Effect of light curing modes of high-powered LEDs on temperature rise under primary teeth dentin (an in vitro study)

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Abstract

Background.

Temperature rise in the pulp chamber is a severe stress that can cause irreversible damage to the pulp. This study aimed to evaluate the effect of three curing modes of a high-powered LED and two remining dentin thicknesses on the temperature rise under primary teeth dentin.

Methods.

One dentin disc of 1 mm thickness was prepared from human primary molar. The dentin disc was exposed to curing light using a high-powered LED for 10 s to simulate bonding agent polymerization (stage 1 curing). Five specimens of resin composite were cured for 20 s. The different modes tested were standard, ramp, and pulse mode (n = 5). After that, the dentin disc was adapted to 0.5 mm thick, and the experiments were repeated. Temperature change data were subjected to analysis of variance (ANOVA) and Tukey's test.

Results.

The highest temperature rise was observed under the 0.5-mm-thick dentin disc with standard mode (7.6 ± 0.2; 4.7 ± 0.4), whereas the lowest values were recorded with pulse mode under 1-mm-thick dentin (2.7 ± 0.1; 2.5 ± 0.2) during stage 1 curing and resin composite polymerization, respectively. Pulse mode produced significantly lower values than standard mode in all conditions ($P < 0.05$). An inverse proportion was found between the mean temperature rise values and the dentin thickness.

Conclusions.

High-powered LEDs should not be used to cure bonding agents in deep cavities. The maximum temperature rise induced by a high-powered LED during resin composite polymerization was not critical for pulpal health. Temperature rise related to dentin thickness and curing modes.

Background

Resin composites are widely used in dentistry for esthetic restoration of anterior and posterior teeth.[1] Previous studies have recorded an increase in pulp chamber temperature of a few degrees during polymerization of resin composites with traditional light curing units (LCUs).[2] More recently, a newer generation of light emitting diodes (LEDs) was introduced to reduce the time required to apply resin composite restorations.[2] These newer LCUs have a radiant exitance of above 1,000 mW/cm^2. Research has shown that the high radiant exitance of LCUs could cause an excessive increase in the pulp chamber temperature,[3] and that the vitality of the pulp tissue may be at risk if there is an increase in temperature exceeding 5.5 °C;[4] therefore, high-powered LEDs may be a potential risk factor for thermal damage to pulpal tissue.[5, 6]

In addition to the radiant exitance, there are several factors affecting the temperature rise during polymerization of resin composites such as residual dentin thickness,[7] exposure time,[8] chemical composition and transmission properties of resin composite,[9–11] and the degree of dentin mineralization.[12] Although primary teeth have dentin with a lower degree of mineralization compared to permanent teeth dentin,[13] larger dentinal tubular structures of the primary teeth than those of the permanent teeth may increase the permeability of primary teeth and make them more susceptible to thermal stimuli.[14] Therefore, there was a need to conduct studies on primary teeth due to the inability to rely on the results of studies conducted on permanent teeth.

Historically, standard mode at constant and full strength radiant exitance was used for polymerization of resin composites.[15] However, LEDs have different alternative curing modes, such as pulse mode, which allows movement within the resin matrix and reduces polymerization shrinkage.[16] Previously published results are inconsistent with regard to the effect of curing modes on the heat generated by LEDs. Some studies have shown that alternative curing modes generate lower heat than the standard mode,[17, 18] while other studies have shown completely different results.[19–21] Although the results of previous studies are useful for understanding the effect of curing modes on the temperature rise, the vast majority of them were concluded from experiments that used several extracted teeth. In fact, the thermal conductivity of dentin differs among teeth came from different individuals;[22] therefore, the results of these studies may be questionable.

When using high-powered LEDs in pediatric dentistry, it is important to select the correct curing mode that will not cause harmful overheating of the pulp. Therefore, the purpose of this in vitro study was to answer the following question: Is it possible that alternative curing modes be a less harmful alternative to the pulp of primary teeth than the standard mode? by studying the rise of dentin temperature accompanying the procedures of applying resin composite. Additionally, the effect of remining dentin thickness on this variable was also evaluated. The null hypotheses of this study were as follows: there were no significant differences in temperature rise (1) among curing modes, and (2) dentin thickness.

Methods

This study was performed in accordance with the Declaration of Helsinki. Informed consent was obtained from the parents of the child.

Resin composite

One resin composite, Filtek Z 250 (3 M Dental Products, St Paul, MN, USA), was used. It is a microhybrid resin composite designed for the restoration of anterior and posterior teeth and is available in a variety of shades. In this study, shade A3 was used.

