What is the Impact of Light Curing Modes of High-Powered LED on Temperature rise in Primary Teeth Dentin: An In Vitro Study

Obada Jabbour (Drobj96@gmail.com)
University of Hama
Reem Alfares
University of Hama

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Abstract

Background: 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 tooth dentin induced by a light emitting diode (LED) with different light curing modes.

Methods: Sixty dentin discs of 0.5- 1- 1.5- and 2-mm thicknesses were prepared from human primary molars. The resin composite placed in a Teflon cavity was cured using a high-powered LED (Foshan JERRY Medical Apparatus CO., LTD, Foshan, China) for 20 s. 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.

Results: The highest temperature rise was observed under a 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 a significantly lower temperature rise than standard mode for all dentin thicknesses ($P < 0.05$). Ramp mode gave significantly lower values than standard mode in the 0.5 mm group ($P < 0.05$). For the standard and ramp modes, the 0.5 mm thick group exhibited a higher temperature rise than the 2 mm thick group ($P < 0.05$).

Conclusions: Temperature rise related to dentin thickness and curing modes. The standard mode led to a significantly higher temperature rise under thinner dentin than the other modes. Pulse mode gave the lowest values. Thus, it is recommended for use in deep cavities.

Clinical Significance: 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 in pediatric dentistry.

Background

Heat generation is a severe stress produced in the pulp chamber by various operative procedures [1]. Studies have suggested that polymerization of resin composites could cause an increase in the pulp chamber temperature [2]. An 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 a 5.5 °C increase in 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 composites [10-12].

Recently, new Light Emitting Diode Light Curing Units (LEDs, LCUs) have been introduced with high radiant exitance, ranging from approximately 500 to 1,400 mW/cm^2. This raised concern that a temperature rise during resin composite polymerization using a 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 allow movement within the resin matrix that would reduce polymerization shrinkage [16]. Studies have suggested that the heat emitted by curing lights depends on the various curing modes used [7]. Previous studies have inserted thermocouples into the pulp chamber to measure the temperature rise [17], but the thermocouple could not be incorporated to record the whole pulp chamber temperature because this system could particularly measure the temperature of quit localized point locations [18]. Moreover, the remaining dentin thickness was assessed by radiographs, so the results of those studies may be questionable.

Although a considerable body of research has investigated the temperature rise in permanent teeth, less attention has been given to primary teeth. The temperature rise of the pulp chamber may be different between primary and permanent teeth due to differences in the 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 make 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 harmful overheating of the pulp. Many studies have evaluated the effect of high-powered LEDs on the temperature rise, but findings obtained from studying a specific brand should not be generalized to other brands. In view of this concern, the purpose of this in vitro study is twofold. The first is to evaluate the effect of three different curing modes of a high-powered LED LCU on the increase in temperature under primary tooth dentin during polymerization of the resin composite. The second is to assess the impact of dentin thickness on the temperature rise.

The null hypotheses of this study were as follows: There were no significant differences in temperature rise (1) among curing modes and (2) among dentin thicknesses.

Materials And Methods

Resin composite:

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

Dentin disc preparation:

Sixty dentin discs of 0.5- 1- 1.5- and 2-mm thicknesses were prepared from caries-free primary molars freshly extracted for physiological root resorption reasons. Every molar was sectioned perpendicular to its long axis with a slow speed saw (Isomet®, Buehler, Lake Bluff, Illinois, USA) at two levels: the first level below the occlusal enamel to expose the dentin, and the second level above the roof of the pulp chamber, so we obtained a block composed of enamel and dentin. A square with a side length of 3 mm was drawn on the pulpal surface of the block; then, this square was cut with a high-speed handpiece and diamond bur passing perpendicular to the square's sides to remove the enamel and obtain a block of dentin. The dentin block was fixed to a hard, plane surface, and its thickness was adjusted by diamond burs. Finally, the surfaces of the dentin disc were grinded with wet carborundum paper (American Rotary Tools Company, Inc, California, USA) until they were even and smooth when inspected visually, and then placed in distilled water in accordance with ISO/TS 11405; 2015.

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 the 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. The radiant exitance increased from 0 to 1100 mW/cm^2 for 5 s and thereafter at a full strength of 1100 mW/cm^2 for 15 s in 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 a concentric cylinder and disc constructed from Teflon. The Teflon 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 Teflon disc was placed above the cylinder. This disc had a central hole of 2 mm depth and a diameter similar to the diameter of the central cavity of the cylinder. The resin composite was directly placed in this hole onto the dentin disc to standardize the amount of resin composite sample.

