Experimental Curing Unit: Influence of the Lighting Modes on the Dental Pulp Chamber Temperature

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Abstract

High irradiance of a curing unit with continuous lighting is associated with high output temperature that could lead to high pulp chamber temperature. The pulse-lighting mode has been studied as an alternative to the continuous lighting.

The aim of our study was to analyze the influence of the lighting modes of the light curing unit on the dental pulp chamber temperature of extracted teeth. We constructed an experimental unit, with different irradiances with light exposure times of 10 and 20 sec; the output temperature and irradiances were measured. The irradiances were used to polymerize resin composites restored in teeth with different light exposure times. Then, the temperature of the dental pulp chamber were determined, whereas, the temperature of the dental pulp without light exposure was used as baseline. A commercially available curing unit that was checked to have continuous-lighting mode with an irradiance of 900 mW/cm2 and is operated only in 20 sec was employed for comparison with the pulsed lighting mode curing unit.

We found that the output light and pulp-chamber temperatures of the pulse-lighting curing unit were significantly lower than those observed for a continuous-lighting curing unit. With respect to the pulsed-lighting curing unit, the output-light temperatures associated with the irradiance levels of 900 in 20 sec and 1,000 mW/cm2 in 10 or 20 sec showed significant differences. The pulp-chamber temperature decreased during resin composite polymerization but was still slightly higher than the baseline. When used in vivo, the slight value added to the normal dental pulp chamber temperature value could be higher than the normal temperature of the pulp chamber which could cause problems in dental pulp chamber.

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Introduction

Commercially available restorative resin composite materials, introduced in the 1960s following the pioneering work of Bowen, have been developed and used in dental practices.[1–3] Along with the development of the materials, there have been major advancements in illumination devices, such as light curing units (LCUs).[4] Particularly, breakthroughs in semiconductor technology have enabled the use of gallium nitrate light-emitting diodes (LEDs) as the light source of the LCUs.[5]

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Most light-curing units are based on the LED technology. Single blue, high-powered diodes that reach irradiances of 1,200 to 1,500 mW/cm^2 (second generation) as well as polywaves containing multiple violet/blue diodes (third generation) have been employed. The third-generation LCU-LEDs are characterized by a high light irradiance, which can be above 2000 mW/cm^2 to achieve a shorter polymerization time.[5] However, an important aspect of a technology such as light irradiance is heat generation.

Researchers have evaluated the temperature rise in the pulp chamber temperature during polymerization of the composite resin in previous studies, demonstrating a positive correlation between LCU irradiance and temperature rise. During the procedure of curing a resin composite, the heat associated with the use of an LCU may have a hazardous impact on the dental pulp, and can damage the tissue if uncontrolled.[6,7] The use of light in high-irradiance treatments may increase the pulp-chamber temperature, affecting the pulp nerve fibers and even leading to tooth sensitivity in patients.

In an effort to reduce the heat associated with the use of high-irradiance LCU-LEDs, scientists have tried to use pulse width modulation in the development of a curing unit. For brightness LED settings, Pulse Width Modulation (PWM) is a method of manipulating, the width of the signal expressed by pulses. Setting the width of the "on" and "off" pulses in one wave period gives the desired duty cycle, the value varies (between 0% to 100%). By using a formula, the output voltage will be obtained in accordance with PWM.

In a previous study, an experimental LCU-LED with pulse lighting and an irradiance of 1,182±1.30 mW/cm^2 in 40 sec was constructed and found that when the light was used to polymerize resin composites restored in extracted teeth, the pulp-chamber temperature reached a value of 36°C, which was lower than the 48.8°C obtained at a higher irradiance of 1,194 mW/cm^2 of the continuous light from the commercially available LCU-LED.[8] To accommodate the patient's desire for shorter dental visits, a light curing unit with a lower irradiance than 1,194 mW/cm^2 and a shorter light-exposure time than 40 sec was designed. We prepared an experimental pulsed-lighting LCU-LED with irradiances of 715 and 800 mW/cm^2 with light-exposure of 20 sec that produce an output-light temperature of 37±1°C.[9,10]; however, we obatined that the resin composite caused cytotoxicity for which viability of the cells exposed to a resin composite was relatively low.[10] Higher irradiance above 715 and 800 mW/cm^2 with light-exposure of 20 sec may be required. Therefore, the present study aimed to analyze the influence of the lighting modes of curing units on the dental pulp-chamber temperature.

