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Research Article

TEMPERATURE CHANGE IN THE PULP CHAMBER INDUCED BY DIFFERENT LIGHT CURING UNITS IN SIMULATED DEEP CAVITIES

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ABSTRACT

Objective: The objective of this study was to evaluate the effect of various types of photopolymerization devices on the temperature of the pulp chamber during the adhesive bonding phase.

Materials and Methods: To this purpose, cavities with a mesiodistal diameter of 5 mm, a buccolingual diameter of 3.5 mm, and a residual dentin thickness of 1.2 mm at the cavity base were prepared. Polymerization lights were applied for 20 seconds using three different devices. The temperature change within the pulp chamber was quantified using a thermocouple, with data collected at 10 and 20 seconds utilized for assessment. The mean intra-pulp temperature in the O-Light, Deepcure-L, and Valo groups at the 10th second was 39.9°C, 41.1°C, and 38.7°C and at the 20th second, had temperatures of 42.4°C, 44.3°C, and 40.4°C, respectively.

Result:A statistically significant difference was observed between the Deepcure-L and Valo groups ($p < .01$) in terms of maximum temperature, increase in pulp chamber temperature, and temperature at the 10th and 20th seconds. The observed changes in pulp chamber temperature between the groups, irrespective of light transmission type, are consistent with the power output of the devices, expressed in mW/cm². All the groups yielded a temperature increase above the limit which has been described critical.

Conclusion: During adhesive bonding phase, lower mW/cm² devices could be preferred in cases where the remaining dentin thickness is reduced.

Keywords: Pulp chamber temperature, Monowave LCU, Polywave LCU, in-vitro

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INTRODUCTION

Clinicians should be aware of the potential damage to the pulp that can occur during restorative procedures (1). These damages are usually caused by chemical, thermal, and mechanical effects. One primary reason for this is the use of photopolymerization devices during restorative procedures, which may damage the pulp cells due to thermal rather than mechanical effects. During the photopolymerization of resin-based materials, temperature changes of up to 20°C were observed within the material (2–4).

The temperature increase within the pulp is constrained by the isolation provided by the tooth's hard tissues. However, the iatrogenic reduction in the thickness of the dental hard tissues may contribute to the subsequent increase in temperature within the pulp. This makes the pulp prone to thermal damage, particularly in deep carious cavities, as well as cases of direct and indirect pulp capping. In addition to the remaining dentin thickness, the type and thickness of the restorative material used, the power of the photopolymerization device, polymerization time, and the polymerization mode are effective in determining the temperature change in the pulp (5). In a study on primates, Zach and Cohen demonstrated that an increase of 5.5°C in the pulp resulted in necrosis in 15% of the teeth, while increases of 11°C and 16°C caused necrosis in 60% and 100% of the teeth, respectively (6). In contrast, a study on human teeth indicated that a temperature increase of 11.2°C for 2 or 3 minutes did not permanently damage the dental pulp (7).

Many different methodologies have been used to study the thermal changes caused by the Light Curing Unit (LCU) in the pulp. The two most commonly used methods for temperature monitoring are the placement of a thermocouple tip under the resin material or in the pulp chamber of the extracted tooth. The design where the thermocouple tip is placed directly under the restorative material does not reflect the temperature absorption capacity of the tooth hard tissues and thus cannot provide information about the temperature change in the pulp, ultimately making the experiment inadequate to mimic clinical conditions (8). The configuration in which the temperature-measuring tip is situated within the pulp chamber more closely resembles clinical conditions, but it is challenging to implement, and the variability of the remaining dentin thickness further complicates the system (9,10).

After years of using halogen, plasma arc, and argon laser light devices, the second generation of LCUs with an emittance range of 500-1500 mW/cm² was introduced in 2002 (11,12). In 2004, high-performance LCUs reaching 5000 mW/cm² were developed utilizing LED technology (13,14). Although LED technology, which is a cold light source, can provide the necessary emittance and a wavelength of 400-500 nm (nanometers) for polymerization without reaching elevated levels, studies have indicated that temperature increases may cause irreversible damage to the pulp. LED units utilize light guides, either a fiber pipe or a diffuser lens. Fiber pipes, known as fiber guides, are typically found in single-peak (monowave) LCUs that contain a single LED. Diffuser lenses are used in the newer multiple-peak (polywave) units, which feature multiple LEDs to encompass all wavelengths needed for resin polymerization. The LCUs included in the study are the O-Light (DTE Guilin, China) at 1000-1200 mW/cm² with 420nm-490nm wavelength spectrum, the Deepcure-L (3 M ESPE, USA) at 1470 mW/cm² with 430-480 nm wavelength spectrum, and the Valo(Ultradent, USA) at 980 mW/cm² with 385–515 nm wavelength spectrum. Among these LCUs, the Deepcure-L represents single-peak fiber-guided LED models, while the O-Light and Valo are multi-peak LED devices emitting through a lens (Figure 1).

