Characterization of heat emission of light-curing units

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Received 2 October 2011; revised 22 November 2011; accepted 31 January 2012
Available online 9 March 2012

Abstract  Objectives: This study was designed to analyze the heat emissions produced by light-curing units (LCUs) of different intensities during their operation. The null hypothesis was that the tested LCUs would show no differences in their temperature rises.

Methods: Five commercially available LCUs were tested: a “Flipo” plasma arc, “Cromalux 100” quartz–tungsten–halogen, “L.E. Demetron 1” second-generation light-emitting diode (LED), and “Blue Phase C5” and “UltraLume 5” third-generation LED LCUs. The intensity of each LCU was measured with two radiometers. The temperature rise due to illumination was registered with a type-K thermocouple, which was connected to a computer-based data acquisition system. Temperature changes were recorded in continues 10 and 20 s intervals up to 300 s.

Results: The Flipo (ARC) light source revealed the highest mean heat emission while the L.E. Demetron 1 LED showing the lowest mean value at 10 and 20 s exposure times. Moreover, Cromalux (QTH) recorded the second highest value for all intervals (12.71, 14.63, 14.60) of heat emission than Blue Phase C5 (LED) (12.25, 13.87, 13.69), interestingly at 20 s illumination for all intervals the highest results (18.15, 19.27, 20.31) were also recorded with Flipo (PAC) LCU, and the lowest (6.71, 5.97, 5.55) with L.E. Demetron 1 LED, while Blue Phase C5 (LED) recorded the second highest value at the 1st and 2nd 20 s intervals (14.12, 11.84, 10.18) of heat emission than Cromalux (QTH) (12.26, 11.43, 10.26). The speed of temperature or heat rise during the 10 and 20 s depends...
1. Introduction

The success of composite curing generally depends on the characteristics of the composite (photoinitiator, filler type, shade, and translucency), the intensity and spectral output of the light-curing unit (LCU), and the mode of curing. The main commercially available LCU types include quartz–tungsten–halogen (QTH) lights, plasma arc (PAC) lights, and light-emitting diodes (LEDs). As a result of their heterogeneous characteristics, these light-curing methods display inherently different initiation rates and polymerization rates, leading to differences in the cross-linking densities of the cured polymeric matrices. Thus, variations in the final mechanical properties are possible when different light sources are used for resin composite polymerization (Rueggeberg, 1999; Hofmann et al., 2000; Burgess et al., 2002; St-Georges et al., 2003).

Application of light to the tooth surface with a dental LCU can potentially damage the pulp (Ashour and Khounganian, 1997; Guiraldo et al., 2008; Santini, 2010). Clinicians should be aware of the potential thermal hazard that could result from visible light curing of composite resins in deep cavities. A simple, but effective, way to protect the pulp is to apply a cement base or lining material to the cavity floor (Kitasako et al., 2000).

The quality of light produced by a dental LCU directly influences the polymerization of restorative materials and highly depends on the intensity or strength of irradiation. Efficient light polymerization requires that the corresponding wavelengths match the maximum absorption of the photoinitiator of the material (Rueggeberg et al., 2005). The halogen lamps used in conventional curing units generate white light (i.e., they have full visible wavelength spectrum). The PAC sources also emit a continuous visible light spectrum, but at higher intensities (>1000 mW/cm²).

Light produced by PAC lamps differs from that generated by halogen lamps. Rather than relying upon a heated tungsten filament, PAC lamps apply a high voltage current across two closely placed electrodes, resulting in a light arc between the electrodes (Yearn, 1985; Musanje and Darvell, 2003). The LED LCU devices are very three compact, promise unlimited life, work at reduced voltage, and do not require filters to limit the wavelength range. They are composed of solid-state LED technology, which uses junctions of doped semiconductors (p-n junctions) that are based on gallium nitride to emit light directly in the blue region of the spectrum. The LED LCUs generally have higher power densities, thereby producing potentially higher thermal emissions and curing depths.

The LED LCUs can be classified into “generations” based on successive improvements to their design (Yap et al., 2004; Rueggeberg et al., 2005). First-generation LED units consist of an array of relatively low-powered chips. Because of their design, they offer low output and poor curing performance compared with conventional quartz–tungsten–halogen (QTH) lights. First-generation LED lights generally require much longer exposure times to provide a similar level of curing performance as QTH lights, and they cause less temperature generation in their targets. First-generation LED LCUs display an average irradiance of 150–400 mW/cm² and a power output of 1 W.

