperature changes with LCU

Power density of all the light sources were tested using two calibrated Demetron radiometers (Kerr, Orange, CA) calibrated for Halogen and LED curing lights (Table 1).

For the first part of the study, the cavity was bulk packed with composite resin and light tips were directly placed over an Odus Universal strip (Odus Dental SA, Vevey Switzerland) and light cured for 40 seconds. The temperature rise was observed for each cycle and the maximum temperatures recorded. To ensure that there was no post cure spike in temperature, the maximum temperature was recorded up to the point where the temperature began to fall rather than the exact moment that the light unit was shut off. After each measurement the composite was cut in half vertically with a pre-measured Hi-Di friction grip pointed diamond bur (733 M 160/M/012, Komet, Besigheim, Germany) and

removed in two halves using a hatchet. Between tests, the cavity was cleaned of debris with distilled water, blot dried and observed under a microscope (Olympus BX61, 10x magnification) to confirm the complete removal of residual debris. Twelve measurements were recorded for each curing unit and measurements were made with sufficient time between tests for the thermocouple to return to the ambient temperature and register a constant temperature for a minimum of 30 seconds. The ambient temperature of the specimens was that of the water bath ($37 \pm 1^\circ\text{C}$).

For the second part of the study, the experimental procedure was similar to the first part of the study with the exception being that the restoration was placed in the cavity in two increments. Each increment was cured for 20 seconds. Less than 5 seconds was allowed between the

curing of the increments. The intra pulpal temperature was again measured twelve times for each curing unit.

The temperature of all LCU at the tip was tested prior to the study. This was done directly over the thermocouple for 40 seconds with only a Odus Universal strip (Odus Dental SA, Vevey Switzerland) separating the two. The experiment was repeated six times and the average values recorded.

The data was tested for normality using a Kolmogorov-Smirnov test and then analysed statistically using one-way Kruskal Wallis method (Non-parametric ANOVA) followed by a Dunn's Multiple Comparison.

RESULTS

The mean temperature scores were calculated for all the experimental groups (Table 2 and Figure 3). The mean pulp chamber temperature values increased with power density for both the conventional halogen curing lights and for the LEDs when bulk cured (Table 2); however a similar increase was not observed when the composite resin was incrementally cured. Similarly, an increase in temperature with power density was recorded when the temperature of the LCU's was measured directly at the light guide tips through an Odus Universal strip. The Spectrum™800 set at 400 mW/cm² recorded the least temperature rise of 9.7 °C, whereas the Spectrum™800 set at 800 mW/cm² recorded 19 °C at the light guide tip. Amongst the LED LCU, the highest temperature at the light guide tips was recorded by Freelight-2 (26.5°C) followed by Mini LED (23.5°C) and the Smartlight™PS (19.8 °C).

When bulk cured, the Spectrum™800 (set at 400 mW/cm²) and the Smartlight™PS displayed similar mean pulp chamber temperature changes (Table.2). The Spectrum™800 (set at 800 mW/cm²) and the Mini LED also displayed similar mean temperature change (Table.2). The Elipar Freelight-2 gave the highest pulp chamber temperature changes. The Spectrum™800 (set at 400mW/cm²) and the Smartlight™ (950mW/cm²) showed the least mean pulp chamber temperature changes (Table.2).

When bulk cured, there was however no significant difference between heat generated by Elipar Freelight™-2, the Mini™ LED and the Spectrum™800 set at 800 mW/cm². When compared with the Spectrum 800 set at 400 mW/cm², the Elipar Freelight-2 ($p=0.001$) and Mini LED ($p=0.05$) showed a significant greater increase in pulp chamber temperature. The Smartlight™ showed significantly less intra-pulpal temperature rise when compared to both the Mini LED and the Elipar Free Light 2 ($p=0.05$ and $p=0.001$ respectively). For all light types except for the Smartlight™PS, bulk curing recorded a significantly larger rise in pulp chamber temperature than incrementally curing (Table 2)

DISCUSSION

A number of studies have reported that heat developed during dental restorative procedures can be harmful to the health of the dental pulp^{3,27}. Polymerization of composites, which is initiated by intense blue light, introduced a further source of heat on top of the heat generated through friction during cavity preparation and by the exothermic setting reactions in restorative materials⁷. Masutani *et al.*

reported that exothermic heat generated following polymerization of resin could contribute to an increase in the intra-pulpal temperature⁵, however Yap *et al.* reported that intra-pulpal temperature rise during the curing of restorative materials was mainly contributed by the light source²⁸.