Figure 1. Fiber guided Deepcure-L(A) and polywave O-Light(B) ve Valo(C)

There is limited data on pulp chamber temperature change in cases of reduced residual dentin thickness during the adhesive polymerization phase. The objective of this in vitro study was to evaluate the effect of various modern photopolymerization devices on pulp temperature during

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the adhesive bonding phase. The H0 hypothesis stated that there would be no significant difference in the temperature increase of the pulp chamber among different LCUs during light irradiation.

MATERIALS AND METHODS

Approval for this study was obtained from the local ethics committee. The entire study was conducted by the Helsinki Declaration. Data from the study with a similar methodology were used to determine the sample size (15). The sample size was calculated using G*Power software with an alpha level of 0.05 and a beta level of 0.95, resulting in a sample size of 20. Twenty maxillary first molars, extracted for periodontal and prosthodontic reasons no more than six months prior, were included in the study. All samples were stored in a 0.5% chloramine-T solution. The included teeth had mesiodistal diameters between 9.1 and 10.3 mm and buccolingual diameters between 9.7 and 11.7 mm. The occlusal surface of the teeth is reduced for the distance from the cavity surface and cavity floor to be 4.0mm ± 0.2mm. X-rays were obtained from all included teeth, and teeth with a narrowed pulp chamber were excluded from the study. Teeth that met the inclusion criteria were decoronated at the enamel cementum level (CEJ) or 1 mm below the CEJ using a 0.14 mm thick metal separator. Following decoronation, the pulp chamber was cleaned with an ultrasonic scaling device (P5 Newton; Satelec, Acteon, France) and then washed with 2.5% NaOCl to remove necrotic pulp tissue. To facilitate direct access to the pulp chamber for the temperature-measuring tip of the thermocouple device, the palatal root was shortened to 4 mm, and a straight path was obtained with a #5 Gates Glidden drill. Class 1 cavities with a mesiodistal diameter of 5 mm, a buccolingual diameter of 3.5 mm, and a dentin thickness at the base of 1.2 mm were prepared on the crown piece. The residual dentin thickness was then measured along the cavity floor at 1 mm intervals with a digital caliper.

The temperature change within the pulp chamber was quantified using a CE-licensed and data-logging thermometer (Tasi TA612C, Suzhou, China) via a K-type thermocouple with 0.5 mm diameter tip by 1-second intervals. The thermometer's integrity was confirmed using another calibrated thermometer (Lutron TM-917, Lutron Electronic Enterprise Co. Taiwan) from the University's Central Labs. The thermocouple utilized was capable of measuring temperature changes between -20°C and +371°C with a resolution of 0.1°C and accuracy of ± 0.2% + 0.7°C. To facilitate heat transfer, the relevant area for the thermocouple tip in the ceiling of the pulp chamber was coated with a thin thermal paste with 14,2 W/mK thermoconductivity (Kryonaut, Thermal Grizzly, Lippstadt, Germany). The thermocouple tip was then inserted through the palatinal root. The crown piece was secured in its original position on the root using a flowable composite. The root tip was sealed with a gingival resin barrier to maintain the position of the thermocouple along the palatal root and within the pulp chamber. Periapical radiographs were obtained to confirm the position of the thermocouple tip within the setup. The teeth were secured in moist floral foam for oral environment simulation. The internal pulp chamber temperature is regulated at 35°C by the manual dripping of hot water (Figure 2). Before the application, the mW/cm² values of all light-curing units were measured three times using a digital power meter (Thorlabs PM130D, USA). During the measurement process, the batteries were maintained at their maximum capacity. For 450-500 nm wavelength, Polywave O-Light had 500 mW/cm², Monowave Deepcure-L had 650 mW/cm², and Polywave Valo had 425 mW/cm² average output. These suboptimal values were considered normal given that the optical tip of the testing device is encased within a housing structure with a distance between the LCU tip. Seeing that the observed output ratio between the LCUs was found to be consistent with the manufacturer's specifications, LCUs are found stable for testing.

