Evaluation of temperature changes in the pulp chamber during polymerization of light-cured pulp-capping materials by using a VALO LED light curing unit at different curing distances

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The aim of this study was to evaluate temperature changes in the pulp chamber during polymerization of four different pulp-capping materials using a LED-light-curing-unit in the contact and noncontact positions. A pulpal circulation mechanism was simulated to measure increases in temperature in four pulp-capping materials that were applied to the occlusal dentin surface. Two different distances were used between the tip of the unit and the material surface during polymerization; 0 and 2 mm. The data were statistically analyzed using factorial-ANOVA, one-way-ANOVA, and Tukey's HSD test. There were statistically differences between contact and noncontact groups ($p < 0.05$). Contact groups produced significantly lower temperature rise compared with noncontact groups. The highest and lowest mean temperature increases were calculated for the Biner LC and the TheraCal LC, respectively. Considering the effects of temperature rising, the distance of the light curing units from restorations should not be overlooked as well as the types of the materials.

Keywords: Temperature rise, Pulp-capping materials, Light curing unit, Pulp chamber

INTRODUCTION

Preservation of pulpal health is one of the major objectives of restorative dentistry. Physical, chemical, biological, and thermal factors can affect dental pulp during operative procedures¹⁻³. Especially in deep cavities, the amount of remaining dentin thickness, types of pulp-capping material, and the heat generation during restorative procedures stand out as factors that affect the health of the pulp⁴⁻⁶.

In deep cavities, the pulp tissue can be affected by bacterial toxins and thermal changes. In such cases, pulp-capping materials can be used to preserve the dentin–pulp complex against increasing temperature, show antibacterial activity, and to block bacterial transition in the pulp chamber^{1,7}. Calcium hydroxide is the most widely used pulp-capping material in restorative dentistry, due to its ability to induce new dentin formation, antibacterial effect, and alkaline pH⁸. Despite its popularity, however, the physical properties of conventional calcium hydroxide such as water solubility, bond strength to dental hard tissues, and compressive strength, are relatively poor⁹. Due to these disadvantages, light-curing pulp-capping materials were developed to treat deep cavities and in case of pulpal exposure. But the heat generated during the polymerization of these materials could lead to an irreversible pulpal damage¹⁰. This increase in temperature could be originated from both the exothermic polymerization of the material and the

energy absorbed from the light curing unit (LCU)¹¹. Studies have shown that the type of LCU used is also a crucial factor affecting the amount of the generated heat¹². Recently, different types of light sources have been developed for use in clinical practice. Contemporary light emitting diode (LED) LCUs, which are more extensively in use compared to other light sources in restorative dentistry, have many advantages. They generate lesser heat, are resistant to overheating and, have longer lifetimes, and their light output decreases minimally over time¹³.

The distance between LCU and material surface is another factor affecting increases in temperature¹⁴. For several reasons, in clinical conditions, it is not always possible to place the LCU in the same position. Differences among the anatomical shapes of teeth, the position of the teeth in dental arch, the depth of the restorations, and the design of the light source can all affect the position of LCU. Increased distances between the LCU and the material surface can cause insufficient polymerization of light-cured materials, due to reduced power¹⁵. Therefore, clinicians often prefer high-powered LED LCUs or longer irradiation time for durable restorations. However, increased light intensity and exposure time are risk factors that increase the temperature rise.

The aim of this study was to evaluate temperature changes in pulp chamber during the polymerization of four different light-curing pulp-capping materials using LED LCU in contact and noncontact positions.

