Pulp chamber temperature changes during orthodontic bonding – an in vitro study

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Aim: Using a thermal camera, the aim of the study was to determine pulp chamber temperature changes during orthodontic bonding produced as a result of variations in curing light sources, different curing distances and bracket types.

Methods: One hundred sixty maxillary premolar teeth were sectioned into two halves and embedded into acrylic moulds. Four curing light sources were used which further divided the overall sample into Halogen, light emitting diode (LED), powered LED, and high-power LED groups. Additional subgroups were created according to the applied curing distances (5 mm, 10 mm) and different bracket types (metallic or ceramic). A standardised bonding procedure was performed and pulp chamber temperature changes were evaluated using a thermal camera. Statistical analysis was performed using a three-way ANOVA.

Results: The Halogen light curing group revealed a significantly higher temperature rise in the pulp chamber compared to the other groups. A shorter curing distance produced increases in pulpal temperature. There was no significant effect as a result of the bracket type.

Conclusions: None of the curing light sources exceeded the critical value for pulp chamber temperature rise. The primary desirable outcome was the lowest temperature increase noted with the high-power LED unit. The secondary outcome related to the different brackets revealed no difference relative to pulp chamber temperature change. From a clinical perspective, high-power LED units could be safely used.

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Introduction

Recent advances in the development of light-cured adhesives have provided significant advantages during orthodontic fixed appliance application. Over the years, alternatives such as light-emitting diode (LED), argon laser, high intensity, low intensity, and plasma arc light-curing units and conventional quartz-tungsten-halogen lights (QTH) have become popular. Their clinical popularity is a result of the easier removal of excess adhesive around the brackets, more accurate bracket positioning and a reduced irradiation time.1 LEDs also have a higher source longevity compared with conventional halogen units. More recently, powerful LED light-curing units have allowed a further reduction in curing time along with better polymerisation of adhesives.2 Previously, Eliades3 briefly indicated the importance of the continual improvements in orthodontic materials and techniques and projected that the use of plasma arc and LED units will be widespread.

However, these high-power LED units generate excessive heat in the irradiated object.4 In this regard, the generated temperature rise may have detrimental effects on the dental pulp.5 Several investigations have shown a significant temperature increase within the pulp chamber accompanying the application of high-energy light sources.6,7 The temperature rise depends on the light source, exposure time, the thickness of the adhesive layer, and the distance between the light unit and the pulp.8 There has been a clinical aim to reduce the heat produced during dental procedures to assure pulp integrity,9 which is also an important
concern during bracket bonding. Previous reports have described temperature changes during bonding using different light sources by thermocouple probes inserted into the pulp chamber, which provided measurements only within a localised area.\(^2\) However, without any contact, infrared thermal cameras provide measured surface temperatures over large surface areas with colored images of temperature changes at a sensitivity of 0.1°C.\(^1\) Minimum-touch time has become important in creating efficient workflows for orthodontists today. Therefore, the most efficient light source and bonding procedures are a requirement to shorten chair time as much as possible. In addition, a literature review has shown that information about pulp chamber temperature changes during orthodontic bonding is lacking. Ceramic brackets which have been available for many years meet the increasing demand for aesthetics but there is no study which describes the pulp chamber temperature changes of ceramic brackets during bonding. Therefore, the specific aims of the present study were to use a thermal camera to investigate the temperature changes in the pulp chamber under different conditions involving the use of different light sources, different curing distances, and bracket types. It was hypothesised that (i) different light sources and curing distances from the tooth surface and (ii) the use of metallic or ceramic brackets will affect the pulp chamber temperature change during bonding.

