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Effect of resin photopolymerization on primary teeth pulpal temperature change

Rezin fotopolimerizasyonunun süt dişleri pulpal sıcaklık değişimi üzerine etkisi

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Abstract

Purpose: The polymerization of restorative materials has the potential to increase pulpal temperature and may result in damage to the health of pulpal tissue. The aim of this study is to investigate the pulpal temperature change of primary teeth with two light-emitting diode (LED) light-curing units (LCUs) (Valo Cordless®, EliparTM DeepCure-S) and three restorative groups (Filtek™ Bulk Fill Flowable, Filtek™ Z250 Universal Restorative and empty cavity) by using a microcirculation model.

Material and methods: Ten sound human maxillary second primary molars were used. Standardized Class V cavity preparations were performed with a dentin thickness of 1 mm and restorative groups were cured with LED LCUs. The highest temperature point in the pulp chamber was recorded. A repeated measures ANOVA and paired samples t-test were used for analysis of the data (p<0.05).

Results: EliparTM DeepCure-S groups exceeded the accepted critical temperature point of 5.6°C for Z250, Bulk Fill, and empty cavity (7.6±0.36, 7.44±0.7, and 5.81±1.6, respectively). None of the groups cured with Valo Cordless® reached the critical point (5.35±0.54, 5.44±0.41, and 5.02±0.89, respectively). The values in the different groups cured with Valo Cordless® were not significantly different (p≥0.05), but empty cavity showed significantly lower temperature values than the composite resin groups when the EliparTM DeepCure-S device was used (p<0.05).

Conclusion: The study demonstrated a correlation between the increased power of LED LCUs and pulp damage in restorative procedures.

Key words: Dental pulp, deciduous tooth, microcirculation, temperature, composite resins.

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Öz

Amaç: Restoratif materyallerin polimerizasyonu pulpal sıcaklığı artırma potansiyeline sahiptir ve pulpa dokusuna zarar verebilir. Çalışmanın amacı, süt dişi pulpal sıcaklık değişimini bir mikrosirkülasyon modeli kullanarak iki LED ışık cihazı (Valo Cordless®, EliparTM DeepCure-S) ve üç restoratif grup (Filtek™ Bulk Fill Flowable, Filtek™ Z250 Universal Restorative ve boş kavite) ile karşılaştırmaktır.

Gereç ve yöntem: On adet sağlam insan üst ikinci süt azı dişi kullanıldı. 1 mm dentin kalınlığı kalacak şekilde standardize Sınıf V kavite preparasyonları yapıldı ve restoratif gruplarda LED ışık cihazları kullanıldı. Pulpa odasındaki en yüksek sıcaklık noktası kaydedildi. Verilerin analizi için tekrarlı ölçümler ANOVA ve eşleştirilmiş örneklemler t-testi kullanıldı (p<0,05).

Bulgular: EliparTM DeepCure-S grupları, Z250, Bulk Fill ve boş kavite için kabul edilen kritik sıcaklık noktası olan 5,6°C'yi aştı (sırasıyla 7,6±0,36, 7,44±0,7 ve 5,81±1,6). Valo Cordless® ile ışık uygulanan grupların hiçbiri kritik noktaya ulaşmadı (sırasıyla 5,35±0,54, 5,44±0,41 ve 5,02±0,89). Valo Cordless® ile ışık uygulanan farklı gruplardaki değerler arasında anlamlı fark yoktu (p≥0,05), ancak EliparTM DeepCure-S cihazı kullanıldığında boş kavite, kompozit rezin gruplarına göre anlamlı derecede daha düşük sıcaklık değerleri gösterdi (p<0,05).

Sonuç: Çalışma, LED ışık cihazlarının artan gücü ile restoratif işlemlerde pulpa hasarı arasında bir ilişki olduğunu göstermiştir.

Anahtar kelimeler: Diş pulpası, süt dişi, mikrosirkülasyon, sıcaklık, kompozit rezinler.