Preparation of specimens

One dentin disc was prepared from a caries-free primary lower second molar with a thickness of 1 mm. The primary molar was extracted for physiological root resorption reasons and stored in distilled water in accordance with ISO/TS 11405:2015.[23] The molar was sectioned perpendicular to its long axis with a slow speed saw (Isomet®, Buehler, Lake Bluff, Illinois, USA) below the occlusal enamel to expose the dentin and then was sectioned at the roof of the pulp chamber level; thus, a block composed of enamel and dentin was obtained. At that point, we obtained the dentin discs by sectioning perpendicular to the long axis of the block using a high-speed handpiece (Bing®, Tawa, Wellington, New Zealand) and diamond bur, and the thickness of the dentin disc was adjusted by wet carborundum paper (American Rotary Tools Company, Inc., California, USA) to 1 mm. After all the experiments were performed on the dentin disc with a thickness of 1 mm, wet carborundum paper was used to adapt the dentin disc thickness to 0.5 mm, and then the same experiments were repeated with this new thickness.

LED LCU

One high-powered LED LCU was used, JR-CL 17 (classic) (Foshan JERRY Medical Apparatus CO., LTD, Foshan, China), with three curing modes. (Table 1) shows the properties of the LED used.

Table 1
The properties of LED JR-CL 17 (classic).

LED JR-CL 17 (classic)			
Output according to manufacturer	Output determined in this study [a]	Curing modes	
800–1200 mW/cm^2	1100 mW/cm^2	Standard	continuous irradiation at full strength
		Ramp	Radiant exitance gradually increasing for 5 s and thereafter at full strength
		Pulse	curing cycle consist of irradiation at full strength for 0.75 s and a 0.25 s pause

[a] The output was determined by radiometer LM-1 (Woodpecker®, Guangxi, China).

Temperature test apparatus

A modified apparatus from that developed by Hubbezoglu et al[15] was used to standardize measurements (Fig. 1). The apparatus consists of two concentric cylinders constructed from acrylic resin matrix, which has a thermal conductivity compared with that of dentin.[24, 25] The lower acrylic resin mold cylinder had a central cavity of 1 mm depth and 3 mm diameter to place the dentin disc and a duct of 1 mm diameter beneath the center of the central cavity for thermocouple wire insertion. A central hole of 2 mm depth and

3 mm diameter was made at the center of the upper acrylic resin mold cylinder to place the resin composite directly onto the dentin disc, which was not treated with bonding agents.

Temperature measurement

For each dentin thickness, five specimens of resin composite were polymerized using one of the three curing modes ($n = 5$). A baseline temperature was established at a constant value (14 ± 1°C) for 5 min before each measurement. The dentin disc was covered with cotton moistened with distilled water until the disc reached the baseline temperature without dehydration. To record temperature rise values, we used a K-type thermocouple connected to a digital thermometer (TES-1300 digital thermometer, TES electrical electronic corp., Taipei, Taiwan).

The dentin disc was placed in the central cavity of the lower cylinder, and the upper cylinder was placed above the lower cylinder. Then, it was exposed to curing light for 10 s using one of the three curing modes to stimulate bonding agent polymerization. The distance between the light guide tip and dentin disc was 2 mm and maintained using the height of the upper cylinder. After that, the dentin disc was allowed to return to the baseline temperature. During this time, the dentin disc was covered with moist cotton to maintain moisture. The central hole of the upper cylinder was filled with the resin composite and then covered with a Mylar strip. The LED tip was positioned on the Mylar strip, and the resin composite was polymerized for 20 s using the same curing mode used previously.

The temperature rise during irradiation was measured at two stages: after the dentin disc was exposed to curing light (stage 1 curing) and after the resin composite was polymerized (stage 2 curing). For each stage, the temperature rise value ΔT was obtained by deducting the baseline temperature from the maximum temperature recorded (Additional file 1).

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 analyses (Tukey’s HSD test) at a significance level of 0.05.

Results

The means and standard deviations of the temperature rise values of the dentin discs are listed in (Table 2). Two-way ANOVA revealed significant differences in temperature rise values according to curing mode (stage 1 and stage 2 curing) and dentin thickness (stage 1 curing). However, there was no significant difference according to dentin thickness during stage 2 curing (Table 3). The lowest values were recorded with pulse mode during resin composite polymerization, whereas the thickness of 0.5 mm exhibited the highest mean values in temperature rise during stage 1 curing (Fig. 2).