**Materials and methods**

The study was approved by the Clinical Research Ethics Committee of Gazi University Faculty of Medicine (25901600/80). The sample under investigation comprised 160 human upper first premolar teeth extracted for orthodontic purposes. Teeth affected by caries, restorations, cracks, hypoplastic areas, and/or defects of enamel structure, as well as a bucco-palatal width of less than 5 mm were excluded. The included teeth were stored in 0.1% thymol solution until required but for no more than one month. Any calculus and debris were removed using fluoride-free pumice. The teeth were mounted in acrylic blocks and orientated such that the long axis of each tooth was set vertically and embedded up to the cemento-enamel junction (Figure 1A). The Mecatome device (Mecatome T201 A Press, France) which included a slowly rotating diamond disc (Figure 1B, C) was used under a water spray, to centrally slice the teeth into two halves (Figure 2). The buccal halves of the prepared teeth were stored at 37°C for 24 hr in an isotonic solution, until required.

**Curing procedures**

The samples were randomly divided into Halogen (Optilux 401, Kerr, West Collins, Orange, USA), LED (EliparFreelight II, 3M ESPE, St. Paul, MN, USA), powered LED (Valo SG, Ultradent Products Inc, USA), and high-power LED (Valo EG, Ultradent Products Inc, USA) groups (Table I), each including 40 teeth. Each group was further divided into four subgroups depending upon two different curing distances (5 and 10 mm), and different types of brackets (metallic or ceramic). As a result, 16 groups, each including 10 teeth were created and all samples were bonded by the same researcher (AAB). The buccal surfaces were etched with 37% ortho-phosphoric acid for 30 sec (3M Dental products, St Paul, MN), rinsed and dried with an oil-free source. In total, 0.018-inch-metallic (Avex MX metallic bracket, Opal Orthodontics, Ultradent Products, USA) and ceramic brackets (AVEX CX, IFU, Opal Orthodontics, Ultradent Products, USA) were bonded using Opal Seal and Opal Bond MV (Opal Orthodontics, Ultradent Products, USA) were bonded using Opal Seal and Opal Bond MV (Opal Orthodontics, Ultradent, USA). Any excess adhesive was gently removed before curing. Light-curing was performed using the times and the calibrations recommended by the manufacturers of each light source.

Before the evaluations, the light intensity of the halogen curing unit was checked with a curing radiometer (Demetron Kerr, Danbury, Connecticut, USA), and the LED unit with a LED curing radiometer (Hilux Ledmax). No measurable reduction in intensity of the light sources was found.

**Evaluation of pulp chamber temperature changes**

The temperature changes within the pulp chamber of the samples were measured at the same room temperature, under standard conditions and in one session. Using a thermal imaging camera (FLIR E45 ThermaCAM, Niceville, FL) as shown in Figure 3A, B, temperature measurements were taken at the beginning and end of the curing period. Each sample was placed with the palatal side facing the thermal camera. The thermal camera’s recording was started by focusing on the pulp chamber during the curing procedure and
the temperature changes were recorded to 0.1°C. A fixed mechanism was constructed in order to create a standard distance between the camera and the samples.

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS version 15.0, SPSS Inc., Chicago, IL, USA). Differences between the groups were tested by applying a three-way ANOVA, followed by a post hoc test. The significance level was assigned as $p < 0.05$.

Results

The temperature changes relative to all light sources and statistical comparisons are shown in Table II. The highest temperature rise was found in the Halogen group (1.15 ± 0.52°C), followed by powered LED (0.65 ± 0.30°C), LED (0.46 ± 0.39°C), and high-power LED (0.31 ± 0.12°C). Group comparisons revealed that the increase was significant in the Halogen group when compared to the other groups ($p < 0.05$).