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Introduction

Dental pulp is a mesenchymal origin soft tissue of teeth that includes nerves, vascular structures, fibers, interstitial fluids, odontoblasts, fibroblasts, and other minor cellular components. Despite the low thermal conductivity of dentin, the pulp is highly sensitive of thermal stimuli [1]. Many dental procedures such as cavity preparation [2], polymerization of restorative materials [3], and finishing/polishing procedures [4] have the potential to increase pulpal temperature. An increase in intrapulpal temperature may result in significant damage to the health of this tissue. A classical study [5] achieved on rhesus monkeys demonstrated a temperature rise of 5.6°C, resulting in irreversible pulpitis in 15% of subjects. Many research studies on pulpal temperature rise refer to this study and it can be said that the widely accepted clinically significant dangerous pulpal temperature increase threshold is 5.6°C [6-9].

The development of bulk-fill Resin-Based Composite (bulk-fill RBC) restorative materials is the most striking innovation of recent times in resin technology [10]. Traditionally, RBCs have been placed in the cavity using a layering technique of 2 mm increments to ensure essential light penetration and reduce polymerization shrinkage [11]. This method prolongs the completion of the restoration process and increases the risk of air bubbles between increments and fluid contamination [12]. A bulk-fill RBC depth increment of 4 to 10 mm could be polymerized in a relatively short time with an adequate light source [13]. The manufacturer explains that this curing time is due to the more potent initiator system or/and higher translucency [14]. The use of these materials could be an advantage when working with uncooperative patients, such as young children, due the shortened working time [15].

Dental visible light sources produce light belonging to the blue area of the electromagnetic spectrum to stimulate the photoinitiator and begin polymerization. An irradiation produced by those light sources is absorbed by the resin based restorations and results in high molecular vibration and heat generation [16]. This means that dental tissues are exposed to heat from two sources: the light energy of the light-curing units (LCUs) and the exothermic character of the polymerization reaction. Intrapulpal temperature changes are related to the characteristics of the LCUs, such as irradiance, wavelength, and curing time, as well as the characteristics of the composite, such as basic chemical base, shade, and filler content. Restoration size and tooth properties, including the quality and thickness of the remaining dentin, also affect intrapulpal temperatures [17].

About 40 years, halogen lamp technology that had been adapted from the airplane industry was the main light source used for curing dental resin composites [18, 19]. But in the last decade, LCUs using Light Emitting Diode (LED) technology have replaced Quartz-Tungsten-Halogen (QTH) devices [20]. LED has many distinct advantages: requires a low power, can be easily battery powered, no filament or optical filter, has a long lifetime source, and provides much greater photon-generating efficiency than any competitive light source [19]. Although the energy efficiency of these devices is high, they produce certain levels of heat.

The aim of this study is to investigate the temperature changes in the primary teeth pulp chamber of empty cavities and during the polymerization of a bulk-fill RBC and a microhybrid resin composite cured with two LED LCUs, aided by a microcirculation device originally designed and described in a study by Ertugrul et al. [21].

The specific objectives of this study are:

- To compare the maximum temperature rises between bulk-fill RBC and microhybrid resin composite.
- To compare the maximum temperature rises between two LED LCUs.
- To compare the maximum temperature rises between just radiant energy from LCUs and both radiant energy and exothermic reactions of composites.

Materials and methods

This study has been approved by the ethics committee of non-interventional clinical researchs of Pamukkale University. Ten intact caries-free human maxillary second primary molar teeth that had been extracted in the previous month were selected for the study. After the extraction of the teeth, the surface tissues and blood were removed under running water and cleaned of soft tissues with pumice slurry for this in-vitro study. The teeth were stored at +4°C in 0.2% thymol solution until use. Roots were separated and removed about 2 mm below the cementoenamel junction, perpendicular to the long axis of the teeth, and the apical part of the pulp chambers were enlarged using a water-cooled diamond bur. Then, all organic tissue scraps in the pulp chamber were gently removed retrograde by an excavator and cleaned with 5.25% sodium hypochloride solution and cotton pellets for one minute. The teeth were then rinsed with distilled water and air dried. Non-retentive buccal Class V cavity preparation was done in the primary teeth with water-cooling diamond fissure bur. The cavity dimensions were approximately 3 mm width, 2 mm height, and 2.5 mm depth. Cavity edges were slightly rounded. 1 mm±0.05 mm dentin thickness was left between the axial cavity floor and pulp chamber, which was assessed with a dial caliper (Yates-Motloid Co., Chicago, IL, USA).