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MATERIALS AND METHODS

The present study was approved by the Research Ethics Committee of the Izmir Katip Celebi University, under report no. 2014/61. One freshly extracted, intact, human mandibular second molar tooth was cleaned using a periodontal scaler and pumice slurry and stored in distilled water at room temperature until use. The roots of the tooth were removed by sectioning approximately 2 mm below the cemento-enamel junction and perpendicular to the long axis, using a water-cooled diamond disk. Additionally, the occlusal enamel of the tooth was completely removed to expose a flat dentin surface using the diamond disk. The pulpal remnants were removed and the thickness of occlusal dentin layer was measured using a precision caliper. Later, occlusal dentin layer was cautiously abraded using an 800-grid silicone-carbide abrasive paper with a polishing machine (Minitech 233, Presi, Grenoble, France) in order to provide an occlusal dentin layer with a uniform thickness of 1 mm all over the occlusal area. A small notch was made at the edge of the dentin surface to remove the cured pulp-capping material from the tooth surface more easily. Finally, the tooth was attached to an apparatus which was originally designed and fabricated by us to simulate pulpal blood microcirculation (Fig. 1).

A standard infusion set (Gemed Medical Co., İstanbul, Turkey) with a 21-gauge (green) injector needle was attached to a distilled water reservoir (1,000 mL). The injector needle was shortened to 5 mm in length, and the tip of the needle (1 mm in length) was placed

on a stainless steel metal plate through an artificial perforation and used as water inflow access. Another needle tip which was connected to a freestanding infusion tube was placed just contiguous to the first one to be used as water outflow exit and needle tips were fixed to the base plate using cyanoacrylate adhesive. The water flow rate of the system was set to a constant amount of 0.026 mL/min by using a digital infusion flow meter (SK-600II infusion pump, SK Medical, Shenzhen, China) which was attached to the system. Distilled water at room temperature was used to simulate blood, and blood pressure in the pulp chamber used in this study was 15 cm H₂O (Fig. 1). The tooth was then mesially perforated using a diamond bur, in order to insert a 0.36-mm-diameter J-type thermocouple wire (Omega Engineering, Stamford, CT) into the pulp chamber to contact the occlusal wall of the pulp chamber. A silicone heat-transfer compound (ILC P/N 213414; Wakefield Engineering, Beverly, MA) was applied to the tip of the thermocouple wire, and the thermocouple wire was fixed at the adjusted position to stay in contact with the occlusal wall of the pulp chamber, using light-curing calcium hydroxide liner cement (Calcimol LC; Voco GmbH, Cuxhaven, Germany). In this manner, the gap around the thermocouple wire was sealed to prevent leakage from the system. Light-curing glass-ionomer cavity liner cement (Glass liner; WP Dental GmbH, Barmstedt, Germany) was used to fix the tooth onto the metal base plate. The thermocouple wire was connected to a data logger (XR440-M Pocket Logger; Pace Scientific, Mooresville, NC) and a computer to record the temperature increase data from inside the pulp chamber during the light activated curing process.

Increases in temperature were measured for four pulp-capping materials (ten measurements for each product): Ultra-Blend Plus, Calcimol LC, Biner LC, and TheraCal LC (Table 1). These materials (prepared according to the manufacturer's instructions) were applied to the occlusal dentin surface to be 1 mm thick and polymerized with an LED LCU by one operator. To control this thickness, a 1-mm high metal ring was used. The light output of the LCU was measured with a radiometer specifically designed for LED before beginning and after each ten measurements. Details of the LCU parameters and curing modes are shown in Table 2. Two different distances between the tip of the unit and the light-cured pulp-capping material surfaces during polymerization were evaluated; 0 mm (with the

Fig. 1 Pulpal circulation mechanism.

Table 1 Materials employed in the study

	Manufacturer	Product Description
Ultra-Blend Plus	Ultradent Products Inc, South Jordan, UT, USA	Light curing calcium hydroxide
Calcimol LC	Voco GmbH, Cuxhaven, Germany	Light curing calcium hydroxide
Biner LC	Meta Biomed Inc, Horsham, PA	Light curing calcium hydroxyphosphaste
TheraCal LC	Bisco Inc, Schamburg, IL, USA	Light curing resin-modified calcium silicate

Table 2 Light curing unit used in this study

LCU	Manufacturer	Lens Diameter	Curing Mode	Light Intensity	Wavelength
VALO LED light curing unit	Ultradent Products Inc, South Jordan, UT, USA	9.6 mm	Standard Power	1000 mW/cm ²	395–480 nm

tip touching the polyester strip) and 2 mm. The surfaces of the materials were smoothed with a strip of polyester that was removed before polymerization. To standardize this distance, a 2-mm high metal ring was used as a spacer, and the light-curing unit was placed over this ring. For each sample, the initial temperature and the maximum temperature increase were calculated. Moreover, a group without any lining material has been added to the study as a control group. For these groups two different distances were used 0 mm and 2 mm and temperature increase were calculated.