The mean temperature rise in the pulp chamber was 0.86 and 0.42°C when the curing was performed at a

Table 1. Technical details about light sources.

| Light sources/models | Manufacturer                      | Power intensity | Wavelength | Cure  |
|----------------------|-----------------------------------|-----------------|------------|-------|
| Halogen (Optilux 401)| Kerr, West Collins, USA           | 550 mW/cm²      | 400–515 nm | 40 sec|
| LED (EliparFreeLight II) | 3M ESPE, MN, USA                  | 1200 mW/cm²     | 430–480 nm | 10 sec|
| Powered LED (Valo Ortho) | Ultradent Products Inc, USA       | 1200 mW/cm²     | 395–480 nm | 10 sec|
| High-powered LED (Valo Ortho) | Ultradent Products Inc, USA       | 3200 mW/cm²     | 395–480 nm | 3 sec |

LED, light-emitting diode; sec, seconds.
distance of 5 and 10 mm, respectively, and reporting a significance at < 0.05 (Table III). There was no significant effect of bracket types on the temperature change in the pulp chamber (Table IV).

The temperature changes relative to all subgroups and statistical comparisons are shown in Table V. The highest temperature rise using the Halogen light was found in the metallic bracket group, which was cured at a 5 mm distance (1.57°C). The LED group showed the highest temperature reading in the metallic bracket group cured at a 5 mm distance (0.85°C). The powered LED group demonstrated that the highest temperature rise in the ceramic bracket group cured at a 5 mm distance (0.91°C). In the high-power LED group, the highest temperature rise was noted for the ceramic bracket group which was cured at a 5 mm distance (0.41°C). Statistical comparisons revealed significant differences within all subgroups relative to curing distances (p < 0.05).

Mean values, standard deviations, and the statistical comparisons of the temperature changes for all light sources irradiated at 5 and 10 mm are shown in Tables VI and VII, respectively. The halogen group with metallic and ceramic brackets produced significantly higher pulpal temperature changes than the other sources, at both curing distances.

**Discussion**

The polymerisation of current bonding adhesives is mostly initiated by visible light sources, in which the curing times have been greatly reduced. However, light-curing sources raise a concern regarding overheating of the pulp. In the present study, the effect of different curing units on pulp chamber temperature
changes was evaluated. Since dentine has a low thermal diffusivity, any thermal energy transferred to the pulp is stored within. In an in vitro study in Rhesus macaca monkeys, it was reported that a temperature increase of 5.5°C in the healthy pulps of monkeys caused detrimental pulp effects, and this value was accepted as a reference for pulp damage in vitro. The results of the present study showed that the temperature increase in any of the current groups did not exceed the critical values for pulp damage.

A shorter curing time provides clinicians with benefits related to reduced chair time and contamination risk accompanying faster clinical performance. The present results showed that the Halogen group produced the highest temperature rise and the high-power LED group demonstrated the lowest rise in the pulp chamber. Similar to the present findings, previous studies reported higher pulp chamber temperature changes from halogen light sources than LED and plasma arc. This result

### Table V. Pulp chamber temperature changes in subgroups and statistical comparisons.

| Groups                               | n  | Mean ± SD  | p       |
|--------------------------------------|----|------------|---------|
| Halogen – Metallic brackets – 10 mm  | 10 | 0.84 ± 0.14 | <0.05   |
| Halogen – Metallic brackets – 5 mm   | 10 | 1.57 ± 0.63 | ns      |
| Halogen – Ceramic brackets – 10 mm   | 10 | 0.90 ± 0.21 | <0.05   |
| Halogen – Ceramic brackets – 5 mm    | 10 | 1.31 ± 0.34 | ns      |
| LED – Metallic brackets – 10 mm      | 10 | 0.17 ± 0.13 | <0.05   |
| LED – Metallic brackets – 5 mm       | 10 | 0.85 ± 0.27 | ns      |
| LED – Ceramic brackets – 10 mm       | 10 | 0.09 ± 0.09 | <0.05   |
| LED – Ceramic brackets – 5 mm        | 10 | 0.75 ± 0.23 | ns      |
| Powered LED – Metallic brackets – 10 mm | 10 | 0.45 ± 0.08 | <0.05   |
| Powered LED – Metallic brackets – 5 mm | 10 | 0.78 ± 0.29 | ns      |
| Powered LED – Ceramic brackets – 10 mm | 10 | 0.49 ± 0.17 | <0.05   |
| Powered LED – Ceramic brackets – 5 mm | 10 | 0.91 ± 0.33 | ns      |
| High powered LED – Metallic brackets – 10 mm | 10 | 0.24 ± 0.06 | <0.05   |
| High powered LED – Metallic brackets – 5 mm | 10 | 0.37 ± 0.08 | ns      |
| High powered LED – Ceramic brackets – 10 mm | 10 | 0.22 ± 0.07 | <0.05   |
| High powered LED – Ceramic brackets – 5 mm | 10 | 0.41 ± 0.15 | ns      |