To achieve the temperature measurements, a Pulpal Blood Microcirculation Model (PBMM) (Figure 1), originally designed and described in study of Ertugrul et al. [21] was used. A small diameter access was drilled on the lingual surfaces of the teeth into the pulpal chamber with a diamond bur to insert a thermocouple wire. A thermocouple wire (TT-K-30-SLE; Omega Engineering, Inc, Stanford, CT, USA) was inserted in the pulp chamber and placed on the axial wall of the tooth using a silicone heat-transfer compound (ZM-STG2; Zalman Tech Co. Ltd, Dongan-gu, South Korea). To position the thermocouple wire and to seal the gap between the drilled access point and wire, a light curing flowable composite (Filtek Ultimate Flowable Restorative, 3M ESPE, St. Paul, MN, USA) with a sixth generation two step self-etch bonding system (Clearfil SE Bond, Kuraray®, Tokyo, Japan) was applied and cured with an LED LCU (VALO Cordless®, Ultradent Products Inc., South Jordan, UT, USA) at a light intensity of 1.000 mW/cm². The other end of the thermocouple wire was connected to a four-channel data logger (DT-3891G; CEM, Shenzhen, PRC), which connected to a computer for monitoring temperature changes in the pulp chamber.

The characteristics of the composite materials and LED LCUs are summarized in tables 1 and 2, respectively. The experimental groups were designed as follows: Group Z-EDC: Filtek TM Z250 Universal Restorative + Elipar™ DeepCure-S, Group BF-EDC: Filtek™ Bulk Fill Flowable + Elipar™ DeepCure-S, Group E-EDC: Empty cavity + Elipar™ DeepCure-S, Group Z-VC: Filtek TM Z250 Universal Restorative + Valo Cordless®, Group BF-VC: Filtek™ Bulk Fill Flowable + Valo Cordless®, Group E-VC: Empty cavity + Valo Cordless®.