Materials and methods

Preparation of the experimental pulsed-lighting curing unit

We constructed the experimental curing unit with pulsed-lighting mode following the procedure described in a previous study.[9,10] Briefly, the curing unit primarily comprised an ATmega328 (Atmel, San Jose, CA, USA) microcontroller and an in-system software with an IRF540 (International Rectifier, Temecula, CA, USA) metal-oxide-semiconductor field-effect transistor (MOSFET). The curing unit used an LED driver, and a light guide mounted with a high-power LED dental with a wavelength of 460–470 nm (LED Engin, Mouser Electronics, Mansfield, TX, USA) was located at the front of the prototype. The curing unit also featured two pushbuttons of the irradiance levels and start button to run the system. When the start button was pressed, electric current is dissipated, a timer counted down from a selected time of 20 or 10 sec to 0 through two components of seven segments (Fig.1).

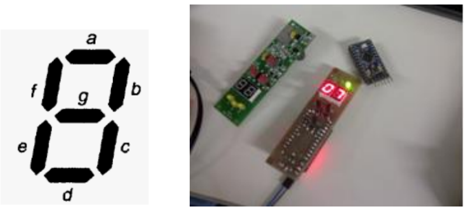

Figure.1. (a). Seven segment display, (b). Two components of seven segment in an LCU.

The pulse signals were then passed to the LED driver to activate the LED lamp and produce light, which was transmitted through the light guide (Fig.2).

Figure 2. Light exposure transmitted through the light guide of an LCU.

In this study, shorter light-exposure times than the previous study two choices of of 20 sec and a shorter time of 10 sec the experimental pulse-lighting mode curing unit was designed with two different duty cycles of 74.5% and 90.2% to obtain irradiation levels of 900 and 1,000 mW/cm^2, respectively, and. A real-time digital oscilloscope (Tektronix Incorp., Beaverton, OR, USA) was used to verify the diagrams of the light and determine whether it was pulsed (time-dependent) or continuous. As comparison to the pulse lighting, a commercially available continuous-light curing unit (Elipar, 3M ESPE, St. Paul, MN, USA) which has an irradiance level of

900 mW/cm^2 and light-exposure operated only in 20 sec was included.

A total of five groups of teeth, were prepared in the present study. Group A: teeth restored with resin composite and polymerized with the pulse-lighting mode curing unit with an irradiance of 900 mW/cm^2 in 10 sec; Group B: teeth restored with resin composite and polymerized with the pulse-lighting mode curing unit with an irradiance of 900 mW/cm^2 in 20 sec; Group C: teeth restored with resin composite and polymerized with the pulse-lighting mode curing unit with an irradiance of 1,000 mW/cm^2 in 10 sec; Group D: teeth restored with resin composite and polymerized with the pulse-lighting mode curing unit with an irradiance of 1,000 mW/cm^2 in 20 sec; Group E: teeth restored with resin composite and polymerized with the commercially available continuous-lighting mode curing unit with an irradiance of 900 mW/cm^2 in 20 sec;

Measurement of the irradiance levels and output-light temperatures

The performance of the experimental curing unit is characterized by the irradiance of the light emitted via the light guide, therefore, the irradiance levels were measured using an analog L.E.D. radiometer (Demetron, Kerr, Orange, CA, USA), and the output-light temperature was determined utilizing a "K"-type thermocouple thermometer (Fluke, USA), with precision of 10^{-1}. Each measurement was repeated ten times at intervals of 60 seconds and a temperature of (23±1) ºC.

Measurement of the pulp-chamber temperature

Ethical approval was granted by the Ethical Committee, Faculty of Dentistry, Universitas Indonesia. We performed the study on fifty caries-free first premolars. All teeth were obtained from the Department of Oral Surgery, Faculty of Dentistry, Universitas Indonesia, extracted for orthodontic treatment then kept in a 0.9% NaCl solution until used.