SD standard deviation, ns non-significant. x, y; A, B; a, b; 1, 2: different signs represent statistical difference among same light sources.

### Table VI. Comparisons of pulp chamber temperature changes with light sources irradiated at 5 mm.

| Groups                               | n  | Mean ± SD  | p       |
|--------------------------------------|----|------------|---------|
| Halogen – Metallic brackets – 5 mm   | 10 | 1.57 ± 0.63 | <0.05   |
| LED – Metallic brackets – 5 mm       | 10 | 0.85 ± 0.27 | <0.05   |
| Powered LED – Metallic brackets – 5 mm | 10 | 0.78 ± 0.29 | <0.05   |
| High powered LED – Metallic brackets – 5 mm | 10 | 0.37 ± 0.08 | ns      |
| Halogen – Ceramic brackets – 5 mm    | 10 | 1.31 ± 0.34 | <0.05   |
| LED – Ceramic brackets – 5 mm        | 10 | 0.75 ± 0.23 | <0.05   |
| Powered LED – Ceramic brackets – 5 mm | 10 | 0.91 ± 0.33 | <0.05   |
| High powered LED – Ceramic brackets – 5 mm | 10 | 0.41 ± 0.15 | ns      |

mm millimeter, ns non-significant, SD standard deviation. Groups with different subscript letters differ from each other.
has been attributed to the different properties of the light sources, and the longer curing time required of the halogen unit. The current exposure time was 40 sec in the Halogen group, and 3 sec the high-power LED group. The effects of a longer exposure time on increasing the pulpal temperature has previously been noted. While the halogen units convert most of the total energy input into heat and convert only 1% into light, LED units generate minimal heat during curing. This might have contributed to the lowest temperature change noted in the high-power LED group, besides the shorter curing time. Conversely, despite their shorter curing time, plasma arc sources resulted in an increased temperature rise compared with halogen light sources in a previous study. This discrepancy can be explained by the different treatment contents between restorations and orthodontic bonding procedures. To overcome this side effect, a recent study concluded that the application of an air flow to be effective in preventing a temperature rise during exposure using high-power LED units.

The distance between the light sources and the pulp chamber is one of the most important factors related to heat generated during polymerisation. Clinically, curing is usually performed very close to the surface of the bracket. In this respect, a 5 mm curing distance could be considered clinically acceptable, but might be difficult to achieve in the posterior regions of the dental arches, and so a 10 mm curing distance was also applied in the present study. Based on the current results, the temperature rise showed a significant difference when curing was performed from different distances, similar to the results of Uzel et al. and Aksakalli et al. The temperature increase was 0.86°C when curing was performed 5 mm from the tooth surface, and 0.42°C at a distance of 10 mm. When different light sources applied 5 mm from the tooth surface were evaluated, a significantly higher temperature increase was generated by the Halogen unit, and the lowest was produced by the high-power LED unit. Similarly, the greatest temperature increase was found using the Halogen unit, while the LED unit produced the lowest temperature change at a 10 mm curing distance. Based on the results, the first hypothesis was accepted. Uzel et al. reported a 0.52°C temperature increase using the LED source when the curing distance was 10 mm. Aksakalli et al. noted a value of 3.78°C, while Ulusoy et al. determined the increase to be 0.52°C. The discrepancy between values likely depends on the different methods used in assessing temperature change, as well as the differences in curing times and light intensities.