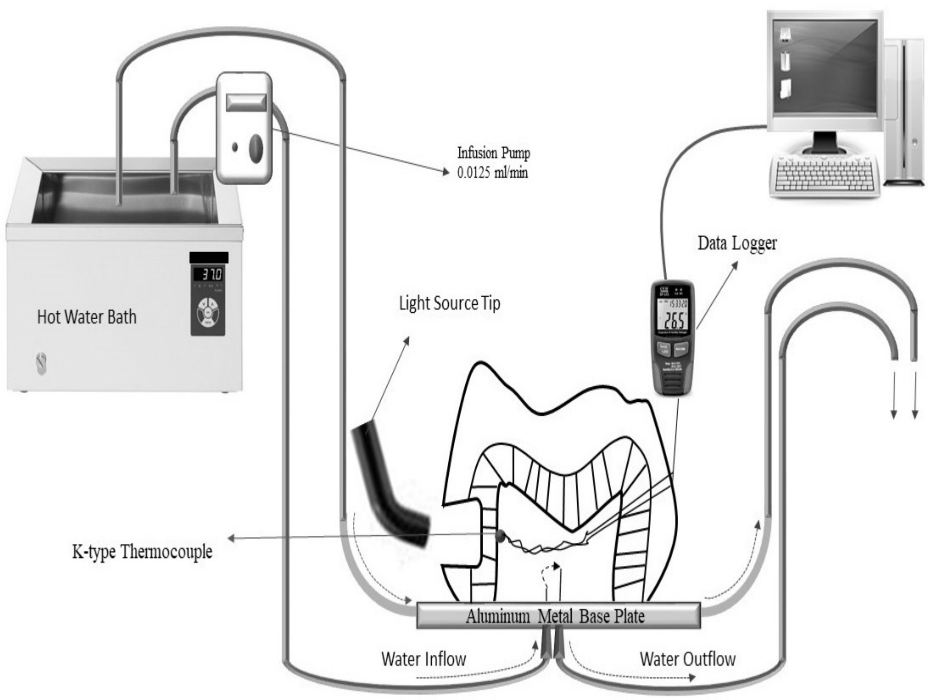

Figure 1. Schema of pulpal blood microcirculation model

Table 1. Characteristics of the composite materials used in this study

Composite materials	Composition	Manufacturer
Filtek™ Bulk Fill Flowable (A2 shade)	Bis-GMA, UDMA, Bis-EMA, procrylate resins, Ytterbium trifluoride, zirconia, silica (64.5 wt%, 42.5 vol%)	3M, ESPE, St. Paul, MN, USA
Filtek™ Z250 Universal Restorative (A2 shade)	Bis-GMA, Bis-EMA, TEGDMA, UDMA, zirconia, silica (82 wt%, 60 vol%)	3M, ESPE, St. Paul, MN, USA

Table 2. Characteristics of the light curing units used in this study

LCU	Light intensity in standard mode	Wavelength range	Lens diameter	Manufacturer
Valo Cordless®	1000 mW/cm²	385-515 nm	9.75 mm	Ultradent, South Jordan, UT, USA
Elipar™ DeepCure-S	1470 mW/cm²	430-480 nm	8.78 mm	3M Oral Care, St. Paul, MN, USA

The distilled water in the water bath was stabilized at 37°C and then circulation system commenced. Filtek™ Bulk Fill Flowable (A2) resin composite material was applied to the cavity on the buccal surface of the primary tooth on the aluminum base and polymerized for 20 seconds with the LED device Elipar™ Deep Cure-S with an irradiance of 1.470 mW/cm² (Figure 2). A measurement was then taken. With the assistance of a probe, the restoration was removed from the cavity and Filtek™ Z250 Universal Restorative was applied to the same cavity and cured with same LED device. A second measurement was then taken. Again, the restoration was removed with help of probe, and a third measurement taken on the empty cavity.

