American Journal of
Experimental and Clinical Research

Am J Exp Clin Res 2022;9(1):454-458

Original Article

Effect of high-powered LED and dentin thickness on intrapulpal temperature rise in primary teeth

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Abstract. Temperature rise in the pulp chamber is a severe stress that can cause irreversible damage to the pulp. The objective of this study was to compare the temperature rise under primary teeth dentin induced by Light Emitting Diode (LED[1]) with different light curing modes. Thirty dentin discs of 0.5- and 2-mm thickness were prepared from human primary molars. Resin composite placed in an acrylic cavity was cured using a high-powered LED (Foshan JERRY Medical Apparatus CO., LTD, Foshan, China) for 20s. The different modes tested in this study were standard mode, ramp mode, and pulse mode (n=5). Temperature was recorded using a k-type thermocouple in direct contact with the dentin disc. Temperature change data were subjected to analysis of variance (ANOVA) and Tukey's test. The highest temperature rise was observed under 0.5 mm thick dentin disc with standard mode (4.7 ± 0.42), whereas the lowest values were recorded with pulse mode under 2 mm thick dentin (2.5 ± 0.23). Pulse mode produced significant lower temperature rise compared to standard mode in both dentin thicknesses ($P < 0.05$). Ramp mode gave significantly lower values compared to standard mode in 0.5 mm group ($P < 0.05$). For standard and ramp modes, temperature rise decreased with the increase of the dentin thickness ($P < 0.05$). Maximum temperature rise induced by high-powered LED was not critical for pulpal health. Temperature rise related to dentin thickness and curing modes. Pulse mode gave the lowest values.

Keywords: Composites, curing mode, dentin, photo-polymerization, primary teeth

Introduction

The heat generation is a severe stress produced in the pulp chamber by various operative procedures [1]. Studies have suggested that polymerization of resin composite could cause increasing of the pulp chamber temperature [2]. Excessive temperature rise can result in irreversible damage to the pulp [3]. Although the critical value of pulp damage is not unified by all studies [4, 5], Zach and Cohen [6] reported that 5.5 ◦C increase in the pulp temperature caused necrosis of 15% of the tissue, on the basis of a study using rhesus monkey teeth.

Several factors affect the temperature rise during polymerization such as dentin thickness [7], radiant exitance [8], exposure time [9], chemical composition and transmission properties of resin composite [10-12].

Recently, new Light Emitting Diodes Light Curing Units (LEDs, LCUs) were introduced with high radiant exitance, ranging from approximately 500 to 1,400 mW/cm^2. This raised concern that temperature rise during resin composite polymerization using high-powered LED could cause pulpal damage [2, 13], especially when used in deep cavities with minimal residual dentin thickness [14].

Historically, standard mode at constant radiant exitance was used for polymerization of resin composites [15]. However, several curing modes have received attention from recent developments because they are allowing movement within the resin matrix that would reduce polymerization shrinkage [16]. Studies have suggested that heat emitted by the curing lights depends on the various curing modes used [7]. Previous studies have inserted thermocouples into the pulp chamber to measure temperature rise [17], but the thermocouple could not be incorporated to record whole pulp chamber temperature [18].

On the other hand, temperature rise of the pulp chamber may be different between primary and permanent teeth because of difference in degree of dentin mineralization [19], tubular density and diameter [20]. Larger dentinal tubular structures of the primary teeth than those of the permanent teeth may increase the permeability of primary teeth and makes them more susceptible to thermal stimuli [21].

When using high-powered LEDs in primary dentition, it is important to select the correct polymerization mode that will not cause a harmful overheating of the pulp. In view of this concern, the purpose of this in vitro study was to evaluate the effect of three different curing modes of a high-powered LED LCU on the increase in temperature under primary teeth dentin during polymerization of the resin composite.

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The null hypotheses of this study: There were no significant differences in temperature rise (1) among curing mode, and (2) dentin thickness.

Materials and Methods

This study was approved by the Research Ethics Committee of the Faculty of Dentistry, University of Hama, Hama, Syrian Arab Republic (No: 659 – 28\04\2021).

Resin composite

One microhybrid resin composite in the shade A3 was used; Filtek Z 250 (3M Dental Products, St Paul, MN, USA).