Table 2
Means and standard deviations of temperature rise values (°C) for each dentin thickness and curing mode tested

Curing mode	**Dentin thickness**							
	Stage 1 curing				**Stage 2 curing**			
	0.5		1		0.5		1	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Standard	7.60	0.234	7.06	0.594	4.78	0.4207	4.6	0.641
Ramp	7.52	0.217	6.56	0.182	4.1	0.4527	3.84	0.391
Pulse	6.32	0.443	4.80	0.458	3.22	0.3701	3.16	0.829

Table 3
The Results of Two-way ANOVA Performed on the curing mode and dentin thickness

Stage 1 curing					
	df	**Sum Sq**	**Mean Sq**	**F value**	**Sig.**
curing mode	2	18.025	9.012	60.418	0.000
dentin thickness	1	7.6	7.6	50.952	0.000
Stage 2 curing					
curing mode	2	11.256	5.628	19.078	0.000
dentin thickness	1	0.208	0.208	0.706	0.409

According to the results of Tukey's test, pulse mode produced significantly lower temperature rise values than standard and ramp modes with the same dentin thickness during stage 1 curing ($p < 0.05$). There were no significant differences between standard mode and ramp mode with the same dentin thickness ($p > 0.05$).

Examine differences among curing modes during resin composite polymerization revealed that pulse mode produces a significantly lower temperature rise than standard and ramp modes in the 0.5 mm thick group ($p < 0.05$), while there was no significant difference between standard and ramp modes in that thick group ($p > 0.05$). Significantly higher temperature rise values were recorded with standard mode than with pulse mode in the 1 mm thick group ($p < 0.05$). However, there were no statistically significant differences between values recorded with ramp mode and values recorded with standard and pulse mode in the 1 mm thick group ($p > 0.05$).

An inverse proportion was found between the mean temperature rise values and the dentin thickness regardless of the curing stage and curing mode. In stage 1 of curing, the 0.5 mm thick group exhibited a significantly higher temperature rise than the 1 mm thick group in samples exposed to ramp mode and pulse mode ($p < 0.05$). However, there were no significant differences between dentin thicknesses in samples exposed to standard mode, and during polymerization of resin composite regardless of curing mode used ($p > 0.05$).

Discussion

Resin composites have been introduced as an esthetic restorative material[26] and are increasingly used in place of amalgam for the restoration of teeth suffering from carious lesions.[27] According to the AAPD,[28] there is strong evidence supporting the use of resin composites for restoration of Class I cavities in primary teeth. However, polymerization of light-cured materials can cause an increase in pulp chamber temperature, negatively affecting the health of the pulp.[29] Studies have suggested that the temperature rise during the polymerization of resin composites depends on the heat generated by curing light and the exothermic polymerization of resin composites.[30] Savas et al[29] found that heat generated by curing light is the crucial factor causing a temperature rise in the pulp chamber. The aim of the current study was to examine the effect of three different curing modes of a high-powered LED LCU on the temperature rise under human primary teeth dentin with two different thicknesses during resin composite application procedures regardless of the heat generated by the exothermic polymerization reaction.

In an attempt to simulate the pulpal microcirculation, previous studies have inserted a thermocouple into the pulp chamber through the root; therefore, the exact position of the thermocouple is unknown.[6] Moreover, the radiography technique that has been used to determine the thickness of the dentin above the thermocouple cannot accurately determine it,[2] especially when the thickness of the dentin is 1 mm or less. The technique of temperature measurement presented in the current study contributed to the deletion of many variables. As the same cavity with the same depth and shape was used, the amount of composite placed each time was similar. According to ISO/TS 11405:2015[23] it is not possible to standardize the composition and structure of the teeth, which may influence the temperature rise.[22] To eliminate this variable, only one dentin disc obtained from one primary tooth was used to perform the experiments. Moreover, a primary lower second molar was chosen to obtain the dentin disc, in light of previous studies that have indicated that the lower second molar is the most vulnerable primary tooth to be affected by caries.[31] The thickness of the resin composite selected was 2 mm to be clinically practical.[32] Additionally, a one microhybrid resin composite with shade A3 was used to eliminate any possible variation in thermal conductivity.[33] Hannig & Bott[6] stated that the presence or absence of the bonding agent will not affect the temperature rise accompanying the polymerization of the resin composite. The experiments were carried out without applying the bonding agent to facilitate repetition of experiments on the same dentin disc. Loney et al[34] demonstrated that a thinner thickness of remining dentin increases temperature changes. Accordingly, we decided to perform our study on two thicknesses of dentin that simulate the thickness of the remaining dentin in the deep cavities. Leprince et al[35] stated that the exposure time has an important effect on the temperature rise value. Therefore, we standardized the exposure time during stage 1 curing (10 s) and during the polymerization of the composite resin (20 s) according to the manufacturer's instructions.[36]