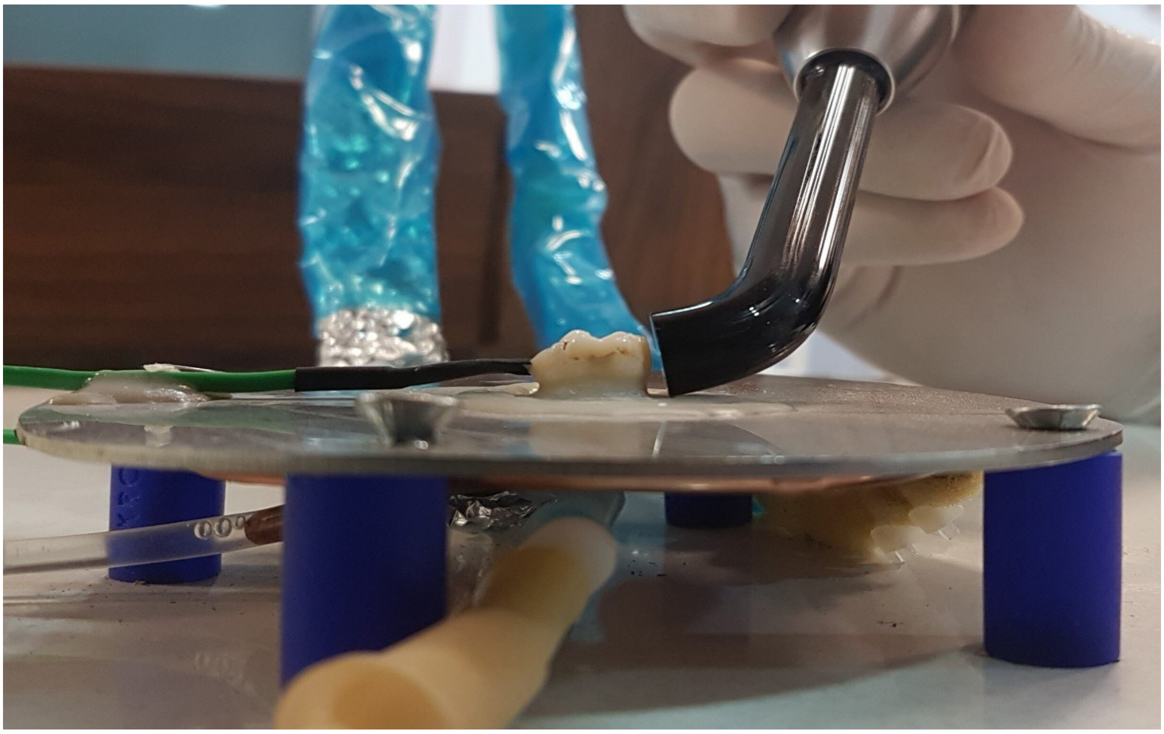

Figure 2. Light curing of restorative material on the aluminum base

On the same tooth, a Valo Cordless® was used with an irradiance of 1.000 mW/cm^2 and polymerization was performed for 20 seconds on the RBCs and empty cavity. After six temperature records, the tooth was removed. All ten teeth were adapted and tested using this same model and measurements were taken without etching and bonding. The distance between the light devices and the composites was set to 0 mm. The highest temperature point in the pulp chamber was recorded using software (Multiple Data Logger, AzeoTech, Inc, Ashland, Oregon, USA).

In the statistical analysis, the conformity of the data to the normal distribution was examined with the Shapiro-Wilk test. Parametric test conditions were satisfied, so repeated measures ANOVA and a paired samples t-test were used for comparing dependent groups with a SPSS program (SPSS version 23.0, IBM Corporation, Armonk, New York). The significance level was set to $p<0.05$ for all tests.

Results

Groups Z-EDC, BF-EDC, and E-EDC exceeded the accepted critical temperature point of 5.6°C (7.6±0.36, 7.44±0.7, and 5.81±1.6, respectively). None of the empty cavity and composite groups cured with the Valo Cordless® reached the critical point (5.35±0.54, 5.44±0.41, and 5.02±0.89). The highest temperature rise was the in Z-EDC group (8.2°C) and the lowest increment was in the E-EDC group (3°C). Both RBC groups (Z-EDC, and BF-EDC) cured with the Elipar™ DeepCure-S showed higher values than the groups cured with the Valo Cordless® (Z-VC, and BF-VC) ($p<0.05$). Within the Valo Cordless® ($p\geq0.05$) cured groups, the increase in temperature was not significant; however, the empty cavity group (E-EDC) showed significantly lower temperature values than the RBC groups (Z-EDC, and BF-EDC) using an Elipar™ DeepCure-S device ($p<0.05$) (Table 3).

Table 3. Average temperature rise values of the experimental groups and comparison (°C)

	Elipar™ DeepCure-S		**Valo Cordless®**		
	Mean±Std. Dev.	**Med (min - max)**	**Mean±Std. Dev.**	**Med (min - max)**	***p***
Filtek™ Z250 Universal (1)	7.6±0.36	7.6 (7-8.2)	5.35±0.54	5.45 (4.6-5.9)	0.0001* (t=11.741)
Filtek™ Bulk Fill Flowable (2)	7.44±0.7	7.6 (5.9-8.1)	5.44±0.41	5.5 (4.7-6)	0.0001* (t=7.081)
Empty cavity(3)	5.81±1.6	5.9 (3-7.8)	5.02±0.89	4.85 (3.9-6.6)	0.196 (t=1.397)
p	0.001* (F=10.241)(1-3, 2-3)		0.355 (F=1.096)		

Discussion

The thermal diffusivity of dentin is lower than that of enamel by 2.5 times [22]. Dentin acts as a barrier against heat, which is produced by the exothermic reaction of resin composites [23] and radiant exposure by LCUs [24]. However, in deep cavities where the amount of remaining dentin is low, these temperature increases can start coagulation and irreversibly damage the pulp. The amount of heat coming from the LCUs is determined by a number of factors including the light intensity, type of tip, and diameter of the tip [20].