By utilizing a single chip of much higher surface area, which emits only one color range of greatly increased output power, second-generation LED models perform better than their first-generation counterparts. Second-generation LED LCUs can achieve polymerization and curing performances that are similar to those produced by QTH lights under similar exposure times (Rueggeberg, 1999; Aasmussen and Peutzfeldt, 2005; Mills et al., 2002; Uhl et al., 2004; Price et al., 2003, 2005; Rueggeberg et al., 2005). However, because of their large chip area, these LEDs may induce higher temperatures than QTH sources. Second-generation LED LCUs display an irradiance of up to 800 mW/cm² and a power output of 5 W.

Third-generation LED lights use a combination of LEDs to produce a broader spectral output. These lights may polymerize a broader range of resins than the second-generation curing lights (Price et al., 2005; Hicks et al., 2005). The irradiance and power output of third-generation LED LCUs exceed 1.100 mW/cm² and 8 W, respectively (Kirkpatrick, 2005; Arika et al., 2005; Uhl et al., 2005; Satsukawa et al., 2005).

Manufacturers have recently turned their attention to high-powered LED LCUs for the polymerization of dental resins. With a high-powered light source, more photons are available per given period of absorption by photoinitiators. As a result, more CQ molecules are elevated to an excited state. High-powered LED LCUs generally have higher power densities, thereby producing potentially higher thermal emissions and curing depths (Moon et al., 2004; Wandewalle et al., 2005). However, temperatures are directly correlated to power-density levels and differences in emission spectra, regardless of the absence of infrared energy in the spectra. Because of their increased output, internal heat generation in the chip is a concern.

Various mechanisms are used to remove internal heat from the chip, including both convective (fans) and conductive (heat sinks; devices used to draw heat away directly) designs (Rueggeberg et al., 2005). Moreover, the generation of spectral emissions beyond the traditional 515-nm limit produces wasted energy, as evidenced by excess heat production and glare, possible pulpal sequelae, and inadequate material polymerization (Mills et al., 2002; Jandt et al., 2000; Martin 1998; Uhl et al., 2003).
Although the light source largely determines the temperature rise during curing, this heating effect also depends on the type of curing unit, quality of light filter, output intensity, and irradiation time (McCabe, 1985; Lloyd et al., 1986; Goodis et al., 1989; Goodis et al., 1997; Shortall and Harrington, 1998; Hannig and Bott, 1999; Daronch et al., 2007). The target material always shows a heat (or temperature) increase due to the exothermic polymerization process and thermal emission from the LCU (Wandewalle et al., 2005; Schneider et al., 2005; Bouillguet et al., 2005; Aguiar et al., 2005; Uhl et al., 2006; Shortall and Harrington, 1998; Atai and Mottevasselian, 2009).

The most important source of heat during polymerization of a light-activated restorative is from the LCU, and not from the material itself (Masutani et al., 1988; Shortall and Harrington, 1998; Knezевич et al., 2001). Previous studies have investigated the in vitro temperature rise during photopolymerization of resin composite materials by using thermocouples, differential scanning calorimetry, or differential thermal analysis (McCabe, 1985; Goodis et al., 1990; Vaidyanathan and Vaidyanathan, 1991; Peutzfeldt et al., 2000; Al-Qudah et al., 2005).

In the present study, we attempted to quantify the temperature rise produced by the light source alone. The study was designed to analyze the heat emissions (temperature rises) induced by LCUs of different intensities, including QTH, PAC, and LED units, through quantification of their thermal emissions. The null hypothesis in this study was that the tested LCUs would show no differences in their heat emissions.

2. Materials and methods

2.1. Tested LCUs

Tested units included the “Cromalux 100” QTH LCU (Mega-Physik GmbH & Co., KG, Rastatt, Germany), “Flipo” PAC LCU (Lokki, Les Roches de Condrieu, France), “L.E. Demetron 1” second-generation LED LCU (DE, Kerr, Dansbury, CT, USA), “Blue Phase C5” third-generation LED LCU (Ivoclar Vivadent, Inc., Amherst, NY, USA), and “UltraLume 5” third-generation LED LCU (Ultradent, South Jordan, UT, USA).