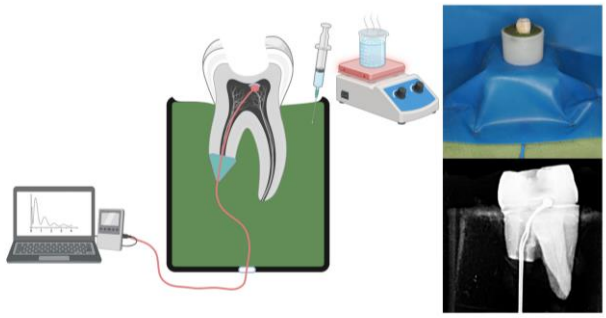

Figure 2. The set-up (upper-right) and pulp chamber temperature experiment illustration (left). Radiographic control for the position of thermocouple tip (lower-right). Created with BioRender.

Polywave O-Light (1000-1200 mW/cm²), Monowave Deepcure-L with 1470 mW/cm² with fiber conduction, and Polywave Valo with 980 mW/cm² emittance power were utilized in 20 samples, respectively, and a total of 60 measurements were conducted. The LCUs are maintained in the same location and angle by a holder device for all the samples, and the irradiation is applied with contact between the LCU and the occlusal cavity. No protective sheath was used with the LCUs. The maximum temperature and the temperature values at the 10th and 20th seconds were analyzed with the SPSS 20.0 software package, with a significance threshold of 5%. The normality of all collected data was investigated via the Shapiro-Wilk test. The maximum temperature and temperature values at the 10th and 20th seconds among the LCU, which followed a normal distribution, were analyzed using ANOVA. Since the variances were not homogeneously distributed, a post hoc Games-Howel test was performed to investigate differences among the groups. The adjusted significance level was set at 0.01.

RESULTS

The temperature profiles of the samples in the three groups are presented in Figure 1. The mean and maximum intra-pulp, as well as the temperatures at 10th and 20th seconds for each group, are presented in Table 1. The chart of the mean intra-pulp temperature at 20th seconds for the O-Light, Deepcure-L, and Valo groups was 42.4°C, 44.3°C, and 40.4°C, respectively. The mean intra-pulp temperature at 10th seconds was 39.9°C, 41.1°C, and 38.7°C, respectively. The highest intra-pulp temperature data at 10th and 20th seconds were obtained in the Deepcure-L group. Subsequently, the O-Light and Valo groups exhibited the lowest and highest temperatures, respectively. The distribution of the readings is shown in Figure 3. LCUs tested have induced over 5.5°C of difference in all experimental groups, while the 20th second mean temperature of the Valo group remained below the critical threshold of 41°C. The difference between the Deepcure-L and O-Light groups, as well as the difference between the Valo and O-Light groups, in terms of maximum temperature, increase in intra-pulp temperature, and temperature at 10th and 20th seconds was not statistically significant ($p > 0.01$). However, a statistically significant difference was observed between the Valo group and the Deepcure-L groups ($p < 0.01$), indicating that the Valo group generated less heat in the pulp chamber.

Table 1. Minimum, maximum, mean±SD for the pulp chamber temperature of the three different light-curing units tested. The letters a,b indicate significant difference ($p < 0.01$) in pairwise comparisons.

Device	Maximum Temperature		10th Second		20th Second	
	Max	Mean ± SD	Min	Max	Mean ± SD	Min
O'light DTE	47.3°C	42.7°C ± 2.3[ab]	37.7°C	43.9°C	39.7°C ± 1.7[b]	38.6°C
DeepCure L	49.2°C	44.3°C ± 2.1[a]	37.3°C	45.0°C	41.7°C ± 2.3[ab]	38.9°C
Valo	44.6°C	40.4°C ± 2.3[b]	36.2°C	41.5°C	38.7°C ± 1.3[b]	36.5°C
p-value		p=0.00			p=0.00	