Dentin discs preparation

Thirty dentin discs of 0.5- and 2-mm thickness were prepared from caries-free primary molars, freshly extracted for physiological root resorption reasons. Every molar was sectioning perpendicular to its long axis below the occlusal enamel to expose the dentin with a water-cooled saw. Then dentin discs were obtained by sectioning perpendicular to the long axis of the tooth and kept in saline until use. A Mylar strip was placed onto the resin composite, then the resin composite was polymerized using one of three modes.

LED LCU

The resin composite was cured with a high-powered LED LCU JR-CL 17 (classic) (Foshan JERRY Medical Apparatus CO., LTD, Foshan, China). Output of the LED 800-1200 mW/cm^2 according to manufacturer. The output of the LED determined in this study was 1100 mW/cm^2 by radiometer LM-1 (Woodpecker®, Guangxi, China).

This LED emits light with three protocols: standard, ramp, and pulse. Radiant exitance increasing from 0 to 1100 mW/cm^2 for 5 s and thereafter in full strength of 1100 mW/cm^2 for 15 s in the ramp mode. The pulse mode consisted of irradiation with 1100 mW/cm^2 for 0.75 s and a 0.25 s pause alternating for 20 s.

Temperature test apparatus

To standardize measurements, we used a modified apparatus from that developed by Hubbezoglu et al [15] (Fig. 1). The apparatus consists of concentric cylinder and disc constructed from acrylic resin. The acrylic resin mold cylinder had a central cavity of 1 mm depth and 3 mm diameter to place the dentin disc. Beneath the center of this cavity there was a duct of 1 mm diameter for thermocouple wire insertion. The acrylic resin disc was placed above the cylinder. This disc had a central hole of 2 mm depth and similar diameter to the diameter of the central cavity of the cylinder. The resin composite was directly placed in this hole onto the dentin disc which was not treated with bonding agents.

Temperature measurement

Five specimens of resin composite of each dentin thickness were polymerized using one of the three curing modes for 20 s (n = 5). All experiments were done in a constant temperature of 14±1°C. To record temperature rise value during the polymerization of resin composite, we used K-type thermocouple connected to a digital thermometer

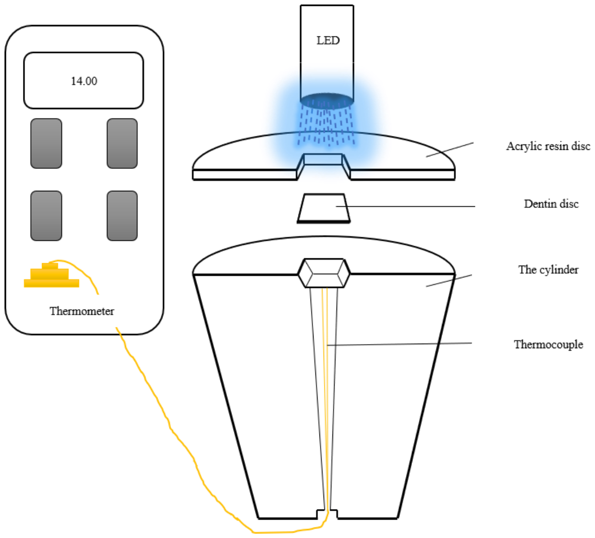

Figure 1 Temperature test apparatus

(TES®, Taipei, Taiwan).

The dentin disc was placed in the central cavity of the cylinder without treating with bonding agents. Then the acrylic resin disc was placed onto the cylinder, and its central hole was filled with the resin composite and then covered with a Mylar strip. The LED tip was positioned on the Mylar strip.

Temperature rise was recorded at two levels:

1. Baseline temperature following temperature stabilization (14±1°C) T_1.
2. Maximum temperature during polymerization of resin composite T_2.

To obtain the temperature rise ΔT, $T_1$was deducted from T_2.

Statistical analysis

Data that were obtained were analyzed using the statistical software IBM SPSS version 25 (SPSS, Inc., Chicago, IL, USA), temperature rise data were subjected to statistical analysis among the LED curing modes and dentin thicknesses using two-way analysis of variance (ANOVA). Statistically significant interactions were followed up with post hoc analyzes (Tukey's HSD test) at a significance level of 0.05.