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 performed at a constant temperature of 14±1°C. To record the temperature rise value during the polymerization of the resin composite, 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 cylinder without treatment with bonding agents. Then, the Teflon 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.

The 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, T1 was deducted from T_2 (Additional file 1).

Statistical analysis:

Data that were obtained were analysed 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 presented 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 all 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, the standard mode produced significantly higher temperature rise values than those of pulse mode with the same dentin thickness ($p<0.05$). The temperature rise values recorded for standard mode were not significantly higher than those of ramp mode with the same dentin thickness ($p>0.05$).

Examine differences between pulse mode and ramp mode revealed that pulse mode produced significant temperature rise values in the 0.5- mm- thick group ($p<0.05$). At other thicknesses, there were no significant differences between pulse mode and ramp mode ($p>0.05$).

An inverse proportion was found between the mean temperature rise values and the dentin thickness. A statistically significant difference was recorded when comparing the 2 mm thick group with the 0.5- and 1-mm thick groups in samples cured with standard mode and between the 2 mm thick group and the 0.5 mm thick group in samples cured with ramp mode ($p<0.05$). However, there were no significant differences among dentin thicknesses in samples cured with pulse mode ($p>0.05$).

Table 1 Means and standard deviations of temperature rise values (°C) for each dentin thickness and curing mode tested

Curing mode	Dentin thickness							
	0.5		1		1.5		2	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Standard	4.78	0.4207	4.6	0.641	4.3	0.609	3.5	0.6819
Ramp	4.1	0.4527	3.84	0.391	3.66	0.439	3.14	0.5594
Pulse	3.22	0.3701	3.16	0.829	2.9	0.447	2.52	0.2387

Discussion

Resin composites are a common filling material due to 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 the temperature rise under human primary tooth dentin with different thicknesses during resin composite polymerization.

A one microhybrid resin composite with shade A3 was used to eliminate any possible variation in thermal conductivity [25]. Moreover, a resin composite specimen with a thickness of 2 mm was selected to be clinically practical [26]. We used exposure times of 20 s in all groups according to resin composite manufacturer instructions [27]. This study aimed to directly investigate the increase in temperature during resin composite polymerization. Therefore, the dentin discs were not treated with binding agents. According to Hannig and Bott [13] there were no statistically significant differences between the temperature rise of the pulp chamber during composite resin polymerization with and without a previously applied bonding agent.

Many in vitro studies have used noncarious dentin to measure the temperature rise during polymerization of resin composites [28, 29]. In this study, caries-free primary molars with physiological root resorption were used, although structural changes in primary tooth dentin may affect 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, a K-type thermocouple was used based on previous studies, which have stated that it is an appropriate technique to measure temperature changes [32] due to the accuracy of the measurement at a specific point [18]. 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, a high-powered LED was used to cure resin composite specimens. These factors boost the 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.

The work of Zach and Cohen [6] stated that 5.5°C is the critical value for pulp damage. The peak values recorded in this study were lower than 5.5°C in all conditions. This could be attributed to LEDs being photonic devices based on semiconductors that convert electrical energy into light radiation [33] and do not generate infrared rays [12]. Based on the results of this study, it may be suggested that high-powered LEDs 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 that there were no significant differences between ramp mode and standard mode. These results disagreed with the work of Al-Qudah et al. [34], 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 standard mode (40 s) they used.

The light energy produced by the curing is related to the 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 increases of the different polymerization modes. Aguiar et al. [37] studied the temperature rise under third molar dentin. They obtained dentin disks from human third molars with thicknesses of 1, 2 and 3 mm. Then, they cured a 2 mm thick layer of composite with five curing modes. Their results showed that the standard mode caused a lower temperature rise than the ramp mode. This may be due to the 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 not enough time for the suppression of the heat. This could explain why the ramp mode exhibited a higher temperature rise than the pulse mode.

The lowest temperature rise under dentin discs 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 the temperature rise in permanent tooth dentin during the 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 (10 s) they used.

Our results do not agree with Chang et al. [38], who studied the temperature rise during polymerization of a flowable resin composite placed in a Teflon block with six modes. They reported that the pulse mode caused no significantly higher temperature rise (58.6 °C) than the standard mode (51 °C), which could be due to the settings of the LCU used in that study, as the radiant exitance of the pulse mode (1200 mW/cm^2) is twice what it is in the standard mode (600 mW/cm^2).