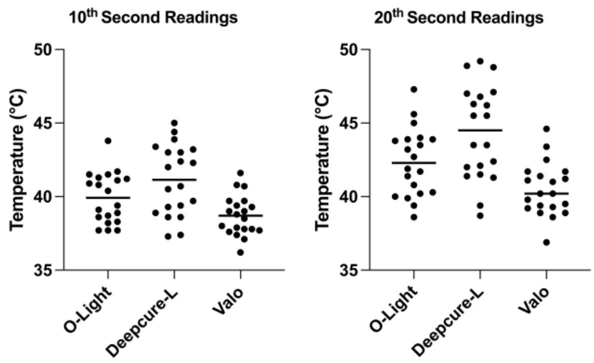

Figure 3. 10th and 20th second readings with means

DISCUSSION

A substantial number of large dentinal tubules are exposed during preparation. The odontoblast extensions within the tubules and the damage to the pulp are caused by several factors, including pressure, the type of cooling, the design of the bur, temperature increase, degree of circulation, dehydration, and so forth. Schuchard (16) and Sato (17) reported that temperature increases may cause structural changes in hard dental tissues and damage to the dental pulp. Especially in cases where the dentin is thin and there is no protective layer on the pulp wall, it is expected that there will be a high-temperature increase in the pulp during the bonding phase for resin materials. Based on the results of the study, the H0 hypothesis was rejected.

To efficiently simulate the closed environment of the pulp chamber and to ensure a clean thermoconductivity by cleaning the pulp remnants within the pulp chamber, the horizontally split crowns were used in the study. Also with this design, a simple gingival resin barrier application to the retrograde palatal entrance was sufficient to retain the K-type thermocouple line and to provide a passive guide to the pulp-dentin junction without the use of adhesive for the thermocouple tip, which would interfere with thermoconductivity. The method we used in our study is similar to the method used by Öztürk et al. (15).

It is established that adhesive materials are toxic to odontoblasts and pulp cells when in direct contact (18). It has been previously demonstrated that at a dentin thickness of 0.7mm, the permeability is significantly reduced in human dentin discs (19). In light of these

MMDJ MEANDROS MEDICAL AND DENTAL JOURNAL
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findings, the lowest threshold for residual dentin thickness in our study is considered to be 0.7mm, beyond which the tooth does not require a biomaterial liner. This makes direct bonding and direct exposure to the LCU clinically relevant. In an in vivo study on tertiary dentin production, Murray et al. reported that tertiary dentin production of 1.5 mm residual dentin thickness samples was 10.6% of 0.5 mm thickness samples. Additionally, the repair response of the pulp was observed to decrease significantly after 1.2 mm residual dentin thickness. The results of this study, when considered alongside those of the aforementioned studies, indicate that the threshold for adhesive bonding without the use of a biomaterial is 1.2 mm. Accordingly, the cavity depths were adjusted following this residual dentin standard (20).

Dental hard tissues, which have lower thermal conductivity and permeability compared to the pulp, play an important role in maintaining the vitality of the pulp (21). A greater thickness of dental hard tissue results in a more substantial insulating effect, which serves to restrict the extent of the intra-pulp temperature increase (21,22) For these reasons, the mesiodistal and buccolingual lengths of the teeth included in our study were selected to be similar. Following the preparation of the cavities, the remaining dentin thicknesses were measured with the assistance of calipers to ensure comparable heat conductivity and permeability due to hard tissues across all samples. The use of three distinct LCUs in each sample ensured that any potential differences in our study results were attributed to the inherent structural characteristics of the samples themselves.

Research has indicated that the basal temperature within the pulp ranges from 34° to 35°C. It has been demonstrated that temperatures exceeding 42.5° to 43°C are sufficient to induce irreversible damage to the pulp, accompanied by a significant increase in reactive blood pressure (21,23,24). All LCUs tested induced a temperature increase exceeding 5.5°C, the threshold for irreversible changes, while only the Valo group remained below the 11°C limit, which induces pulp necrosis in 60% of teeth (6). While an increase in intrapulpal temperature to these levels does not invariably result in irreversible pulpal damage in all cases, the potential for damage may be heightened in the presence of pre-existing pulpal inflammation and limited perfusion. It is also noteworthy that even in cases without permanent damage, the heightened patient sensitization induced by high-temperature changes may increase the clinician's tendency to misdiagnose the treatment as a failed restoration. The findings of this study indicate that the utilization of low-powered polywave units, such as Valo, could reduce this likelihood by providing a lower increase in pulp chamber temperature in similar deep cavities tested. To emulate the basal temperature observed in clinical settings, the temperature of the setup and the sample was maintained at 35°C throughout the study phases. While microcirculation contributes to regulating intrapulpal temperature, one study showed that its overall impact can be considered negligible due to the low blood volume (21).