We prepared the teeth as shown in Fig 3. Each tooth was radiographed to visualize its pulp (Fig. 3a). Firstly, we reduced the tip of the crown (Fig. 3b), prepared a Class-I cavity in an occlusal surface of the tooth until a 2 mm cavity depth with 2 mm of remaining dentin near the highest pulp horn was obtained (checked by radiography). We then reduced the length of the root until a larger root canal was obtained to enable insertion of the thermocouple wire into the pulp chamber. Subsequently, we located the tip of the wire so that it touched the pulp roof (the position of the tip of the wire in the pulp chamber was verified radiographically, Fig. 3c). A dental wax fixed the wire to the bottom part of the reduced root.

We restored a resin composite material in the prepared cavity. The surface of the light guide of the LCU-LED was located near to the top of the material (Fig. 3d). While polymerizing the resin composite, we recorded the temperature of the pulp chamber using the thermocouple thermometer. The temperature of the pulp chamber without restoration was also recorded, as the baseline temperature.

We test the normality of distribution by the Shapiro-Wilk. Then, we evaluated the obtained data by the Two-way analysis of variance (ANOVA) method to determine whether there were significant differences in the output-light temperatures, and pulp-chamber temperatures among the groups that were exposed to different irradiances (with a confidence level of 95%). We then performed the Bonferoni post-hoc test to analyze the differences between the groups.

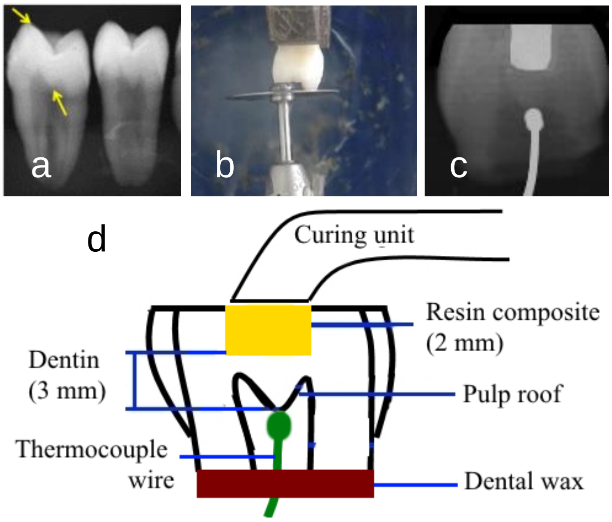

Figure 3. Tooth preparation for thermometer measurements in a dental pulp chamber: (a) radiographic check of the pulp chamber, (b) reducing the crown tip, (c) radiographic check for the location of the thermocouple wire tip in the pulp chamber, and (d) restored resin composite in Class-I cavity and position of the curing unit.

Results

In the present study, we constructed an experimental curing unit emitting a bright glowing light. The real-time digital oscilloscope confirmed that the pulsed-lighting mode generated a time-dependent signal demonstrated as a typical square-wave diagram, shown in Fig. 4.

In Fig. 4, the square waves illustrated the percentage of the duty cycle specifically describes the percentage of “on” time over an interval or period of time. The 74.5% duty cycle meant that it spent around 74.5% of the “on” time and around 25.5% of the “off” time. In the graph it was seen nearly as square waves; similarly, when the duty cycle was 90.2%.

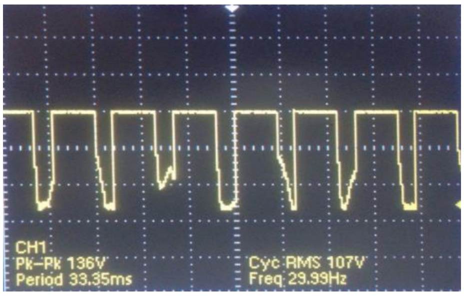

Figure 4. A diagram of the time-dependent signal of the pulsed-lighting mode of the experimental curing unit.

The use of two different duty cycles allowed the experimental pulsed-lighting curing unit to produce two different irradiance levels, which were associated with different output-light temperatures. Both the irradiance levels and output-light temperatures of the pulsed- and continuous-lighting modes of two curing units with lighting durations of 10 and 20 sec are shown in Table 1.