The lower rise in temperature recorded with pulse mode is related to pause phases between the irradiation phases. These lower values of temperature may be explained by the failure of the pulse mode to achieve the same degree of polymerization obtained with standard mode. In this manner, the results of this study suggest that the pulse mode produced a lower temperature rise and produced a less polymerized resin composite.

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, due to the low thermal conductibility of dentin [35]. The present study confirmed this because differences were observed in the temperature rise among dentin thicknesses. Our study reported that the temperature rise of dentin with a thickness of 2 mm was significantly lower than those with thicknesses of 0.5 mm and 1 mm in samples cured with the standard ($p<0.05$). When the resin composite was cured with ramp mode, we observed that dentin discs with a thickness of 0.5 mm exhibited a significantly higher temperature rise than the 2 mm thick group. However, there was no statistically significant difference in the temperature rise between dentin thickness when resin composite cured with pulse mode ($p>0.05$).

In view of physics, thermal diffusivity is the ratio of thermal conductivity to volumetric heat capacity and the density of the material [40]. Studies have suggested that the pulse mode allows slower formation of polymeric chains due to the pause phases, which means that polymerization of resin composites with pulse mode results in lower cross-link density and lower heat capacity [41], so that the ability of resin composites to dissipate heat during polymerization increases. This could be explained by the fact that the pulse mode produced the lowest values of temperature rise, and no significant rise in temperature among the different thicknesses of dentin.

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 modes. With respect to the dentin thickness, we found a statistically significant difference between 2 mm dentin thickness when compared with 0.5- and 1-mm thick groups in samples cured with standard and between 2 mm thickness when compared with 0.5 mm thick groups in samples cured 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 acts as a refrigerant to heat [42]. Additionally, a cavity made from Teflon molds was used instead of a cavity prepared in human teeth. Thus, it did not fully mimic in vivo conditions.

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

Conclusions

Under the limitations of the present study, few conclusions can be drawn:

1. 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 in pediatric dentistry.
2. The standard mode led to a significantly higher temperature rise under thinner dentin than the other modes.
3. Pulse mode allows the target to cool between light pulses, thus it is recommended for use in deep cavities.
4. Dentin is an important normal structure that protects the pulp from thermal damage.

Abbreviations

LED: Light Emitting Diode; LCU: Light Curing Unit.

Declarations

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 all parents or legal guardians of children. Permission to use the primary teeth was obtained from the University of Hama. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication: Not applicable.

Availability of data and materials:

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

OJ: Methodology, software. Formal analysis, Data Curation, Investigation, Writing - Original Draft, Visualization, Project administration.

RA: Conceptualization, Validation, Resources, Writing - Review & Editing, Supervision.

All authors read and approved the final manuscript.

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References

1. Kodonas K, Gogos C, Tziafa C. Effect of simulated pulpal microcirculation on intrachamber temperature changes following application of various curing units on tooth surface. J Dent 2009;37:485-90. doi: 10.1016/j.jdent.2009.03.006.

2. Jo S-A, Lee C-H, Kim M-J, Ferracane J, Lee I-B. Effect of pulse-width-modulated LED light on the temperature change of composite in tooth cavities. Dental Materials 2019;35:554-63. doi:

3. Guiraldo RD, Consani S, Mastrofrancisco S, Consani RL, Sinhoreti MA, Correr-Sobrinho L. Influence of light curing unit and ceramic thickness on temperature rise during resin cement photo-activation. Bull Tokyo Dent Coll 2008;49:173-8. doi: 10.2209/tdcpublication.49.173.

4. Gross DJ, Dávila-Sánchez A, Runnacles P, et al. In vivo temperature rise and acute inflammatory response in anesthetized human pulp tissue of premolars having Class V preparations after exposure to Polywave® LED light curing units. Dent Mater 2020;36:1201-13. doi: 10.1016/j.dental.2020.05.015.

5. Runnacles P, Arrais CA, Pochapski MT, et al. In vivo temperature rise in anesthetized human pulp during exposure to a polywave LED light curing unit. Dent Mater 2015;31:505-13. doi: 10.1016/j.dental.2015.02.001.

6. Zach L, Cohen G. PULP RESPONSE TO EXTERNALLY APPLIED HEAT. Oral Surg Oral Med Oral Pathol 1965;19:515-30. doi: 10.1016/0030-4220(65)90015-0.