A current aim was to assess if the differences in translucency and fluorescence between metallic and ceramic brackets affects pulp chamber temperature change during curing. As far as is known, there is no information about pulp chamber temperature changes during orthodontic bonding related to the effect of different bracket types. Ceramic brackets were introduced to meet the increasing demand for more aesthetic appliances. It has been reported that the opacity and thickness of overlaying ceramics influence light transmission. Aesthetic brackets are translucent or non-translucent, according to their optical properties. Monocrystalline ceramic brackets are included in the translucent bracket group while polycrystalline brackets are non-translucent. The translucency of monocrystalline brackets provides

### Table VII. Comparisons of pulp chamber temperature changes with light sources irradiated at 10 mm.

| Light Source | Brackets Type | n  | Mean ± SD       | p    |
|--------------|---------------|----|-----------------|------|
| Halogen      | Metallic      | 10 | 0.84 ± 0.14c    | <0.05|
| LED          | Metallic      | 10 | 0.17 ± 0.13c    | ns   |
| Powered LED  | Metallic      | 10 | 0.45 ± 0.08b    | <0.05|
| High powered LED | Metallic   | 10 | 0.24 ± 0.06a    | ns   |
| Halogen      | Ceramic       | 10 | 0.90 ± 0.21c    | <0.05|
| LED          | Ceramic       | 10 | 0.09 ± 0.09a    | ns   |
| Powered LED  | Ceramic       | 10 | 0.49 ± 0.17b    | <0.05|
| High powered LED | Ceramic   | 10 | 0.22 ± 0.07a    | ns   |

mm millimeter, ns non-significant, SD standard deviation. Groups with different subscript letters differ from each other.
light passage depending on their single crystal structure. However, polycrystalline brackets are not translucent, due to the lack of boundaries between the crystals and impurities incorporated during the manufacturing process. Therefore, light is prevented from passing through. Relative to the current findings, a comparison of metallic and ceramic brackets with respect to temperature changes in the pulp chamber showed no significant difference between the curing units. This result might have been influenced by the use of only polycrystalline ceramic brackets. Knowledge in the literature has emphasised that curing usually takes place at the incisal and cervical edges when a metal bracket is light-cured. However, when an adhesive is irradiated directly through a translucent bracket, the level of adhesive cure is influenced by the translucency of the bracket. Therefore, within the limitations of the present study, it may be concluded that there was no apparent effect of the bracket type on temperature changes produced in the pulp chamber. Yu and Lee suggested that size, shape, and roughness vary between different manufacturers which could cause a difference in the optical properties of ceramic brackets. Accordingly, further studies would be beneficial to evaluate the curing procedures in a comparison between monocrystalline and polycrystalline structures, and also to clarify the influence of bracket translucency during light-curing.

There are limitations to this study which require consideration. Firstly, in vitro studies may provide an initial estimate, but in vitro conditions do not represent clinical reality and so the limitations of laboratory studies should be considered when interpreting the results. Secondly, the current samples included only premolars, as these are the most commonly extracted teeth for orthodontic reasons. However, in order to generalise the results, teeth with a thinner enamel layer, such as lower incisors, could also be evaluated in future experiments. In addition, although the samples were standardised by excluding teeth with a buccopalatal width less than 5 mm, the dentine and enamel thicknesses of each sample could not be determined, and so light transmittance might have been variable.

Conclusions
The lowest temperature increase was generated using a high-power LED unit, therefore pulpal damage should not be a concern when high-power LED units are used for curing bonding adhesives. A greater distance of the light source to the tooth surface leads to a lesser increase in temperature. The type of bracket, either metallic or ceramic, did not reveal a significant difference regarding pulp chamber temperature change during bonding.

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Conflict of Interest
The authors declare no conflict of interest.

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