2.2. Measurement of light intensity

The intensity of the five commercially available LED, QTH and PAC light sources was measured using Demetron 100 and Demetron LED light meters (Demetron Research Corp., Danbury, CT, USA). The intensities of all LCUs were measured five times with each light meter, and the readings were averaged.

2.3. Measurement of heat emissions

For all units, the temperature increase due to light-curing emissions was registered by means of a type-K thermocouple (wires that are 0.5 ± 0.05 mm). The thermocouple was connected to a TC-08 thermocouple data logger computer-based data acquisition system (Pico Technology Ltd., Hardwick, Cambridge, UK) for data storage via microcomputer resident software (Pico Technology Ltd., UK). The experimental model was designed such that a 0-mm distance was fixed between the LCU tip and the thermocouple wire.

All measurements were taken in an ambient environment, with a controlled temperature of 28 ± 1°C and relative humidity of 20 ± 10%. After stabilization of the temperature of the set (measured by the thermocouple) to 28 ± 1°C, the value of the initial ambient room temperature was subtracted from the value of the temperature during the testing procedure. The soldering point of the thermocouple was kept in close contact with the fiber optic rod of the LCU during measurements/illumination (Table 1). Temperature changes were recorded in three consecutive intervals of continuous illumination for 10 and 20 s up to 300 s each interval started after 100 s cooling period.

2.4. Statistical analysis

The SPSS statistical software program (version 10.0, SPSS Inc., Chicago, IL, USA) was used to analyze temperature data. Variability between the groups was assessed with analysis of variance (ANOVA) and Tukey’s posthoc test at a significance level of 5% ($p < 0.05$).

3. Results

3.1. Light intensity characteristics of the LCUs

Table 1 shows the mean light intensity values (mW/cm²) for all of the tested LCUs. The Flipo (PAC) LCU showed the highest mean light intensity, whereas Both L.E. Demetron 1 and Cromalux appear to have the same average light intensity.

3.2. Heat emission characteristics

As shown in Figs. 1 and 2, although the characteristics of the heat emission curves appeared to be similar for all LCUs, but each LCU showed its own characteristic heat emission or “footprint”. The Flipo (PAC) LCU showed the highest mean heat emissions, whereas the L.E. Demetron 1 (second-generation LED) showed the lowest mean value for illumination times of 10 and 20 s. Figs. 3 and 4 show that heat characteristics for each LCU measurements were taken for 10 s (Fig. 3) and 20 s (Fig. 4) at three intervals, for a total time of 300 s, with a cooling period of 100 s applied between measurement sets. Also Flipo showed the highest, and L.E. Demetron 1 showed the lowest, mean heat emissions with 10- and 20-s illuminations. The steep increase in temperature measured by the thermocouple does not only represent the warming up of the light source, but also demonstrated the steep decrease after the unit was switched off and also showed the cooling period of 100 s.

Table 2 displays the heat emission values (temperature rises) for illumination times of 10 and 20 s. At 10-s illumination, Flipo showed the highest values for all three intervals, whereas L.E. Demetron 1 showed the lowest values. The Cromalux 100 QTH LCU showed the second highest values for all intervals, followed by the Blue Phase C5 third-generation LED. At 20-s illumination, Flipo again showed the highest results for all intervals, and L.E.

Although the speed of the temperature or heat rise during the 10- or 20-s illumination period generally depends on the light intensity of emitted light and the illumination time, the tested QTH LCU (Cromalux 100) showed a higher temperature rise than the second-generation LED LCU of the same power density (L.E. Demetron 1).
3.3. Statistical analysis

The heat emission results with the different illumination times were compared among groups (Tables 3 and 4). At illumination times of 10 and 20 s, the heat emissions among all groups showed highly significant differences, with the exception of Cromalux 100 (QTH) and Blue Phase C5 (third-generation LED) at 10-s illumination and Cromalux 100 (QTH), Blue Phase C5, and UltraLume5 (third-generation LED LCUs) at 20-s illumination.

4. Discussion

Within the limitations of this study, it can be concluded that the tested LCUs showed significant differences in terms of their heat emission profiles. Thus, the null hypothesis was rejected. Previous studies have indicated that LED LCUs generally generate smaller temperature rises than QTH units. However, these studies used first-generation LED LCUs, which have lower power densities than some of the second- and third-generation LED LCUs used today (Asmussen and Peutzfeldt, 2005). In the present study, no significant differences were found between the Cromalux 100 (QTH) and Blue Phase C5 (third-generation LED) LCUs at 10-s illumination, because the light intensity of Blue Phase C5 (~625 mW/cm²) was higher than that of Cromalux 100 (~515 mW/cm²).