7. Rajesh Ebenezar AV, Anilkumar R, Indira R, Ramachandran S, Srinivasan MR. Comparison of temperature rise in the pulp chamber with different light curing units: An in-vitro study. J Conserv Dent 2010;13:132-5. doi: 10.4103/0972-0707.71644.

8. Atai M, Motevasselian F. Temperature rise and degree of photopolymerization conversion of nanocomposites and conventional dental composites. Clin Oral Investig 2009;13:309-16. doi:

10.1007/s00784-008-0236-2.

9. Murchison DF, Moore BK. Influence of curing time and distance on microhardness of eight light-cured liners. Oper Dent 1992;17:135-41. doi:

10. Chung KH, Greener EH. Correlation between degree of conversion, filler concentration and mechanical properties of posterior composite resins. J Oral Rehabil 1990;17:487-94. doi: 10.1111/j.1365-2842.1990.tb01419.x.

11. Knezević A, Tarle Z, Meniga A, Sutalo J, Pichler G, Ristić M. Degree of conversion and temperature rise during polymerization of composite resin samples with blue diodes. J Oral Rehabil 2001;28:586-91. doi: 10.1046/j.1365-2842.2001.00709.x.

12. Schneider LF, Consani S, Correr-Sobrinho L, Correr AB, Sinhoreti MA. Halogen and LED light curing of composite: temperature increase and Knoop hardness. Clin Oral Investig 2006;10:66-71. doi: 10.1007/s00784-005-0028-x.

13. Hannig M, Bott B. In-vitro pulp chamber temperature rise during composite resin polymerization with various light-curing sources. Dent Mater 1999;15:275-81. doi: 10.1016/s0109-5641(99)00047-0.

14. Bouillaguet S, Caillot G, Forchelet J, Cattani-Lorente M, Wataha JC, Krejci I. Thermal risks from LED- and high-intensity QTH-curing units during polymerization of dental resins. J Biomed Mater Res B Appl Biomater 2005;72:260-7. doi: 10.1002/jbm.b.30143.

15. Hubbezoglu I, Dogan A, Dogan OM, Bolayir G, Bek B. Effects of light curing modes and resin composites on temperature rise under human dentin: an in vitro study. Dent Mater J 2008;27:581-9. doi: 10.4012/dmj.27.581.

16. Yap AU, Soh MS. Thermal emission by different light-curing units. Oper Dent 2003;28:260-6. doi:

17. Baroudi K, Silikas N, Watts DC. In vitro pulp chamber temperature rise from irradiation and exotherm of flowable composites. Int J Paediatr Dent 2009;19:48-54. doi: 10.1111/j.1365-263X.2007.00899.x.

18. Hamze F, Ganjalikhan Nasab SA, Eskandarizadeh A, Shahravan A, Akhavan Fard F, Sinaee N. Thermal Scanning of Dental Pulp Chamber by Thermocouple System and Infrared Camera during Photo Curing of Resin Composites. Iran Endod J 2018;13:195-99. doi: 10.22037/iej.v13i2.18756.

19. da Silva EM, Penelas AG, Simão MS, Filho JD, Poskus LT, Guimarães JG. Influence of the degree of dentine mineralization on pulp chamber temperature increase during resin-based composite (RBC) light-activation. J Dent 2010;38:336-42. doi: 10.1016/j.jdent.2009.12.007.

20. Gindri LD, Fröhlich TT, Rosso CR, Rocha RO. Etching time and bonding of adhesive systems to dentin of primary teeth: A systematic review and meta-analysis. Int J Paediatr Dent 2021;31:122-30. doi:

10.1111/ipd.12711.

21. Agematsu H, Abe S, Shiozaki K, et al. Relationship between large tubules and dentin caries in human deciduous tooth. Bull Tokyo Dent Coll 2005;46:7-15. doi: 10.2209/tdcpublication.46.7.

22. Gul P, Celik N, Ozgeris FB, Demirkaya-Miloglu F, Kiziltunc A, Seven N. Effects of Bisphenol A Released From Composite Fillings on Reproductive Hormone Levels in Men. Int Dent J 2021;71:343-51. doi: 10.1016/j.identj.2020.12.008.

23. Buyukkok C, Kaptan A. Temperature increases in primary teeth pulp chamber during polymerization of glass ionomer-based restorative materials. Eur Oral Res 2021;55:28-33. doi: 10.26650/eor.20210024.