The sampling rate of the data logger was set to one sample every 2 s for a recording duration, starting with light application for approximately 40 s, until the temperature started to decrease. The collected data, in both tabular and graphic form, were monitored in real time and transferred to the computer. Later, the difference between the initial and highest temperature readings (Δt) was taken.

Statistical analysis

Prior to the data collection, a power analysis was performed with G*Power 3.0.10 (Franz Faul, Christian-Albrechts-Universität, Kiel, Germany) to estimate the sample size. The analysis indicated that a group sample size of 9 would result in more than 80% power (actual power=96%; critical $F=5.59$; noncentrality parameter $\lambda=18.79$) for numerator d.f.=1 while a group sample size of 10 would give more than 80% power (actual power=97%; critical $F=5.19$; noncentrality parameter $\lambda=54.52$) for numerator d.f.=4 to detect significant differences with 1.40 and 2.30 effect sizes, respectively, and at $\alpha=0.05$ significance level.

Increased temperature data were analyzed using the IBM SPSS Statistics version 20.0 statistical package (SPSS, Chicago, IL, USA). The dependent variable across groups was examined in terms of existence normality assumption by performing a Shapiro-Wilk test and Levene's test for constant homogeneous variances.

A factorial ANOVA design was used to test the main effects and the interaction effect of the factors such as material type and curing distance. A statistically significant interaction effect was found, and follow-up tests were run, using combined factors within a one-way ANOVA, followed by pairwise comparisons between the combined factor levels to determine which combinations contributed significantly to the interaction.

RESULT

In evaluation of curing distance factor, independently of

Table 3 Temperature rises (in degrees celcius) for distance factor in pulp chambers during polymerization of the materials by the curing units and results of ANOVA, independent of other factors

Distance Groups	n	Mean $\pm$ SD
Noncontact Groups	40	9.38 ^a $\pm$ 0.89
Contact Groups	40	7.51 ^b $\pm$ 1.10

*The letters sign statistically different groups ($p<0.05$)

Table 4 Temperature rises (in degrees celcius) for pulp-capping materials factor in pulp chambers during polymerization by the light curing unit and results of ANOVA, independent of other factors

Pulp Capping Materials	n	Mean $\pm$ SD
Ultra-Blend Plus	20	8.78 ^a $\pm$ 0.96
Calcimol LC	20	8.06 ^b $\pm$ 0.96
Biner LC	20	9.41 ^c $\pm$ 1.41
TheraCal LC	20	7.53 ^b $\pm$ 1.34
Control Group	20	11.53 ^d $\pm$ 0.72

*The letters sign statistically different groups ($p<0.05$)

others factors, the mean temperature rises of the contact and noncontact groups are presented in Table 3. The temperature increases of the noncontact groups were significantly higher than those of the contact groups ($p<0.05$).

For pulp-capping materials, the highest temperature rise ($9.41^{\circ}\text{C}\pm 1.41^{\circ}\text{C}$) and the lowest temperature rise ($7.53^{\circ}\text{C}\pm 1.34^{\circ}\text{C}$) were calculated for Biner LC and the TheraCal LC, respectively. Overall, while there was no significant difference between the TheraCal LC and the Calcimol LC groups ($p>0.05$), there were statistically significant differences among all the other groups ($p<0.05$) (Table 4). Table 5 and Figure 2 present the mean temperature increases for all the pulp-capping materials and the distance factors.

