Kinetics of pulpal temperature rise during light curing of 6 bonding agents from different generations, using light emitting diode and quartz-tungsten-halogen units: An in-vitro simulation

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ABSTRACT

Background: Application of bonding agents (BA) into deep cavities and light curing them might increase pulpal temperature and threaten its health. The purpose of this study was to evaluate temperature rise of pulp by light curing six BA using two different light curing units (LCU), through a dent in wall of 0.5 mm.

Materials and Methods: This in vitro experiment was carried out on 96 slices of the same number of human third molars (6 BAs × 2 LCUs × 8 specimens in each group). There were 6 groups of BAs: N Bond, G-Bond, OptiBond XTR, Clearfil SE, Adper Single Bond 2 and V Bond. Each group of BA (n = 16) had two subgroups of light emitting diode (LED) and quartz-tungsten-halogen light cure units (n = 8). Each of these 16 specimens were subjected to light emitting for 20 s, once without any BAs (control) and later when a BA was applied to surface of disk. Temperature rises in 140 s were evaluated. Their mean temperature change in first 20 s were calculated and analyzed using two-way repeated-measures and one-way analysis of variance (ANOVA) and Tukey (α = 0.05). Furthermore rate of temperature increase was calculated for each material and LCU.

Results: Minimum and maximum temperature rises in all subgroups were 1.7 and 2.8°C, respectively. Repeated measures ANOVA showed that both of adhesive and LCU types had significant effect on temperature rise after application of adhesives. Tukey post-hoc analysis showed Clearfil SE showed significantly higher temperature rise in comparison with Adper Single bond 2 (P = 0.047) and N Bond (P = 0.038). Temperature rose in a linear fashion during first 30-40 s and after that it was non-linear.

Conclusion: 20 s of light curing seems safe for pulpal health (with critical threshold of 5.5°C). However, in longer durations and especially when using LED units, the process should be broken to two sessions.

Key Words: Composite resins, dental materials, differential thermal analysis, polymerization

INTRODUCTION

A healthy dental pulp plays a crucial role in maintaining health and integrity of tooth. Several factors however can endanger health of dental pulp, among which temperature rise is one of the most important ones.¹ A small increase in pulpal temperature can cause inflammatory reaction, histopathological
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changes, vascular damage and cell death, in a way that about 5.5, 11 and 16°C can devitalize 15%, 60% and 100% of pulp cells respectively. Therefore, this is a concern in dental treatments.

A source of pulpal temperature is practicing restoration with resinous materials. Two factors contribute to thermal increase during setting of resinous materials. One is exothermic polymerization of resin monomers, which can increase pulp temperature up to 5.5°C. This depends on the degree of conversion (DC) of used composite, as well as size of restoration and thickness of intermediate dentin (which should not be less than 1 mm). The DC is ratio of single carbon-carbon bonds in a polymer structure to double carbon-carbon bonds among monomers. It indicates the polymerization extent.

The other factor is light-curing. Light curing might increase temperature up to 6°C, which might be still tolerable by tissues. These include light wavelength and intensity, curing duration, distance of light curing and type of light curing unit (LCU). Two light-curing systems are used to initiate polymerization reaction. These systems include conventional quartz-tungsten-halogen (QTH) lamps and solid-state light emitting diodes (LED). The absorption wavelength of activator matches the wavelength of QTH light output. On the other hand, novel LED units are developed based on targeting the peak absorption wavelength of activator, by emitting a relatively narrow-band light at 430-480 nm. LEDs are becoming increasingly popular in dental practice. They do not generate infrared wavelengths and have a constant light output. Therefore, they might cause less pulpal temperature rise than QTH units. However, this is controversial and some authors have stated that LEDs can produce as much heat as QTH lamps do.

Such temperature rises can endanger pulpal health, since a 5.5°C increase in pulp temperature would cause about 15% pulpal non-vitality. Due to their proper esthetics and function, light-curable composites are widely accepted in dental practice. Therefore, it is of significant importance to determine potential temperature rises after usage of materials (different composites and LCUs). Nevertheless, thermal characteristics of composites and especially bonding agents (BA) are largely unknown.

