In-vitro assessment of temperature rise in the pulp during orthodontic bonding

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Introduction: In this in-vitro study, we evaluated the temperature changes in the pulp chamber during bracket bonding using 4 different light sources. Methods: Eighty intact extracted maxillary incisors were used. The teeth were divided into 4 groups of 20 teeth each. Brackets (Mini Twin, Dentaurum, Ispringen, Germany) were bonded with Transbond XT (3M Unitek, Monrovia, Calif) adhesive and light cured with low-intensity halogen light for 40 seconds, high-intensity halogen light for 40 seconds, light-emitting diode (LED) light for 20 seconds, and plasma arc light (PAC) for 6 seconds. Light curing was performed 5 mm from tooth surfaces. A J-type thermocouple wire was positioned in the center of the pulp chamber. The results were analyzed with analysis of variance (ANOVA) and the Tukey HSD test. Results: ANOVA and the Tukey HSD test showed that pulp chamber temperature changes were influenced by the type of light source. All groups showed significant differences between each other (P <0.001). The intrapulpal temperature changes induced by different light sources were the following: high-intensity halogen (6.84°C ± 2.44°C), low-intensity halogen (4.71°C ± 0.96°C), LED (2.95°C ± 1.12°C), and PAC (0.96°C ± 0.83°C). Conclusions: High- and low-intensity halogen light induced significantly higher intrapulpal temperature changes than did the LED and PAC. Except for the high intensity halogen light, orthodontic bonding with light-curing units did not exceed the critical 5.5°C rise in temperature reported to produce pulpal damage. (Am J Orthod Dentofacial Orthop 2010;137:379-83)
HQTH) have significant potential for use in dentistry. LEDs have narrow spectral ranges and are therefore highly efficient light sources. The plasma-arc curing (PAC) light is also designed for high-speed curing of composite filling materials in direct resin restorations.

However, some questions about the effects of these curing lights have been raised. In the curing session, these lights can cause the temperature to rise in pulp, and this can be harmful to the vitality of the tooth. In this in-vitro study, we evaluated the temperature changes in the pulp chamber during bracket bonding using 4 light sources: QTH, HQTH, LED, and PAC.

### MATERIAL AND METHODS

Eighty intact maxillary central incisors extracted from adults were used. Teeth of homogeneous size and shape were used to provide similar thicknesses of hard tooth structure and ensure similar distances from the pulp to the surface of the tooth. Pulp extensions were evaluated with radiographic films by using calibrated calipers. Periapical radiographs for all teeth were made with the same x-ray unit (Siemens, 60 kV, 10 mA, Munich, Germany) with a 5-cm fixed focal image distance. The radiographs were processed automatically with Periomat (Dürr Dental, GmbH & Co, Bietigheim-Bissingen, Germany). After radiographic evaluation, teeth with abnormally large or small pulp chambers were excluded from the study.

The maxillary central incisors were divided into 4 groups of 20 teeth each. The root portions were sectioned with carborundum disks (Komet, Gebr Brasseler, Lemgo, Germany) approximately 2 mm below the cementoenamel junction perpendicular to the long axis of the teeth. The opening into the pulp chamber was enlarged as needed to insert the thermocouple wire. The pulp chamber was cleaned of remaining pulpal tissues with a spoon excavator and sodium hypochlorite application for 1 minute. Then the pulp chambers of the teeth were rinsed with distilled water and air dried.

The teeth were etched for 30 seconds with 37% orthophosphoric acid (3M Dental Products, St Paul, Minn), rinsed with water from a 3-in-1 syringe for 30 seconds, and dried with an oil-free source for 20 seconds. Metallic orthodontic brackets (Dentaurum, Ultra-miniTrim, Ispringen, Germany) were bonded by using Transbond XT (3M Unitek, Monrovia, Calif) adhesive, excess composite was gently removed with a scaler before curing, and light cured with 4 light units (Table I).