Results

The means and standard deviations of temperature rise values of the dentin discs were listed in Table 1. Two-way ANOVA revealed significant differences in temperature rise values ($F=8.724$) according to curing mode ($p=0.000$) and dentin thickness ($p=0.000$). The lowest values were recorded with pulse mode in both dentin thicknesses, whereas dentin thickness of 0.5 mm exhibited the highest mean values in temperature rise (Fig. 2).

According to the results of Tukey's test, pulse mode produced significantly lower temperature rise values than those of standard mode with the same dentin thickness ($p<0.05$). In 0.5 mm thick group, the temperature rise values

Table 1. Means and Standard Deviations of temperature rise values (°C) for each dentin thickness and curing mode tested.

TABLE 1
MEANS AND STANDARD DEVIATIONS OF TEMPERATURE RISE VALUES OF THE DENTIN DISCS

Curing mode	Dentin thickness			
	0.5		2	
	M	SD	M	SD
Standard	4.780	0.4207	3.5	0.6819
Ramp	4.1	0.4527	3.14	0.5594
Pulse	3.22	0.3701	2.52	0.2387

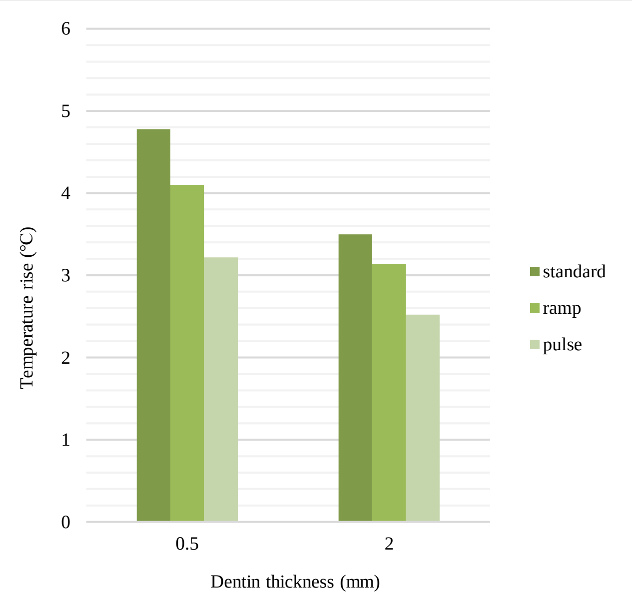

Figure 2 Results of temperature rise (°C) for the experimental groups

recorded for standard mode were significantly higher than those of ramp mode ($p<0.05$), while there were no statistically significant differences between standard mode and ramp mode in 2-mm-thick ($p>0.05$).
Examine differences between pulse mode and ramp mode revealed that pulse mode produced significant temperature rise values in 0.5-mm-thick ($p<0.05$). While in 2 mm thick group there was no significant deference between pulse mode and ramp mode.

A statistically significant direct proportion was found between the mean temperature rise values and the dentin thickness ($p<0.05$) in samples cured with standard and ramp mode.

Discussion

Resin composites are a common filling material because of their aesthetic qualities. However, the filling material should be harmless for dental pulp as well as aesthetic [22]. Several factors can contribute to temperature rise in the pulp chamber during dental procedures, including remaining dentin thickness, curing mode, and light energy per unit area [7, 23, 24]. In this in vitro study, an attempt was made to examine the effect of three different curing modes of a high-powered LED LCU on temperature rise under human primary teeth dentin with different thicknesses during resin composite polymerization.

A one microhybrid resin composite with shade A3 was used to eliminating any possible variation in thermal conductivity [25]. Moreover, a resin composite specimen size of 2 mm thickness was selected to be clinically practical [26]. We used exposure times of 20 s in all groups according to resin composite manufacturer instructions [27]. According to Hannig and Bott [13] there were no statistically significant differences between temperature rise of the pulp chamber during composite resin polymerization with and without previously applied bonding agent. We relied on these results as justified to perform our experiments without use bonding agent.

Many in vitro studies have used non-carious dentin to measure temperature rise during polymerization of resin composite [28, 29]. In this study, caries-free primary molars with physiological root resorption were used, although structural changes of primary teeth dentin may be affecting the temperature transmitted to the pulp [30, 31]. However, young caries-free primary teeth cannot be obtained from an ethical point of view [23].