Considering the importance of the subject, lack of studies on thermal characteristics of BA and controversy over heat generated by LEDs, this study was conducted. Its aim was to assess the heat generated by six brands of composite BA cured by LED and QTH measured using a thermograph through a 0.5 mm dentin layer.

**MATERIALS AND METHODS**

This *in vitro* experimental study was performed on 96 sections of 96 intact human third molars.

**Sample preparation**

Private dental clinics were attended to collect extracted third molars. A total of 96 intact teeth were stored in 0.2% thymol solution for 48 h and afterward were placed in distilled water for minimum 6 h until next step. The number of teeth was determined 96 samples in 6 groups of BA by 2 groups of LCUs by 8 specimens in each group in order to obtain a test power of 90% or greater, based on results of Dogan et al.

**Sectioning the teeth to prepare dentin disks**

Teeth were removed from water and were fully merged in self-curable poly methyl methacrylate resin blocks (Acropars, Marlik, Iran). Transverse sections, 0.5 mm thin, were prepared from blocks, using Isomet Saw (Buehler Ltd., IL, USA) under water cooling in Isomet. The thickness of cuts was calibrated beforehand, using a micrometer with 1 micron sensitivity (Mitutoya, Japan). The device blade was adjusted to cut tooth at a 90° angle. After crown of each tooth was fully sectioned, sections were explored until finding the first one with pulp horn sections on them. The section before this section was included and the rest were excluded. The sections which were consisted of inner dentin were evaluated regarding their thickness and angle of cut.

![Figure 1: Schematic illustration of the closest intact slice to the pulp](image)
BA
Six BA used in this study are fully described in Table 1.

Preparing bonded dentin disks
The experiments were carried out at a constant temperature (37°C). Each dentin disk was held on a flat disk-shape K thermocouple probe with 0.1°C accuracy (Testo, Testo AG, Lenzkirch, Germany). The thermocouple was connected to computer using a data logger, which allowed recording probe temperature in real time.

Light curing
The non-bonded dentin disks were first light cured for 140 s and temperature rise was recorded. The time of illumination was selected regarding to our pilot experiment which showed that all samples (after application of adhesives) reached the maximum temperature far below this time. The specimens before applying BA acted as control and the same specimens after applying BA acted as experimental cases. Any inconsistent specimen was excluded from the study and replaced with a new disk made from a fresh tooth. The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth).

The collected data were also used to draw the curves of temperature rise within 140 s. These curves were used to calculate the thermal equilibrium and kinetics of temperature rises caused by each of the materials plus each light curing device and also by each LCU alone. The temperature curves have two parts. First, the non-bonded dentin disks were first light cured for 140 s and temperature rise was recorded. The time of illumination was selected regarding to our pilot experiment which showed that all samples (after application of adhesives) reached the maximum temperature far below this time. The specimens before applying BA acted as control and the same specimens after applying BA acted as experimental cases. Any inconsistent specimen was excluded from the study and replaced with a new disk made from a fresh tooth. The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth). The adhesives were then applied to the other surface of dentin disks, in a random order (according to tooth).

These light intensities were set by manufacturers. Light output of QTH and LED was calibrated using a radiometer (Optilux model 100, 10503, Kerr, USA) to meet manufacturers’ recommended values. Light curing was done with both units and temperature rise was recorded in 140 s. The same specimens before application of BA were subjected to light curing with a similar protocol and their temperature rise was recorded as the control values.

Statistical analysis
The recorded temperatures in time were used to calculate mean temperature rises in different groups (2 LCUs, 6 BAs and with or without BA) during the first 20 s (as the time routinely considered for polymerization of BAs). The effects of BA and LCUs were assessed using two-way repeated-measures analysis of variance (ANOVA). Since the interactions were significant, one-way ANOVA along with a Tukey post-hoc test was used as well to compare adhesives and light cure units. Statistical analyses were performed using SPSS program (SPSS Inc., IL, USA). P ≤ 0.05 were considered to be significant.