Table 1  Light intensities of the light-curing units (LCUs) used in this study.

<table>
<thead>
<tr>
<th>LCU</th>
<th>Demetron 100 radiometer</th>
<th>Demetron LED radiometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cromalux 100</td>
<td>500</td>
<td>530</td>
</tr>
<tr>
<td>L.E. Demetron 1</td>
<td>500</td>
<td>540</td>
</tr>
<tr>
<td>Blue Phase C5</td>
<td>600</td>
<td>655</td>
</tr>
<tr>
<td>UltraLume 5</td>
<td>600</td>
<td>650</td>
</tr>
<tr>
<td>Flipo</td>
<td>700</td>
<td>750</td>
</tr>
</tbody>
</table>

Data represent mean values of \( n = 5 \) measurements.

Figure 1  Characterization of heat emission of light cure units (LCUs) for 10 s.

Figure 2  Characterization of heat emission of light cure units (LCUs) for 20 s.
At 20-s illumination, there were no significant differences among Cromalux 100, Blue Phase C5, and UltraLume 5 (Table 4), due to the fact that the illumination time was increased. Thus, the amount of heat generated by the LCUs was related to the wavelength and power density of the light emitted. Our results are consistent with previous studies showing that the earlier-generation create much smaller temperature rises than do QTH lights because they have a relatively narrow emission spectrum, with wavelengths centered at the absorption maximum of camphorquinone. Thus, very little radiation of longer wavelengths is present in the emitted light. This fact has been offered as an explanation for the finding that Demetron 1 curing units in previous investigations have resulted in less heat generation than QTH curing units.

The highest temperature rise was observed with the PAC (Uhl et al., 2003; Ozturk et al., 2004; Yazici et al., 2006), which also had the highest light output among the evaluated units (~725 mW/cm²). Plasma arc lamps emit a continuous spectrum of light; therefore, their operating temperatures increase in proportion to the amount of blue light produced. However, the use of high-intensity PAC lights can cause increased heat generation in the cured dental materials, potentially leading to pulpal

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**Figure 3** Characterization of heat emission of light cure units (LCUs) for 10 s three intervals durations for 300 s.

**Figure 4** Characterization of heat emission of light-curing units for 20 s three intervals durations for 300 s.
damages (Shortall and Harrington, 1998; Hannig and Bott, 1999; Krämer et al., 2008; Guiraldo et al., 2008; Santini, 2010).

The findings of the current study agree with those of Bouillguet et al. (2005) and Bagis et al. (2008), who showed that increasing the irradiation time for all tested LCUs increased the external temperature of the tooth measured with thermocouples. UltraLume 5 produced the second-lowest heat emission values at 10 s, but not at 20 s. The reason for this finding is that the UltraLume 5 has five LED light sources (a main central LED delivers the narrow, high-power spectral bandwidth diode with a peak wavelength at 450 nm, and four additional peripheral diodes low-power LEDs with peak wavelengths at 400 nm), which are set into an angled toward the center that focuses the light into a high-intensity rectangular reflector.

### 5. Conclusions

Dentists should give careful consideration to the choice of LCU when curing light-activated bonding agents and restoratives in deep cavities close to the pulp. The findings of this study indicate that:

- **The potential risk for heat-induced pulpal injury during composite resin polymerization is increased when visible light-curing units with high-energy outputs are used, compared to when low-energy output light energy sources are used.**
- **For all of the devices tested, an increase in irradiation time caused a proportional elevation in the heat emission (temperature).** The cooling devices (fan, heat sink) were able...
to reduce the temperature during the 100-s cooling period between the illumination sessions.

- Use of high-power LCUs (in particular, PACs) may represent a potential hazard for the tooth, depending on the light power and application time.
- Third-generation LED LCUs (Blue Phase C5, UltraLume 5) generally generated heat emissions (temperature rises) that were similar to or the same as those of the QTH unit at 10 and 20 s. This result is different from the use of lower power-density LED LCUs (first- and second-generation units).
- The QTH LCU resulted in a higher temperature rise than the LED LCUs of the same power density.

**Ethical Statement**

There is no ethical issue regarding this study.

**Conflict of interest**

No conflict of interest declared.

**References**