In the current study, K-type thermocouple was used based on previous studies, which have stated that it is an appropriate technique to measurement of temperature changes [32]. We placed the light guide tip in direct contact with the resin composite. The resin composite was also in direct contact with dentin. In addition, high-powered LED was used to cure resin composite specimens. These factors boost heat of reaction. Therefore, this study represents a worst-case situation for temperature rise during polymerization of resin composite, especially with little dentin thickness groups.

Zach and Cohen [6] stated that 5.5°C is the critical value to pulp damage. The peak values recorded in this study were lower than 5.5°C in all conditions. This could be attributed to LEDs are photonic devices based on semiconductors that convert electrical energy into radiation of light [33], and do not generate infra-red rays [12]. Based on the results of this study, it may be suggested that high-powered LED could be used safely in primary teeth with similar clinical situations.

In the current study, the mean temperature rise of the dentin discs was affected by various curing modes. Our results indicate the peak temperature measured with the ramp curing mode was lower than that observed with the standard mode. These results agreed with the work of Al-Qudah et al [34] who recorded significantly lower temperature values when using Optilux 501 (Kerr, Peterborough, UK) in the ramp mode as compared with the standard mode.

The light energy produced by the curing related to exposure time and radiant exitance [35]. Loney and Price [36] observed that the energy produced by LCUs is a main factor for the different temperature rises of the different polymerization modes. Aguiar et al [37] reported that standard mode caused lower temperature rise than ramp mode in a study using third molar dentin. It may be because of high radiant exitance of the ramp mode (1280 mW/cm^2) compared to the standard mode (560 mW/cm^2) in their study.

The ramp mode used in this study began at radiant exitance of 0 to the maximum power (1100 mW/cm^2) for 5 s. Thus, there was no enough time for the suppression of the heat. This could explain why the ramp mode exhibited higher temperature rise than the pulse mode.

The lowest temperature rise under dentin was recorded with the pulse mode. These data were in agreement with those of Hubbezoglu et al [15] who evaluated the effect of three curing modes on temperature rise in permanent teeth dentin during polymerization of six resin composites and their bonding agents. They observed that pulse mode gave lower temperature rise values than soft-start and standard modes in all conditions. However, the values obtained were lower than those of the current study, which could be due to the short exposure time they used.

Our results do not agree with Chang et al [38] who studied temperature rise during polymerization of resin composite with six modes. They reported that the pulse mode caused no significantly higher temperature rise (58.6 ℃) than standard mode (51 ℃), which could be due to settings of the LCU used in that study.

The second part of the study investigated the effect of increasing dentin thickness on the recorded temperature rise. According to Guiraldo et al [39] dentin thickness is a critical factor that influences the amount of heat reaching the pulp, because of the low thermal conductibility of dentin [35]. The present study confirmed this because differences were observed in the temperature rise between dentin thicknesses. Our study reported that the temperature rise with dentin thickness of 2 mm were significantly lower than those with dentin thickness of 0.5 mm ($p<0.05$) in the standard and the ramp mode groups, although there was no statistically significant difference in the temperature rise between dentin thickness in the pulse mode group ($p>0.05$).

The results of our study show that the effects of curing modes on temperature rise were statistically significant. The first null hypothesis has been rejected that there were no significant differences in temperature rise among curing mode. With respect to the dentin thickness, we found a statistically significant difference between the two thicknesses in samples cured with standard or ramp mode. In this respect, the second null hypothesis has been partially rejected.

The limitation of this study is the thermocouple method, which will alter the temperature recording accuracy because it involves contact with the surface tested [34]. In addition, this study neglected the regulatory role of pulpal microcirculation which acted as a refrigerant to heat [40]. Thus, it did not fully mimic in vivo conditions.

Further studies should be performed to confirm the safety of high-powered LED during polymerization of bonding agents.

Under the limitations of the present study, it may be concluded that:

1. Temperature rise during polymerization of resin composite with the high-powered LED appeared to be below 5.5 ℃. Hence, it is safe for use in pediatric dentistry.
2. Standard mode led to significantly higher temperature rise under thinner dentin than others modes.
3. Pulse mode allows the target to cool between light pulses so it recommended to use in deep cavities.
4. Dentin is an important normal structure protect the pulp from thermal damage.

Acknowledgements

This work was supported by University of Hama, Hama, Syrian Arab Republic (grant numbers 837, 2021).

Conflict of interest

The authors declare no conflicts of interest

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