The collected data were also used to draw the curves of temperature rise within 140 s. These curves were used to estimate the thermal equilibrium and kinetics of temperature rises caused by each of the materials plus each light curing device and also by each LCU alone. The temperature curves have two parts. First,

Table 1: The used BA

<table>
<thead>
<tr>
<th>Brand</th>
<th>Composition</th>
<th>Manufacturer</th>
<th>Properties</th>
<th>Recommended light curing time</th>
<th>Lot number</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Bond</td>
<td>Phosphoric acid acrylate, HEMA, BisGMA, urethane dimethacrylates, ethanol, film forming agent, catalysts, stabilizers</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
<td>Etch and rinse – Single bottle (5th generation)</td>
<td>≥500 mW/cm² 20 s</td>
<td>N76256</td>
</tr>
<tr>
<td>G-Bond</td>
<td>4-meat, TEGDMA, UDMA, acetone, water, initiator</td>
<td>GC-USA</td>
<td>Self-etch, single bottle, single step (7th generation)</td>
<td>Halogen/LED (700 mW/cm²): 20 s (1200 mW/cm²): 10 s</td>
<td>1006231</td>
</tr>
<tr>
<td>OptiBond XTR</td>
<td>Primer; GPDM, HEMA, dimethacrylate, photoinitiator, water, ethanol, acetone Adhesive: Bis-GMA, HEMA, tri-functional monomer, ethanol, photoinitiator, barium glass filler, fluoride-containing filler, nano-filler</td>
<td>Kerr-USA</td>
<td>Self-etch, two bottle (6th generation)</td>
<td>5-20 s according to the light curing unit manufacturer’s recommendation</td>
<td>Primer: 3562882 Adhesive: 3562883</td>
</tr>
<tr>
<td>Clearfil SE</td>
<td>MDP, HEMA, bis-GMA, hydrophobic dimethacrylates, submicron silica fillers, N, Ndiethanol-p-toluidine, CQ</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
<td>Self-etch, two bottle (6th generation)</td>
<td>The recommended light curing time is 10 s</td>
<td>Primer: 01039A Adhesive: 01550A</td>
</tr>
<tr>
<td>Adper Single Bond 2</td>
<td>bis-GMA, HEMA, dimethacrylates, polyalkenoic acid copolymer, initiators, water and ethanol</td>
<td>3M/ESPE-USA</td>
<td>Etch and rinse – Single bottle (5th generation)</td>
<td>The recommended light curing time is 10 s</td>
<td>N246651</td>
</tr>
<tr>
<td>V Bond</td>
<td>bis-GMA, HEMA, dimethacrylates, polyalkenoic acid copolymer, initiators, water and ethanol</td>
<td>Temrex-USA</td>
<td>Etch and rinse – Single bottle (5th generation)</td>
<td>Not available</td>
<td>110105</td>
</tr>
</tbody>
</table>

TEGDMA: Triethylene glycol dimethacrylate; UDMA: Urethane dimethacrylate; GPDM: Glycerol phosphate dimethacrylate; HEMA: Hydroxyethylmethacrylate; bis-GMA: Bisphenol-glycidyl methacrylate; MDP: Methacryloyloxydecyl dihydrogen phosphate; CQ: Camphorquinone; LED: Light emitting diode
the temperature increase is linear. After some time, it becomes a non-linear, such that the rate of temperature rise decreased as the function of time. Therefore, in the first part (when the function is linear), it is possible to estimate temperature changes by dividing the first maximum temperature by the passed time needed to reach that temperature:

\[
\text{Rate of temperature rise in the linear part (°C/S)} = \frac{\text{Max } (\Delta t_1/°C)}{t_1(S)}
\]

\( t_1 \) is the time point of the first maximum temperature.

In the second part, it is possible to estimate the temperature changes by dividing the temperature rise in the second part by the elapsed time.

\[
\text{Rate of temperature rise in the non-linear part (°C/S)} = \frac{\text{Max } (\Delta t_2/°C) - \text{Max } (\Delta t_1/°C)}{t_2 - t_1(S)}
\]

RESULTS

Temperature rise on control dentin disks
Two-way ANOVA analysis for the data obtained without the application of adhesives showed that there was no significant difference between the mean values for heat rises of BAs cured by two LCUs (\( P = 0.14 \)) and between the 6 groups (\( P = 0.6 \)).

Temperature rise on BA-coated dentin disks
When the heat sources were both LCUs and BA pasted onto the disk surfaces, ANOVA showed a difference between the adhesives (\( P = 0.04 \)). However, Tukey test did not find a significant difference between the BA, compared one by one.