Table 5 Temperature rises (in degrees celcius) for pulp-capping materials factor and distance factors in pulp chambers during polymerization by the light curing unit and results of ANOVA

	n	Mean±SD
Ultra-Blend Plus-Noncontact	10	9.31 ^a ±0.55
Ultra-Blend Plus-Contact	10	8.25 ^b ±1.02
Calcimol LC-Noncontact	10	8.88 ^{ab} ±0.48
Calcimol LC-Contact	10	7.24 ^c ±0.47
Biner LC-Noncontact	10	10.58 ^d ±0.70
Biner LC-Contact	10	8.24 ^b ±0.84
TheraCal LC-Noncontact	10	8.75 ^{ab} ±0.35
TheraCal LC-Contact	10	6.32 ^c ±0.64
Control Group-Noncontact	10	12.08 ^d ±0.45
Control Group-Contact	10	10.98 ^d ±0.47

*The letters sign statistically different groups ($p<0.05$)

Fig. 2 The mean temperature rises for all groups.

DISCUSSION

An increase in temperature during operative procedures can affect the health of vital pulp¹⁶. Several factors can affect temperature increase in pulp chamber, such as cavity preparation procedures, bleaching of the teeth, laser light applications, polishing of dental materials, and polymerization of light-cured materials¹⁷⁻¹⁹. Polymerization-induced temperature increase depends on two factors: the crucial factor causing temperature rise during the polymerization of light-cured materials is the heat generated by LCU. The exothermic

polymerization of the material is the secondary factor¹¹. This literature information is compatible with the results of current study. According the results of the control group, when the light curing unit was applied without any lining material, an excessive heat was generated. Although exothermic reaction of the resin based materials is generating some heat, these lining materials primarily prevent the conduction of the heat generated by LCU to the pulp chamber.

In addition, various factors, such as the light intensity of the LCU, the amount of remaining dentin thickness, the composition of the restorative materials, the distance between LCU and material surface, the position of LCU, and exposure time can affect the extent of the increase in temperature during the polymerization process^{14,20-22}. Among these factors, the distance between the LCU and the restoration surface arises as an important factor for the success of the restoration. Studies reported that, an increase in distance of the light source from the materials surface results in a decrease in microhardness and the degree of conversion of the restorative materials for all types of light sources studied^{23,24}. Thus, in this study, we aimed to determine the effects of curing distance and types of pulp-capping material on temperature increase in the pulp chamber.

Over the years, the effects of external heat application on pulp tissues have been investigated in many studies^{6,19,25}. However, the level of temperature increase that can be tolerated by dental tissues remains unknown. In their animal study, Zach and Cohen²⁵ found that a 5.6°C temperature increase in the pulp chamber induced necrosis of the pulp in 15% of teeth. Temperature increases of 11.1°C and 16.6°C induced necrosis of the pulp in 60% and 100% of teeth, respectively. In addition, Eriksson *et al.*²⁶ suggested that duration of temperature increase is an important factor for creating permanent change in pulp tissues. The authors reported that 42°C is a critical temperature when sustained for one min duration.

In previous studies, different techniques were used to evaluate temperature increase, such as calorimeter, thermocouple, differential thermal analysis, and infrared cameras. In the current study, the thermocouple technique was selected to measure temperature changes during polymerization of pulp-capping materials due to its reliable and precise results²⁷⁻²⁹.

Pulp microcirculation plays an important role in elimination temperature increases when the pulp tissue is affected by a thermal stimulus²⁰. When pulpal temperatures exceed 43°C, the pulpal neuron is stimulated and the blood circulation of the pulp chamber increases, so it is a mechanism for heat dissipation³⁰. A few studies in the literature have evaluated the role of pulp microcirculation as a cooling agent in the thermal behavior of the dentin pulp complex. In most *in vitro* studies, the treated teeth were placed in a water tank containing standing water at 37°C^{31,32}. In this study, in order to simulate the circulation of the pulp chamber, a pulpal circulation mechanism was created. This mechanism allowed water to circulate within the pulp

chamber at a defined flow rate and pressure to simulate a clinical case. These mechanisms provide more realistic results, as simulating blood circulation in the pulp chamber with water flow reflects clinical conditions better than without water flow.