The light curing was done as follows: group 1, QTH (Hilux, Benlioglu Dental, Ankara, Turkey) for 40 seconds; group 2, HQTH (Optilux 501, Kerr, Danbury, Conn) for 40 seconds; group 3, LED (Elipar Freelight, 3M ESPE, St Paul, Minn) light for 20 seconds; and group 4, PAC (Power PAC Plasma Curing, ADT, San Carlos, Calif) for 6 seconds.

The outputs of the light tips from the Hilux, Optilux 501, and LED curing units were measured by using a digital curing radiometer (Demetron, Danbury, Conn). Output of the PAC system, which could not be measured with the cure radiometer, was 1200 to 1500 mW per square centimeter according to the manufacturer (Table I).

A J-type thermocouple wire of 0.36-in diameter (Omega Engineering, Stamford, Conn) was connected to a data logger (XR440-M Pocket Logger, Pace Scientific, Mooresville, NC) during the light-curing procedures. All light-curing procedures and measurements were performed by the same operator (T.U.) to ensure uniformity in the procedures. A silicone heat-transfer compound (Philips ECG, Waltham, Mass) was injected into the pulp chamber to facilitate the transfer of heat from the walls of the pulp chamber to the thermocouple. The thermocouple wire was put into the pulp chamber by touching the center region of the roof. Before temperature measurements were made, the position of the thermocouple was verified by using radiographs and corrected as needed. Calibration of the data logger was not required. Specification accuracy was maintained without user adjustments. The manufacturer reported a temperature accuracy of ± 0.15°C from 0°C to 40°C. The collected data were monitored in real time and transferred to a computer. The data were available in both tabular and graphic forms.

After the temperature measurements, the teeth were vertically sectioned in a mesiodistal direction by using

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Manufacturer</th>
<th>Diameter of tip (mm)</th>
<th>Power intensity (mW/cm²)</th>
<th>Exposure time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hilux</td>
<td>Benlioglu Dental, Ankara, Turkey</td>
<td>10</td>
<td>500</td>
<td>40</td>
</tr>
<tr>
<td>Optilux 501</td>
<td>Kerr, Danbury, Conn</td>
<td>8</td>
<td>850</td>
<td>40</td>
</tr>
<tr>
<td>Elipar Freelight</td>
<td>3M ESPE, St Paul, Minn</td>
<td>8</td>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td>Power PAC Plasma Curing</td>
<td>ADT, San Carlos, Calif</td>
<td>6.5</td>
<td>1200-1500</td>
<td>6</td>
</tr>
</tbody>
</table>
a slow-speed diamond saw (Isomet, Buehler, Lake Bluff, Ill) under running water. With a calibrated caliper, the enamel and dentin thickness from the middle of the roof of the pulp chamber to the end of the procedure was measured. Teeth with extremely thick or thin enamel or dentin were excluded from the study, and new specimens were prepared with the same procedures.

For each group, temperature variation was determined as the change from baseline temperature to the highest or lowest temperature recorded after the various light curing procedures. A positive temperature variation value indicated an increase in pulp temperature, whereas a negative temperature variation value indicated a decrease in pulp temperature. Twenty calculated temperature changes were averaged to determine the mean value in temperature rise. A temperature increase of 5.5°C was set as the baseline value, above which Zach and Cohen\(^8\) reported pulpal damage.

### Statistical analysis

Descriptive statistics, including means, standard deviations, and minimum and maximum values, were calculated for each of the 4 groups of light-curing units. Analysis of variance (ANOVA) and then the Tukey honestly significant difference (HSD) tests (version 10.0, SPSS, Chicago, Ill) were used to analyze temperature changes between the groups at a significance level of \( P \leq 0.05 \).

### RESULTS

The descriptive statistics for each experimental group are shown in Table II. ANOVA and the post-hoc tests showed that pulp-chamber temperature changes were influenced by the type of light source.