Temperature rise before and after application of adhesives in the first 20 s
Repeated measures ANOVA procedure showed that both of the adhesive and LCU types had significant effect on the temperature rise after application of adhesives. The Tukey post-hoc analysis revealed that Clearfil SE showed significantly higher temperature rise in comparison with Adper Single bond 2 (\( P = 0.047 \)) and N Bond (\( P = 0.038 \)) [Table 2, Figures 2 and 3].

Repeated measures ANOVA procedure for each group showed that the effect of LCUs was only significant in Adper Single bond 2 (\( P = 0.008 \)).

Thermal equilibrium
The temperature changes during the elapsed time are shown in Table 3 and Figure 4. The findings showed that LED units had higher maximum temperatures.

Table 2: Mean and standard deviations of temperature rise within 20 s of light curing, in different experimental groups

<table>
<thead>
<tr>
<th>BA</th>
<th>LCU</th>
<th>Temperature rise without BA</th>
<th>Temperature rise with BA</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adper Single bond 2</td>
<td>QTH</td>
<td>1.86 (0.23)</td>
<td>2.15 (0.18)</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>1.81 (0.1)</td>
<td>2.4 (0.15)</td>
<td></td>
</tr>
<tr>
<td>Clearfil SE-bond</td>
<td>QTH</td>
<td>2.02 (0.36)</td>
<td>2.6 (0.49)</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>2 (0.4)</td>
<td>2.8 (0.45)</td>
<td></td>
</tr>
<tr>
<td>V Bond</td>
<td>QTH</td>
<td>1.72 (0.13)</td>
<td>2.29 (0.22)</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>1.9 (0.25)</td>
<td>2.16 (0.31)</td>
<td></td>
</tr>
<tr>
<td>G-Bond</td>
<td>QTH</td>
<td>2.01 (0.14)</td>
<td>2.61 (0.32)</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>1.84 (0.33)</td>
<td>2.63 (0.9)</td>
<td></td>
</tr>
<tr>
<td>Optibond XTR</td>
<td>QTH</td>
<td>1.86 (0.21)</td>
<td>2.2 (0.5)</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>2.3 (0.38)</td>
<td>2.7 (0.54)</td>
<td></td>
</tr>
<tr>
<td>N Bond</td>
<td>QTH</td>
<td>1.7 (0.26)</td>
<td>2.08 (0.63)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>1.82 (0.45)</td>
<td>2.59 (0.28)</td>
<td></td>
</tr>
</tbody>
</table>

BA: Bonding agent; LCU: Light curing unit; QTH: Quartz-tungsten-halogen; LED: Light emitting diode

Figure 2: Temperature rises of different adhesives before and after application of bonding agents, all cured by quartz-tungsten-halogen unit

Figure 3: Temperature rises of different adhesives before and after application of bonding agents, all cured by light emitting diode unit
in both first (linear) and second (non-linear) parts [Figure 4]. They had also higher rates of heating in the first part, but not in the second part.

DISCUSSION

The study findings showed that none of evaluated BA polymerized using any of the light curing devices reached a dangerous level of temperature rise (at least 5.5°C for 15% of pulpal necrosis). Therefore, used light intensities with both devices seem safe with the different groups of adhesives. These results were in agreement with Dogan et al. and Pereira Da Silva et al. who did not find a damaging temperature of BA cured using QTH and LED units.

The evaluated materials showed a significant difference, which could be due to their different viscosities, different amounts of free radicals, their optimized setting temperatures, etc. It should be noted that composition of the materials were arranged in a way that besides proper characteristics, it can be set with a high DC. Therefore, since DCs of different materials were at the highest possible limit, their differences were reduced.

Although, the results of the present study was in agreement with some studies, it was in contrast to some other articles reporting QTH units as more heat generating than LEDs and plasma arch units. QTH lamps might produce more heat since their intensity is expected to increase the temperature more since more photons are absorbed by unit of area on tooth tissue. Besides, it might be capable of inducing more polymerization due to warming material and reducing its viscosity and therefore radical mobility, as well as increasing collision frequency of unreacted active groups and radicals. The latter is confirmed and accentuated by our finding that in absence of BA, LED and QTH do not differ significantly, but after bonding, the temperature rise of LED increases significantly. On the other hand, Dogan et al. used light intensities similar to this study. However, they reported greater produced heats by QTH (despite its lower intensity). The reason can be their shorter time of light curing by LED (10 s for LED, 40 s for QTH). Some other studies found LED to generate less curing heats, which might be related to properties of composites/adhesives and wavelengths and intensities of LCUs.