In studies, the temperature change in the pulp during the use of LCU has generally been investigated at the time of composite polymerization; however, it has not been investigated in the polymerization of adhesive systems (23,25). The results of our study indicate that the highest temperature increase was observed in the Deepcure-L, O-Light, and Valo groups, in that order. The Deepcure-L device operates at a power level of 1470 mW/cm², while the O-Light and Valo devices operate at 1000-1200 mW/cm² and 980 mW/cm², respectively. It is noteworthy that the preliminary power testing of the O-Light compared to the other manufacturers pointed to a result near 1000 mW/cm² output, which is consistent with, but near the lower limit of the specifications declared by the manufacturer. The intra-pulp temperature changes observed between the groups, regardless of the light transmission type, are consistent with the power of the devices, expressed in mW/cm². The findings of our study indicate that there was no statistically significant difference between the O-Light and Deepcure-L groups, despite the differences in light transmission types and the similarities in power levels. Our results demonstrate that the increase in pulp chamber temperature is not contingent on the type of light transmission (fiber or lens) but is instead directly proportional to the power of the device utilized. To assure pulpal health in the adhesive bonding phase where the remaining dentin is considered thin, a lower mW/cm² LCU can be preferred if multiple devices are present. If there is only one high-output device in a clinical situation, such as the single-peak high mW/cm² group, it is possible to leave a small gap between the LCU tip and the teeth, which will serve to reduce both the emittance and the thermal effect. Concerning this idea, it may be of interest to consider the results of a study that stated a reduction in light irradiance of approximately 28% and a reduction in the degree of conversion of adhesive by approximately 5% with a dentin-LCU distance increase from 4.6 mm to 6.9 mm (26).

Polywave curing units (Valo and O-Light) exhibit a lack of emittance uniformity due to variations in light distribution from different LEDs, resulting in unit-specific hot spots of high emittance based on the LED chip locations. In contrast, fiber-guided monowave units (Deepcure-L) concentrate emittance primarily on the center beams. The non-uniform energy distribution in polywave curing units is believed to contribute to heterogeneous curing (27). However, there is no clear consensus in the literature regarding the effects of polywave and monowave LCU units on composite polymerization (28–31). Based on our findings, the higher emittance and center beam-focused design of the fiber-guided Deepcure-L unit led to greater temperature increases within the pulp chamber. Therefore, clinicians may consider using these high mW/cm² center beam-focused devices in procedures requiring maximum light penetration, such as bulk composite curing, rather than during the adhesive bonding phase.

Existing studies indicate that photocuring of bonding agents in deep cavities can lead to a significant temperature increase on the dentin surface which is in line with the results of our study (32–34). These studies emphasized the importance of clinicians being mindful of the potential risk of thermal damage to the pulp, particularly when using high-output light sources. No dentin conditioning or adhesive was used on the samples. We decided not to use adhesives in a clinical setting where direct bonding is required because repeated application and removal of the adhesive layer would distort the surface, compromise sample standardization and ultimately affect the readings.

The limitations of this study include its in vitro design, the lack of long-term effects assessment, and the absence of histological analysis. Conducting the study in an in vitro setting does not fully replicate the complex biological and thermal regulation mechanisms found in vivo, particularly pulpal blood flow, which plays a crucial role in heat dissipation. Additionally, the study focused solely on immediate temperature changes during polymerization, without evaluating potential long-term effects on pulpal health, such as delayed inflammation or necrosis.

CONCLUSION

The tested monowave group (Deepcure-L) induced a significantly higher increase than a tested polywave (Valo) group, therefore H0 hypothesis was rejected. The findings of our study indicate that heightened awareness of elevated intra-pulpal temperatures in cases with the thinnest dentin layer may enhance treatment outcomes and pulpal survival. LCUs with high output (>1000 mW/cm²) should be used with caution and it is essential to consider that the generated heat using LCUs require supplementary protective measures to ensure the maintenance of pulpal health. During adhesive bonding phase, lower mW/cm² devices could be preferred in cases where the remaining dentin thickness is reduced. Further studies are required to gain a comprehensive understanding of the thermal damage caused by LCU devices, utilizing both in vivo and ex vivo functional tissue analysis in conjunction with histology and clinical outcomes.

Acknowledgments
The authors deny any conflicts of interest related to this study.

Authorship contributions
First Author: Concept, Design, Analysis, Literature Search, Writing; Second Author: Design, Data Collection and Processing, Literature Search, Writing.

Data availibity statement
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of competing interest
The authors declare that they have no relevant or material interest that relates to this study.

Ethics
The study protocol was approved by the İzmir Katip Çelebi University Health Research Committee (No: 2024 – SAE--0161) and conducted in accordance with the Declaration of Helsinki.

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MMDJ
MEANDROS MEDICAL AND DENTAL JOURNAL
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Meandros Medical and Dental Journal
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