The greatest temperature rises were observed during photo-activation of orthodontic composite resin with HQTH curing (6.84°C ± 2.44°C), followed by QTH curing (4.71°C ± 0.96°C), and LED curing (2.95°C ± 1.12°C); the lowest temperature rise was with PAC curing (0.96°C ± 0.83°C).

<table>
<thead>
<tr>
<th>Light-curing unit</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Tukey HSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>QTH</td>
<td>20</td>
<td>4.71</td>
<td>0.96</td>
<td>3.04</td>
<td>6.54</td>
<td>A</td>
</tr>
<tr>
<td>HQTH</td>
<td>20</td>
<td>6.85</td>
<td>2.44</td>
<td>3.75</td>
<td>14.09</td>
<td>B</td>
</tr>
<tr>
<td>LED</td>
<td>20</td>
<td>2.95</td>
<td>1.12</td>
<td>1.41</td>
<td>5.38</td>
<td>C</td>
</tr>
<tr>
<td>PAC</td>
<td>20</td>
<td>0.96</td>
<td>0.83</td>
<td>0.32</td>
<td>3.24</td>
<td>D</td>
</tr>
</tbody>
</table>

### DISCUSSION

Adequate polymerization is a crucial factor in obtaining optimal physical properties and clinical performance of orthodontic composite bonding materials. Problems associated with inadequate polymerization include inferior physical properties, solubility in the oral environment, increased microleakage, and bonding failure. Sometimes adequate polymerization is associated with curing time, especially in conventional curing units such as QTH and HQTH, or power intensity of the light sources. The thermal changes during light curing are well known, but we lack information about temperature changes in pulpal areas in curing application.

In this in-vitro study, we evaluated temperature rises during polymerization of orthodontic bonding adhesive systems by 4 commercially available light-curing units. Data indicated statistically significant differences between all light-curing units (\( P <0.001 \)). Different light sources causing intrapulpal temperature changes (in highest to lowest order) were as follows: HQTH, QTH, LED and PAC.

The central incisors used in this study were selected with similar features for standardization. The reason for
choosing this group of teeth was that they had a high risk of thermal damage from the light sources because they have thinner enamel and dentinal structure characteristics on the labial side. Teeth with unusual pulpal anatomic structures were excluded. The reason for this procedure was to eliminate possible varying effects of structural differences in terms of thermal conductivity and specific heat. Nevertheless, some differences in tooth morphology could be seen in spite of careful tooth selection; this was because of the experimental design’s variables: enamel and dentinal structure and thickness. This might explain the temperature differences between the teeth tested. On the other hand, the teeth we used were collected from adults, and therefore thermal conduction to the pulp chamber could be limited compared with younger patients’ teeth in terms of tooth morphology. Also, the maxillary central incisors are the most noticeable teeth in the dentition. If these teeth have pulpal damage, their color will change, and esthetic smiles might be affected negatively.

Thermocouples were selected to evaluate temperature alterations during the removal of remaining adhesive because of high precision and reliable readings previously demonstrated with this technique in operative and prosthetic dentistry. Thermal changes on pulpal tissue were evaluated by various study designs, such cavity preparation, light curing, and laser application, bonding, debonding, and stripping in orthodontic and restorative dentistry literature.8,11–13 In this study, we used an orthodontic-bonding adhesive-curing protocol to simulate clinical conditions and determine the effects of different devices on thermal changes in dental pulp. The thermal effect on the pulp tissue depends on the variations in the enamel and dentin thickness of the pulp chamber wall.

The decisive factor for temperature rise during light-activated polymerization of resin composites was the energy absorbed during irradiation, whereas the exothermic composite polymerization process is of secondary importance for temperature rise.8,14 An increase in the pulp temperature can occur from a light unit with high power intensity caused by the radiation energy. Power PAC (1200 mW/cm²) and Optilux 501 (850 mW/cm²) curing units have higher energy outputs than Hilux (500 mW/cm²) and Elipar Freelight (400 mW/cm²).