Comparative studies have demonstrated that the amount of remaining dentin thickness plays an important role in protecting the pulp chamber from temperature increase^{33,34}. In the literature, while same group of teeth were used in some studies^{2,19}, only one tooth was used in the others^{12,14,32}. Studies that used the same group of teeth showed that some differences in tooth morphology such as enamel and dentinal structure and thickness that can cause the differences in the thermal conductivity of the teeth tested^{3,27,33}. For this reason, to standardize residual dentine thickness, one permanent second molar tooth was used for each group. This procedure provided to eliminate any possible variables of teeth that might manifest as differences in thermal conductivity and specific heat.

According to the results of this study, TheraCal LC had the lowest mean temperature increase of all the other pulp capping materials, independent of distance factor. The reason for the low temperature increase with TheraCal LC might be because its content is different from the other materials. While all the materials contain calcium hydroxide, only TheraCal LC contains resin modified calcium silicate filler. Calcium silicate has a low specific heat capacity (C) compared with calcium hydroxide which is the content of the other materials that used in this study³⁵. The specific heat capacity is directly proportional with the thermal conductivity of the materials. So, a material which has a low specific heat capacity shows high thermal insulation properties. Because of these insulation characteristics, calcium silicate, has been used over the years as an insulation material in many industrial branches^{36,37}. Therefore, calcium silicate's high temperature insulation characteristic gives TheraCal LC its insulation ability.

In two different positions of the light source, the difference between the amounts of temperature delivered to the pulp tissue during polymerization of each pulp-capping material is as follows: Ultra Blend Plus:1.06°C, Calcimol LC:1.64°C, Biner LC:2.34°C, and Theracal LC:2.43°C. The reason for this difference between the materials is thought to be caused by the variation in the compositions and content of the materials. In evaluating distance factor, independent of pulp-capping materials factor, there were statistically significant differences between contact and non-contact groups, and the temperature increase observed in the noncontact groups was significantly higher than that of the contact groups. These differences can be related to different power densities between the two curing distances. In previous studies, it has been found that when the curing distance between the LCU and the restoration surface increases, the temperature increase is lower. The highest temperature increase was found when the LCU was closest to the restoration surface³⁸. For this purpose, in this study, we aimed to find the

maximum temperature at which that might occur. The light source used in this study is a high-powered LED LCU for the polymerization of light-cured dental materials. Its glass lens provides the ability to focus and collimate the light intensity, resulting in minimally decreased power density with increased distance. Its light intensity reaches the highest value at a distance of 2 mm, after which it decreases again³⁹. The light intensity of the LCU influences the temperature increase caused by the polymerization process of restorative materials. When the light intensity that reaches the restoration material surfaces increases, there may also be an increase in temperature rise. Although the high light output and collimated beam is an advantage for an adequate polymerization⁴⁰, these properties of LCU may have led to the high temperature increase in this study, especially at 2 mm.

This *in vitro* study demonstrated that all the results were above the critical point of 5.6°C, which was reported by Zach and Cohen²⁵. Although we used the pulpal microcirculation mechanism to simulate clinical situations, other mechanisms, such as fluid motions in dentinal tubules and the surrounding periodontal tissues of the teeth, were not considered. These regulatory mechanisms might limit the intrapulpal temperature increase. However, clinicians should be aware of the potential thermal hazard of the light curing units to the pulp. Applying the self-cure lining materials in deep cavities, decreasing the time of curing period, choosing the correct type LCU, using the LCU with the right power density and polymerization mode, setting the correct distance between the LCU and restoration surface, may maintain the health of the pulp tissue. However, it must be emphasized that the results of this study cannot be directly extrapolated to the clinical situation. The present study was a laboratory investigation and the experiment was performed in the room temperature. Different results might be achieved with intra-oral conditions.

CONCLUSIONS

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

- The distance of LCU from the restoration surface affect temperature increase in the pulp chamber.
- TheraCal LC, with low temperature changes during polymerization, might be preferable as an indirect pulp-capping material in deep cavities.

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