A K-type thermocouple was used to measure temperature in the present study based on previous studies, which have suggested that it is an appropriate technique to measure temperature changes at a specific point.[37] In the current study, a high-powered LED was used to cure resin composites placed in direct contact with dentin. The light guide tip was also in direct contact with the resin composite. In addition, the thickness of the dentin disc was little. Therefore, this study represents a worst-case situation for temperature rise during polymerization of resin composite in primary teeth.

Zach & Cohen[4] stated that 5.5°C is the critical limit that allows continued vitality of the pulp. In the current study, in stage 1 of curing with 0.5 mm thick dentin, the high-powered LED produced an excessive increase in the temperature above the critical temperature value regardless of the curing mode used. With the dentin thickness of 1 mm, exposure to the standard and ramp modes also led to a temperature rise above the critical value, while exposure to the pulse mode resulted in a rise in temperature below the critical value. Our results confirm the findings of previous studies that have suggested that bonding agents should not polymerize with high intensity light.[38] Regarding this aspect, it should be taken into account that the high temperature rise values recorded in this study may be a potential risk factor that prevents the continuation of the vitality of the dental pulp when the remining dentin is of little thickness.

Exposing the dentin to the pulse mode resulted in a statistically significant lower temperature rise than the other two modes, which was probably due to the pause phases between the irradiation phases. We found it difficult to compare the results of the stage 1 curing with the previous literature due to the lack of studies that dealt with the thermal properties of binding agents.[39] However, our result agreed with the work of Dogan et al[17] who recorded significantly lower temperature rise values for pulse mode compared with standard mode in a study performed on human permanent teeth dentin with thicknesses of 0.5 and 1 mm.

It is interesting that we observed a decrease in the temperature rise values recorded during the polymerization of the resin composite compared to those recorded during stage 1 curing (polymerization of bonding agents). This may be explained by the ability of the composite resin to reduce the penetration of light into the dentin.[32] The peak values recorded during resin composite polymerization were lower than 5.5°C under all conditions. This could be attributed to LEDs not generating infrared rays.[11] Based on the results of the current study, we can suggest that it is possible to use high-powered LEDs as a safe alternative to traditional LEDs for polymerization of the composite resin in primary teeth with similar clinical situations.

The lowest temperature rise under the dentin disc during polymerization of the resin composite was recorded with the pulse mode. These data were in agreement with those of Hubbezoglu et al[15] who studied the effect of standard, soft-start, and pulse modes on the temperature rise during the polymerization of six resin composites. They observed that pulse mode gave lower temperature rise values than other modes. However, the values recorded were lower than those of the current study, which could be due to the short exposure time (10 s) they used.

Szalewski et al[40] measured the temperatures following polymerization of resin composites with seven curing modes (four continuous modes with exposure times of 3-5-10 and 20 s, two pulse modes with exposure times of 5 and 10 s, and soft-start mode). an acrylic resin matrix was used to apply the resin composites. When one exposure time was used (5, 10 s), they found that the continuous mode and pulse mode produced similar temperature rise values (14, 15.5 °C respectively). These results do not agree with those of our study, which may be because that study neglected the effect of dentin on temperature rise. Another study revealed no significantly higher temperature rise for pulse mode than standard mode during polymerization of bulk-fill composite placed in a cavity prepared in Teflon blocks.[20] We can explain the difference between our results and the results of that study by the difference in the value of the radiant exitance of the LCUs used. The authors used two different radiant exitances for standard mode (600 mW/cm^2) and pulse mode (1200 mW/cm^2), while the same radiant exitance was used in the current study. The temperature rise during polymerization of the composite resin is related to the degree of conversion,[41] and therefore, the lower values of temperature recorded with pulse mode can be clarified by the failure of the pulse mode to achieve the same degree of polymerization obtained with standard mode.

Polymerization of the resin composite with ramp mode produced no significant lower temperature rise than standard mode. These results disagreed with the work of Al-Qudah et al[18] who recorded significantly lower temperature values when using Optilux 501 (Kerr, Peterborough, UK) in ramp mode than in standard mode. This can be related to differences in the exposure time between the ramp mode (20 s) and the standard mode (40 s) they used.