Our results showed statistically significant differences among the 4 light-curing units (Table III). HQTH (Optilux 501) with the longest exposure time induced significantly higher intrapulpal temperature changes than did the QTH, LED, or PAC. Also, this value (6.85°C ± 2.44°C) exceeded the critical value (5.5°C) reported for pulpal damage.5,6,8 However, the critical values were not exceeded in the QTH, LED, or PAC groups. Our findings contrasted with the concern of increasing heat-induced pulpal injury with high-energy output lights but show the importance of exposure time. Furthermore, total light energies that were put into the system (light intensity × exposure time) were as follows in descending order: 850 × 40 = 34,000 mW per square centimeter per second (Optilux 501), 500 × 40 = 20,000 mW per square centimeter per second (Hilux), 400 × 20 = 8000 mW per square centimeter per second (Elipar Freelight), and 1200 × 6 = 7200 mW per square centimeter per second (Power PAC).

PAC units have demonstrated markedly reduced curing times: exposures of 6 seconds. LED lights have certain other advantages over both halogen and PAC lights: they are cordless, smaller, and lighter; do not require a noisy cooling fan; and have estimated lifetimes of more than 10,000 hours.15,16 Moreover, LED technology is still developing, and high-intensity LED curing lights are on the way. According to Dunn and Taloumis,17 halogen-based light-curing units might be replaced by LED as semiconductor technology improves.18 Decreasing the total cure time for bonding would be beneficial for the clinician and the patient. Another important question is related to light curing time and degree of conversion (DC) of orthodontic composite resin. The DC of resins is a major factor that influences their physical properties. Unreacted monomer might leach from the polymerized material and irritate the soft tissues.19 Üsümez et al20 evaluated the DC of 2 lingual retainer adhesives, Transbond Lingual Retainer and Light Cure Retainer, cured with QTH, HQTH, LED, and PAC at various curing times. In their study, 100 adhesive samples (5 per group) were cured for 5, 10, or 15 seconds with HQTH (Optilux 501); for 3, 6, or 9 seconds with PAC; or for 10, 20, or 40 seconds with LED (Elipar Freelight). Samples cured for 40 seconds with QTH (Hilux) were used as a control. The results showed that, for the Transbond Lingual Retainer, the highest DC values were achieved in 6 and 9 seconds with the PAC. Curing with the HQTH for 15 seconds and with the LED for 40 seconds produced statistically similar DC values, but these were lower than those with the PAC. According to this study, it is possible to cure orthodontic bonding adhesive in approximately half the time that is required with HQTH or a quarter of that required with QTH, without compromising the physical properties. In our study, we used Transbond XT as the orthodontic bonding adhesive. Transbond Lingual Retainer and Transbond XT were produced by the same company, and their contents are similar. Therefore, the same reaction might have been expected from Transbond XT with the same light-curing procedure.
Our experimental design did not consider heat conduction in the tooth because of blood circulation in the pulp chamber and fluid motion in the dentin tubules during the in-vivo orthodontic adhesive bonding process. In addition, the surrounding periodontal tissues can promote heat convection in vivo, limiting the intrapulpal temperature rise. On the other hand, actual temperature increases might be higher in clinical conditions in teeth from younger subjects. Therefore, although we demonstrated that LED and PAC are especially safe with regard to thermal trauma, clinicians should be aware that thermal damage to the pulp can result from longer adhesive light-curing procedures.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn.

1. The intrapulpal temperature changes induced by various light sources were as follows in descending order: HQTH, QTH, LED, and PAC.
2. HQTH (40 seconds) and QTH (40 seconds) induced significantly higher intrapulpal temperature changes than did LED (20 seconds) and PAC (6 seconds).
3. Orthodontic bonding with light-curing units did not exceed the critical 5.5°C value reported to cause pulpal damage, except for the HQTH.

REFERENCES