In restorative dentistry, the utilization of LCUs using a high-energy output LED (LED-LCUs) has increased in recent years due to their shorter curing times and increased polymerization. Although the thickness of the composite and the remaining dental hard tissue provide some protection [25], the light source in polymerization processes is still considered the main risk to pulpal health [26].

Regardless of the expected output, different brands of LED-LCUs do not produce the same amount of heat. The light in the spectral distribution and the type and diameter of the LED-LCU tip used can affect heat generation [20]. The two contemporary LCUs used in this study are commercially available and widely used, but they emit light of different quantities and qualities. Valo Cordless® has three available power modes: standard, high, and extra power (1.000, 1.400, and 3.200 mW/cm^2, respectively).

These modes cure continuously for 20 seconds, 4 seconds, and 3 seconds, respectively. It has a 9.75 mm lens diameter and utilizable wavelength range of 385-515 nm. Elipar™ DeepCure-S has a single 1.470 mW/cm^2 power mode and pre-set cure times of 5, 10, 15, and 20 seconds, continuous mode (120 seconds), and tack cure mode. The lens diameter of this device is 8.78 mm, and it has a 430-480 nm wavelength range. Despite the differences in wavelength and tip diameters, the main reason for the measured average temperature difference seems to be that the devices emit different powers of light. Elipar™ Deepcure-S generates approximately 1.5 times more power than the Valo Cordless®, resulting in greater heat generation. One of the most important advantages of LED over QTH devices is that they are more energy efficient, producing more light and less heat [27]. With higher energy outputs (irradiance), there is a risk of increased temperature even with LED technology [28].

In this study, composite groups cured with the Elipar™ DeepCure-S had a significantly higher mean temperature rise compared to the empty cavity group, while no difference was observed in the Valo Cordless® groups. This may be related to the thermal insulation values of composite resins. Low thermal-conductive materials transfer less heat between materials compared to high thermal conductive materials.

Filtek™ Bulk Fill Posterior Restorative contains bisGMA, UDMA, bisEMA, and procrylat resins as its major composition. Filtek TM Z250 Universal Restorative contains bisGMA, TEGDMA, UDMA, and Bis-EMA [29]. In both Filtek™ Bulk Fill Flowable and Filtek TM Z250 Universal Restorative the major filler component is zirconia/silica filler with a particle size range of 0.01 to 3.5 µm [30]. Additionally, in Filtek™ Bulk Fill Flowable, zirconia/silica fillers are combined with ytterbium trifluoride (YbF_3) filler with a range of particle sizes from 0.1 to 5.0 µm. The inorganic filler loading is about 42.5% by volume and 64.5% by weight in Filtek™ Bulk Fill Flowable and slightly lower for Filtek TM Z250 at 60% volume and 82% weight [29, 30]. Composite resins that contain quartz or silica exhibit more thermal diffusivity, whereas radiopaque fillers such as strontium and barium provide lower thermal diffusivity [31, 32]. The silicate particles or zirconia-silica clusters in the composition of the composites have the potential to transfer more heat during polymerization [31]. In this study, although the composite resin groups exhibit higher temperature values compared with empty cavity groups, the values were not significantly different to the groups cured with the Valo Cordless®. Conversely, with the Elipar™ DeepCure-S device, although bulk-fill composite has a lower zirconia-silica content than Z250 composite, which provides increased temperature diffusion and contains YbF_3 to increase radiopacity, which provides low temperature diffusion, it gave similar temperature values to Z250. One of the potential reasons for this outcome may be the cavity dimensions and thickness of RBC used in this study.