The significant superiority of LED in heat generating for four of BA within 20 s was not clinically considerable, because a fraction of Celsius degree does not seem to affect pulp health. It is less important when noticing the ability of healthy tissue in balancing the increased temperature through its arterioles and surrounding dentin which can disperse the heat away. Therefore, it seems that these two devices are both safe in light curing restorations when the pulp is healthy, but problem is that in deep cavities, pulp condition is questionable and needs more caution. Traumatized and irradiated tissues as well as tissues

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### Table 3: Estimation of rate of temperature rise for different BA (only experimental groups), based on times elapsed to reach maximum temperatures

<table>
<thead>
<tr>
<th>BA</th>
<th>LCU</th>
<th>Max ((\Delta T_1)) (°C)</th>
<th>Elapsed time to reach Max 1 (t_1) (s)</th>
<th>Max ((\Delta T_2)) (°C)</th>
<th>Elapsed time to reach Max 2 (t_2) (s)</th>
<th>Linear temp. rise rate (°C/s)</th>
<th>Non-linear temp. rise rate (°C/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adper Single Bond 2</td>
<td>QTH</td>
<td>2.1</td>
<td>20</td>
<td>3.8</td>
<td>63</td>
<td>0.1</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>2.4</td>
<td>20</td>
<td>8.8</td>
<td>90</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Clearfil SE-Bond</td>
<td>QTH</td>
<td>3.2</td>
<td>25</td>
<td>6.1</td>
<td>135</td>
<td>0.13</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>5.8</td>
<td>40</td>
<td>7.9</td>
<td>125</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>V Bond</td>
<td>QTH</td>
<td>2.3</td>
<td>22</td>
<td>4.5</td>
<td>95</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>3.1</td>
<td>21</td>
<td>7.2</td>
<td>100</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>G-Bond</td>
<td>QTH</td>
<td>2.6</td>
<td>20</td>
<td>3.8</td>
<td>65</td>
<td>0.13</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>5.2</td>
<td>38</td>
<td>8.6</td>
<td>100</td>
<td>0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>Optibond</td>
<td>QTH</td>
<td>3.1</td>
<td>25</td>
<td>5.2</td>
<td>75</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>5.6</td>
<td>35</td>
<td>9.2</td>
<td>95</td>
<td>0.16</td>
<td>0.06</td>
</tr>
<tr>
<td>N Bond</td>
<td>QTH</td>
<td>2.08</td>
<td>20</td>
<td>4.7</td>
<td>77</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>LED</td>
<td>3.4</td>
<td>23</td>
<td>6.3</td>
<td>80</td>
<td>0.15</td>
<td>0.05</td>
</tr>
</tbody>
</table>

BA: Bonding agent; LCU: Light curing unit; QTH: Quartz-tungsten-halogen; LED: Light emitting diode
in some medically compromised and elderly patients might be highly vulnerable to thermal irritations.\cite{8,15}

This study was limited by some factors. Results of an in vitro study cannot be generalized to clinical situation with highly vascular periodontal and pulpal tissues, without further clinical assessments.\cite{34} Furthermore, results of a brand cannot be generalized to other brands.\cite{15} This is why we used several generations of adhesives from different manufacturers. On the other hand, method of measurement was accurate and allowed detection of small differences. Another limitation was that some materials needed blending, which exposed experiment to human error. However, we carefully selected teeth and cut them and excluded many specimens with inconsistent data in order to reduce many sorts of human error. In the current study, the high intensity for both QTH and LED devices was used in order to simulate the worst clinical situation regarding the pulpal temperature rise.

**CONCLUSION**

It might be concluded that the types of LCU did not differ, unless BA were applied. It presence of
BA, LED might induce more heat. The heat seems tolerable by tissue since temperature rise is not more than about 2 or 3°C during the first 20 s, which is below the critical threshold of pulp tolerance (5.5°C). According to our findings, if more than 20 s of light curing was needed, it is recommended to break the light curing into two sessions (each session 20s or less) to allow the pulp to cool down.

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