Curing unit, Lighting mode	Irradiance level (mW/cm^2)	Lighting duration (sec)	Output light temperature (^{o}C)
Experimental, Pulse-lighting	900±0	10	36.7±0.76
		20	37.7±0.76
	1,000±0	10	39.1±0.88
		20	40.9±0.41
Commercial, Continuous-lighting	900±0,	20	51.5±0.12

Table 1. Irradiance levels and output-light temperatures for the pulsed- and continuous-lighting modes of the curing units.

Table 1 shows that the pulsed-lighting mode produces both a low (900 mW/cm^2) and a high (1000 mW/cm^2) irradiance level, each one of them with lighting durations of 10 and 20 sec. The 900 mW/cm^2 irradiance obtained from the pulsed light of the experimental curing unit was similar to that emitted from a continuous-light commercial device.

There were significant differences ($p<0.05$) in the output-light-temperature values obtained for different light-exposure durations. The output-light temperature of the pulsed-lighting curing unit ranged from 36.7(0.76) to 40.9(0.41)^{o}C. For the same irradiance level, the output-light temperature determined after 10 sec was lower than that measured after 20 sec (p<0.05). All the output-light temperatures obtained in the pulsed-lighting mode were lower (p<0.05) than the value measured for the continuous-lighting mode 51.5(0.12)^{o}C, which was.

The pulp-chamber temperatures obtained for the pulsed- and continuous-lighting modes are summarized in Table 2.

Lighting modes, Irradiance (mW/cm^2)	Lighting duration (sec)	Pulp chamber temperature (without lighting) (^{o}C)	Pulp chamber temperature (during lighting) (^{o}C)
Pulse-lighting, 900±0	10	27.20±0.28	27.27±0.28
	20		27.35±0.21
Pulse-lighting, 1,000±0	10		28.22±0,18
	20		28.45±0.28
Continuous-lighting, 900±0	20		29.82±0.58

Table 2. Pulp-chamber temperatures obtained without and with pulsed and continuous lighting of the curing units.

As shown in Table 2, the pulp-chamber temperature measured without lighting of the restored resin composite was (27.20±0.28)^{o}C, which was the baseline pulp-chamber temperature. During lighting to polymerize the restored resin composites —using either pulsed or continuous lighting all the pulp-chamber temperatures were higher than the baseline temperature. In general, the pulp-chamber temperatures increased upon using the pulsed-lighting curing unit with irradiances of 900 and 1,000 mW/cm^2 for 10 to 20 sec. The same happened when the continuous-lighting curing unit was used. A statistical analysis indicated significant differences (p<0.05) in the pulp temperatures before and during light curing. There were also significant differences (p<0.05) in the pulp-chamber temperatures obtained for different lighting durations at each irradiance in the different lighting modes.

Discussion

The results obtained from the present study in pulp chamber temperature changes following light curing teeth restorations using an LCU LED with continuous-lighting curing units in vitro were in accordance to those revealed from Oberholzer TG, et al.[11] This study used a Class I cavity prepared on the occlusal surface with remaining dentine thickness of 1mm that was packed with composite resin and light cured for 40 seconds. A K-type thermocouple (Lutron, Electro-tech, Wynburg, SA), accessed through a hole drilled into the tooth and positioned underneath the cavity preparation, was used to measure the pulp chamber temperature. The pulse-lighting curing unit with irradiances raised from 800, to 1,000 mW/cm^2 revealed with increase in the pulp chamber temperature values that increased from 2.5 to 2.6^{o}C. An increase in temperature with irradiance was recorded when the temperature of the LCU was measured directly at the light guide tips.

The different lighting modes with a similar irradiance level of 900 mW/cm^2 with light exposure in 20 sec could be compared in the different output light temperature. The pulse-lighting mode produced output light temperature of 37.7±0.76^{o}C which was higher than that emitted from the continuous-lighting mode of 51.5±0.12^{o}C (Table 1). The pulse-lighting curing unit constructed with PWM signal is controlled by the duty cycle to work with an "on–off" mode to expose light in pulse. The the pulse-lighting curing mode with the duty cycle of 90.2%, below 100% spends less time in the "on" state than that of the continuous-lighting curing unit with 100% duty cycle, having "on" for all of the time. When current is dissipated, the "on" time activates the LED to produce a bright light; oppositely, when the pulse is "off" no light is emitted. In the process, the energy of light exposure warms the LED; between the "off" and the next "on", the solid-state behavior of the LED is still able to glow although the pulse is already "off". During the "off" time, no heat is created that cause the LED to cool down, consequently no heat was created. Regarding the continuous-lighting mode for which the the light is "on" all the time, more heat is created. It is clear that the pulsed-lighting mode maintains the heat thus lowering the output temperature. As a consequent, the pulse-lighting mode led to lower pulp chamber temperature compared to that from the continuous lighting (see Table 1).