The potential risk of heat induced pulpal injury during composite resin polymerization is increased when using visible light curing units with high energy output as compared to low energy output light sources^{16, 29, 30}. Manufacturers of newer generation LEDs with high power density often claim that their machines produce less intra-pulpal temperature increase than the conventional halogen curing lights. This study was undertaken to verify this claim.

In vitro experiments using extracted teeth will not yield the same results that are expected to be found in *vivo* situations where there is movement of blood through the pulp with the consequent potential for heat dissipation³¹. However, the *in vitro* experiments can yield results that may serve to alert the clinicians of the potential hazards to the health of the pulp. In this study, the observed temperature value is not merely from the light unit, but is also a result of the heat generated by the composite itself during conversion (exothermic reaction). The use of a single tooth model and standardising other parameters such as composite brand, thickness and total time of cure with all the curing lights allows for a better comparison of temperature changes within the pulp chamber. It should be noted that in clinical settings the use of liners or other thermal insulating bases may help to offset the conduction of thermal energy to the pulp¹⁰.

Asmussen and Peutzfeldt reported that some new generation LEDs generate heat. They presumed that the possible reason for this variation from previous studies was that "first generation" curing lights were of lower power density than some of the present day LED curing units³². The Ultralume 5, which is a third generation high power density LED curing light, caused an intra-pulpal temperature increase of about 5.7°C when used to cure composite in a Class II cavity preparation with an axial wall depth of 2.5mm¹⁹. The present study showed that all light sources tested caused a rise in pulp chamber temperature and hence claims that LED curing units generate little or no heat when compared to conventional curing units is not true.

High power density lamps reduce curing time but also increase the risk of pulpal damage³⁰. In the present study, when bulk cured, the Spectrum™800 set at 400mW/cm² resulted in less pulp chamber temperature changes when compared to Spectrum™800 set at 800mW/cm², indicating that intra-pulpal temperature increases with an increase in power density. The Spectrum™800 set at 400mW/cm² yielded less intra-pulpal temperature changes as compared to the Mini LED (1000mW/cm²) and the Freelight-2 (1150mW/cm²). The Spectrum™800 set at 800mW/cm² resulted in more or less the same temperature changes as the Mini LED with higher power density of 1000mW/cm². The Elipar Freelight 2 which had the highest power density (1150mW/cm²) in this experiment created the greatest temperature changes. The Spectrum™800 set at 800 mW/cm² resulted in temperature change increases that are almost double to the ones measured for the same light when set at 400mW/cm². This again indicates substantial temperature increases with increasing power density.

Incremental curing of composite resin has been advocated for many years to decrease the effects of polymerization on bond strength. Modern LED can provide an adequate cure for incrementally condensed composites in 20 seconds³³. The present study shows that with the exception of Smartlight™PS, incrementally cured composite resins produced a pulp chamber temperature increase that was significantly lower than when bulk cured. This indicates that the power density of the light cure unit may play an important role in intra-pulpal temperature rise when resins are bulk cured, but not when incrementally cured. It should also be noted that the distance of the light source from the surface of the resin may affect the temperature changes observed for both incrementally cured and bulk cure resins may³⁴.

Several studies^{5, 12} have reported that the temperature changes are dependent on the characteristics of the light source. In the present study, the Smartlight™PS resulted in more or less the same temperature changes as the Spectrum™800 set at 400mW/cm² when bulk cured even though the power density of the Smartlight™ is more than twice the power density of Spectrum™800 set at 400mW/cm². This was not expected as generally the LCUs with high power densities resulted in temperature increases higher than those produced by the lower power density curing lights. There might be an inbuilt technology that ensures that the light output does not result in high temperature increases despite the fact that it is a very high power density light.

The result of the present study indicates that the risk for heat induced pulpal damage during photo-polymerization of resin composites should be taken into consideration. However in clinical conditions, the rises in temperature within the pulp may be further offset by the blood circulation in the pulp chamber and the fluid motion in the dentinal tubules^{28, 31}. The surrounding periodontal tissue can also promote heat convection, thus limiting the intra-pulpal temperature rises¹.

CONCLUSION

Within the limitations of this study it was shown that:

Both the conventional halogen curing lights and the LED curing lights generated heat that resulted in temperature increases within the pulp chamber when used to cure composite resin. Though this temperature rise may not be sufficient to cause irreversible intra-pulpal thermal damage, it would be safer to incrementally cure resins.

Power density and characteristics of curing lights may play an important role in temperature increases within the dental pulp.

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