The second part of the current study investigated the effect of dentin thickness on the recorded temperature rise. Studies have suggested that dentin thickness is a critical factor that influences the amount of temperature rise in the pulp chamber[42] because of the low thermal conductibility of this normal structure.[43] The present study confirmed this because differences were observed in the temperature rise between dentin thicknesses. Our study found that the temperature rise of dentin with a thickness of 1 mm was significantly lower than that with a thickness of 0.5 mm during stage 1 curing in samples exposed to ramp mode or pulse mode. However, there was no statistically significant difference in the temperature rise between dentin thicknesses during polymerization of resin composite regardless of curing mode ($p > 0.05$). Guiraldo et al[42] evaluated the temperature rise in the pulp chamber during polymerization of Filtek P90 silorane-based composite placed in a cavity prepared in bovine teeth with two remining dentin thicknesses (0.5 and 1 mm), and they found a significantly higher temperature rise in 0.5 mm dentin thickness (40.07ºC) than 1 mm dentin thickness (39.61ºC). These results disagree with those of the present study and may be due to the different temperature curves of silorane-based composites when compared with those of dimethacrylate-based composites.[44]

The first null hypothesis of the present study has been rejected that there were no significant differences in temperature rise among curing modes due to the statistically significant difference observed in temperature rise among curing modes. Regarding the thickness of the dentin, a statistically significant difference was found between the 1 mm dentin thickness when compared with the 0.5 mm thick groups in samples exposed to ramp mode and pulse mode during stage 1 curing; therefore, the second null hypothesis has been partially rejected.

This study presented an in vitro experiment to measure the temperature rise accompanying the procedures of applying resin composite, but this study has several limitations that do not allow its results to be applied directly to clinical conditions such as blood microcirculation and the cellular and intercellular matrix of pulpal tissue, which acted as a refrigerant to heat.[45] Even though this study has limitations for being performed without applying bonding agents, the results can be considered clinically relevant.

Further studies should be performed to confirm the safety of the fast curing mode of high-powered LEDs during the polymerization of resin composites.

Conclusions

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

1. High-powered LED should not be used for polymerization of bonding agents when remining dentin thickness is 0.5- mm
2. The temperature rise during polymerization of the resin composite with the high-powered LED appeared to be below 5.5 °C. Hence, it appears to be safe for use during the restoration of primary teeth.
3. The pulse mode led to a significantly lower temperature rise than the other modes regardless of dentin thickness. This may be because it allows the target to cool between light pulses, so it is recommended for use in deep cavities.
4. Dentin thickness is an important factor to protect the pulp from thermal damage.

Abbreviations

LED: Light Emitting Diode; LCU: Light Curing Unit; AAPD: American Academic of Pediatric Dentistry.

Declarations

Authors' contributions

OJ: Methodology, software. Formal analysis, Data Curation, Investigation, Writing - Original Draft, Visualization, Project administration. RA: Conceptualization, Validation, Resources, Writing - Review & Editing, Supervision.

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Competing interests

The authors declare that they have no competing interests with regards to authorship and/or publication of this article.

Ethics approval and consent to participate

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). Informed consent was obtained from the parents of child. Permission to use the primary molar was obtained from the University of Hama. All methods were performed in accordance with the relevant guidelines and regulations.