A depth of 2.5 mm is suitable for Filtek™ Bulk Fill Flowable and its recommended maximum depth per increment is 4 mm. Regarding Filtek™ Z250 Universal Restorative, the recommended maximum depth is 2.5 mm in A2 shade. While the cavity design is optimal for bulk-fill composite, it is borderline for the Z250. As the thickness of the composite increases, the irradiation measured at the composite base decreases due to the decrease in light transmission [23, 33]. The conversion of carbon-carbon double bonds in monomers to carbon-carbon single bonds during the polymerization of the composite resin is an exothermic reaction. The degree of conversion is positively correlated with light intensity [34]. Thus, the decreased radiant heat and exothermic reaction, especially for the Z250 restorative due to the decreased light intensity, may have resulted in similar temperature increases for both composites at the bottom cavity surface. The deep cavity design and thick RBCs layer may have affected the polymerization reaction of Z250 and caused no significant difference in temperature because of the exothermic reaction, despite the lower zirconia-silica content of the bulk-fill composite. In a study by Shortall and Harrington [35], it was shown that the heat generated when light is applied to an empty cavity is greater than in the light curing of a 2 mm thick composite resin layer. This result is due to more heat being transferred during the polymerization of the adhesive layer compared to the composite resin. Guiraldo et al. [25] found that as the thickness of the light-cured composite resin increased, the temperature decreased significantly. This is due to the fact that the composite both absorbs some of the light and generates heat during polymerization, and reflects some of the light back. The decrease in the intensity of the light limits the temperature increase due to irradiation. The power of the light devices used in our study is higher than those used in the studies mentioned, and it seems that as the light power increases, the extenuating capacity of the material loses its importance. This result is consistent with the study by Mouhat et al. [20] which showed that there is a risk of pulpal damage if the irradiance exceeds 1.200 mW/cm^2 in the thin dentin layer.

In this study, the curing of the empty cavity does not fully simulate the polymerization of the adhesive layer. However, the fact that the critical temperature is exceeded when Elipar™ DeepCure-S is used in the empty cavity and the critical temperature is formed approximately half a degree below the critical temperature when Valo Cordless® is used, reveals the importance of using cement as a barrier for adhesive restorative procedures using high-power LED-LCUs in deep primary tooth cavities.

In this study, after the resin is placed on the primary molar tooth for composite resin groups, a small indentation was created by inserting the probe tip into the corner of the composite, which was then light cured. After the temperature measurement was taken, the probe tip was placed in the preformed recess and removed from the cavity, and the next composite material was tested by placing it with the same method. After testing the empty cavity, the primary tooth was removed from the model, a new primary tooth was adapted, and all procedures were repeated. The anatomical and physiological structures of the teeth are different from each other; the thickness of the hard tissue and diameters and numbers of the dentinal tubules are variable. Some in vitro studies examining the effect of dental procedures on pulpal temperature increase aimed to provide standardization by performing the whole experiment on a single tooth [36-39]. Since applications performed on a single tooth may produce results affected by the specific anatomical and ultrastructural features of that tooth, we used ten primary molars by changing the tooth used in each test circulation. Thus, the validity and reliability of the experiment increased and standardization was achieved.

In this study, the mean temperature rises in the pulp chamber ranged between 5.81 and 7.6˚C for the Elipar™ DeepCure-S groups and 5.02 and 5.44˚C for the Valo Cordless® groups. While the Elipar™ DeepCure-S groups were above the critical temperature of 5.6˚C, Valo Cordless® groups were slightly below this temperature. The groups that used the Elipar™ DeepCure-S in high power mode were above the critical temperature of 5.6˚C, whereas the Valo Cordless® groups were close to but below this temperature. This indicates that there is a correlation between the increased power of LED-LCUs and pulpal damage in restorative procedures applied to primary teeth, and that 1.000 mW/cm^2 in the thin dentin layer may be a critical power threshold for pulpal tissue health. In addition, the absence of a significant difference in temperature increase between microhybrid and bulk-fill RBC polymerization used in the study shows that bulk-fill RBCs can be used within safety limits in primary teeth with the use of appropriate LCUs.

Within the limitations of the study, it was found that the high output power of LED-LCUs in deep primary tooth cavities may pose a threat to pulpal health. There was no difference in measured temperature between bulk-fill and microhybrid RBCs.

Conflicts of interest: No conflict of interest was declared by the authors.

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Authors' contributions to the article

Y.E. and I.F.E. have constructed the main idea and hypothesis of the study. Y.E. and I.F.E. developed the theory and arranged the material and method section. Y.E. and I.F.E. have done the evaluation of the data in the Results section. Discussion section of the article written by Y.E. and I.F.E. reviewed, corrected and approved. In addition, all authors discussed the entire study and approved the final version.