Within the pulsed-lighting mode and regarding different irradiance level of 900 and 1,000 mW/cm^2, the lower irradiance level was associated with lower output temperature (see Table 2). Energy levels are multiplication of an irradiance level and the time. The irradiance levels of 900 mW/cm^2 in 10 sec produced energy of 9,000 mJ/cm^2, which was lower than when the 1,000 mW/cm^2 was used producing 10,000 mJ/cm^2. Similarly, when the light exposure of 20 sec was used. It is clear that lower irradiance of 900 mW/cm^{2}with the shortest light exposure of 10 sec produced the lowest output temperature, thus the lowest pulp-chamber temperatures. Therefore, the lower irradiance and the shortest exposure duration resulted in the lowest energy, thus the lowest pulp chamber temperature.

The pulp-chamber temperature obtained during light exposure for resotred resin composites in teeth were far below the output temperature emitted from all the curing units (see Table 1). Some factors may have hampered the transfer of heat from the curing unit to the pulp chamber. First, the resin used in this study was a composite material containing a micro-/nano-sized glass filler. These micro-/nano filler sizes could restrict the mobility of the light in the resin monomer, resulting in relatively low heat-transfer rates. Second, polymerization process creates heat as a result of exothermic reaction between of carbon–carbon double bonds (C=C) occurred at the dentin beneath the resin composite. However, thickness of the restored resin composite and the remaining dentin, each of 2 mm may have lowered heat transferred from the resin composite and the dentin. With respect to a resin composite, there are heat conductivity in resin composite (0.0026 cal/s/cm^2/°C/cm) and dentin (0.0015 cal/s/cm^2/°C/cm), and also thermal diffusivity in resin composite (0.675 mm^2/s) and dentin (0.183 mm^2/s).[12-14] Therefore, the total heat may reduce the pulp chamber temperature. This situation has also been found in previous studies.[12-14]

All the irradiance levels of the experimental pulsed-lighting curing unit for either 10 or 20 sec caused the output and pulp-chamber temperatures to rise. This situation was in the 2-mm-deep cavities restored with nano-filled resin composites as well as in the relatively thick remaining dentin. However, if the resin composite has a larger filler diameter and the cavities are deep with a thin remaining dentin layer, the temperature rise in the pulp chamber could be higher. This situation should be considered for applications in clinical work. With respect to the pulp chamber temperatures after light exposure which was around 27-29°C (Table 2), the value was rather low. The difference of the pulp chamber temperatures from baseline temperature obtained from the pulse-lighting and continuous-lighting modes were around 2°C. With respect to ex vivo, the increase of 27-29°C was not much and these temperatures are not of any danger. However, when this condition happens in vivo for which the pulp chamber temperature may be higher, i.e. 36-37°C, the increase of 2°C would cause the temperature to rise to 38-39°C; this temperature could be a danger to pulp health. Therefore, further studies are needed to explore the influence of the irradiance of the experimental pulsed-lighting curing unit on sensitivity in teeth with deep cavities and thin remaining dentin.

Conclusions

Pulsed lighting mode with irradiance levels of 900 and 1,000 mW/cm^2 in either 10 or 20 sec produced significantly lower output-light and pulp-chamber temperatures as compared to the continuous-lighting mode with an irradiance level of 900 mW/cm^2 in 20 sec. Within the pulsed-lighting curing unit values, there were also significant differences in the output-light temperatures, as well as, in the pulp-chamber temperatures with respect to differences in the irradiance levels and light-curing time. In an effort to suppress the increase in the pulp chamber temperature, a lower irradiance level in a shorter light curing duration of the pulse-lighting mode curing unit might be suggested for clinical application.

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Declaration of Interest

None.

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