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Figures

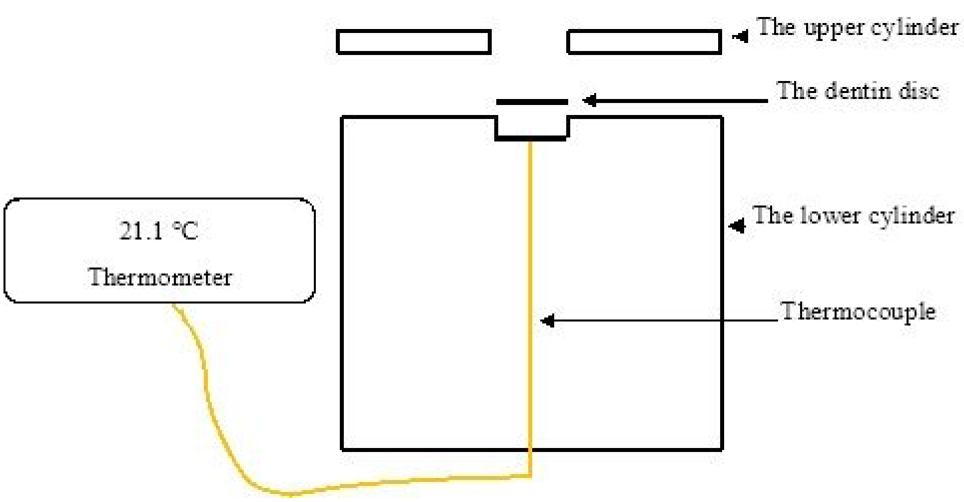

Figure 1

Schematic diagram showing a cross-section of the temperature test apparatus

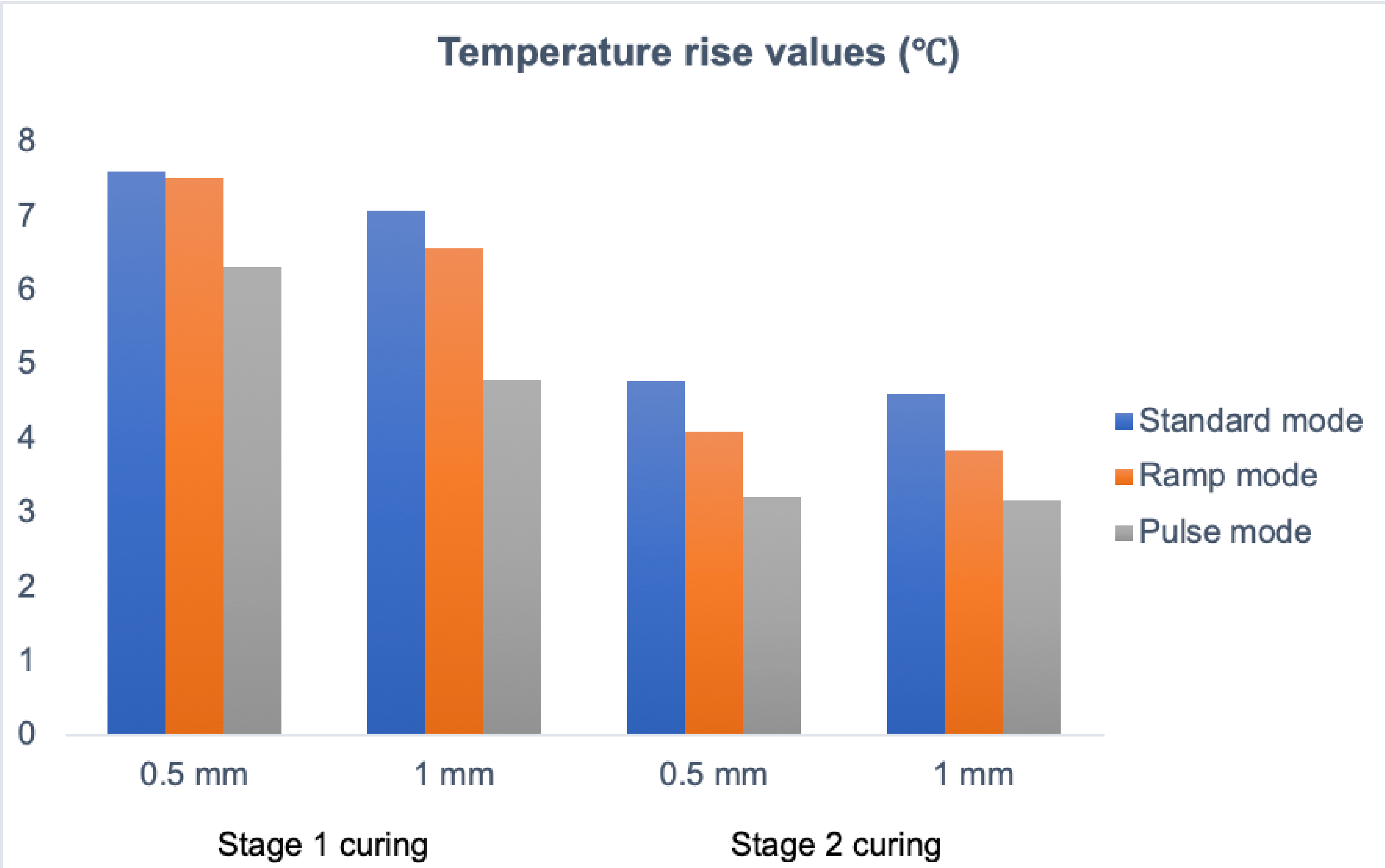

Figure 2

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

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