24. Uhl A, Völpel A, Sigusch BW. Influence of heat from light curing units and dental composite polymerization on cells in vitro. J Dent 2006;34:298-306. doi: 10.1016/j.jdent.2005.07.004.

25. Uhl A, Mills RW, Jandt KD. Polymerization and light-induced heat of dental composites cured with LED and halogen technology. Biomaterials 2003;24:1809-20. doi: 10.1016/s0142-9612(02)00585-9.

26. Shortall AC, Harrington E. Temperature rise during polymerization of light-activated resin composites. J Oral Rehabil 1998;25:908-13. doi: 10.1046/j.1365-2842.1998.00336.x.

27. 3M ESPE Dental Products. Instructions for Use Filtek Z250, 2014 Available from: https://multimedia.3m.com/mws/media/219552O/3m-filtek-z250-universal-restorative-instructions.pdf Accessed 13 April 2022]

28. Hosaka K, Kubo S, Tichy A, et al. Clinical effectiveness of direct resin composite restorations bonded using one-step or two-step self-etch adhesive systems: A three-year multicenter study. Dent Mater J 2021;40:1151-59. doi: 10.4012/dmj.2020-428.

29. Dogan A, Hubbezoglu I, Dogan OM, Bolayir G, Demir H. Temperature rise induced by various light curing units through human dentin. Dent Mater J 2009;28:253-60. doi: 10.4012/dmj.28.253.

30. Koutsi V, Noonan RG, Horner JA, Simpson MD, Matthews WG, Pashley DH. The effect of dentin depth on the permeability and ultrastructure of primary molars. Pediatr Dent 1994;16:29-35. doi:

31. Mjör IA. Dentin-predentin complex and its permeability: pathology and treatment overview. J Dent Res 1985;64 Spec No:621-7. doi: 10.1177/00220345850640042O.

32. Ohmoto K, Taira M, Shintani H, Yamaki M. Studies on dental high-speed cutting with carbide burs used on bovine dentin. J Prosthet Dent 1994;71:319-23. doi: 10.1016/0022-3913(94)90475-8.

33. Jandt KD, Mills RW. A brief history of LED photopolymerization. Dent Mater 2013;29:605-17. doi: 10.1016/j.dental.2013.02.003.

34. Al-Qudah AA, Mitchell CA, Biagioni PA, Hussey DL. Effect of composite shade, increment thickness and curing light on temperature rise during photocuring. J Dent 2007;35:238-45. doi: 10.1016/j.jdent.2006.07.012.

35. Unsal KA, Karaman E. Effect of Additional Light Curing on Colour Stability of Composite Resins. Int Dent J 2021. doi: 10.1016/j.identj.2021.06.006.

36. Loney RW, Price RB. Temperature transmission of high-output light-curing units through dentin. Oper Dent 2001;26:516-20. doi:

37. Aguiar FH, Barros GK, Lima DA, Ambrosano GM, Lovadino JR. Effect of composite resin polymerization modes on temperature rise in human dentin of different thicknesses: an in vitro study. Biomed Mater 2006;1:140-3. doi: 10.1088/1748-6041/1/3/008.

38. Chang HS, Cho KJ, Park SJ, et al. Thermal analysis of bulk filled composite resin polymerization using various light curing modes according to the curing depth and approximation to the cavity wall. J Appl Oral Sci 2013;21:293-9. doi: 10.1590/1678-775720130036.

39. Guiraldo RD, Consani S, Consani RL, et al. Comparison of silorane and methacrylate-based composites on the polymerization heat generated with different light-curing units and dentin thicknesses. Braz Dent J 2013;24:258-62. doi: 10.1590/0103-6440201301904.

40. Lin M, Xu F, Lu TJ, Bai BF. A review of heat transfer in human tooth—experimental characterization and mathematical modeling. Dental Materials 2010;26:501-13. doi:

41. Soh M, Yap AU. Influence of curing modes on crosslink density in polymer structures. J Dent 2004;32:321-26. doi:

42. Runnacles P, Arrais CAG, Maucoski C, Coelho U, De Goes MF, Rueggeberg FA. Comparison of in vivo and in vitro models to evaluate pulp temperature rise during exposure to a Polywave® LED light curing unit. J Appl Oral Sci 2019;27:e20180480. doi: 10.1590/1678-7757-2018-0480.

Figures

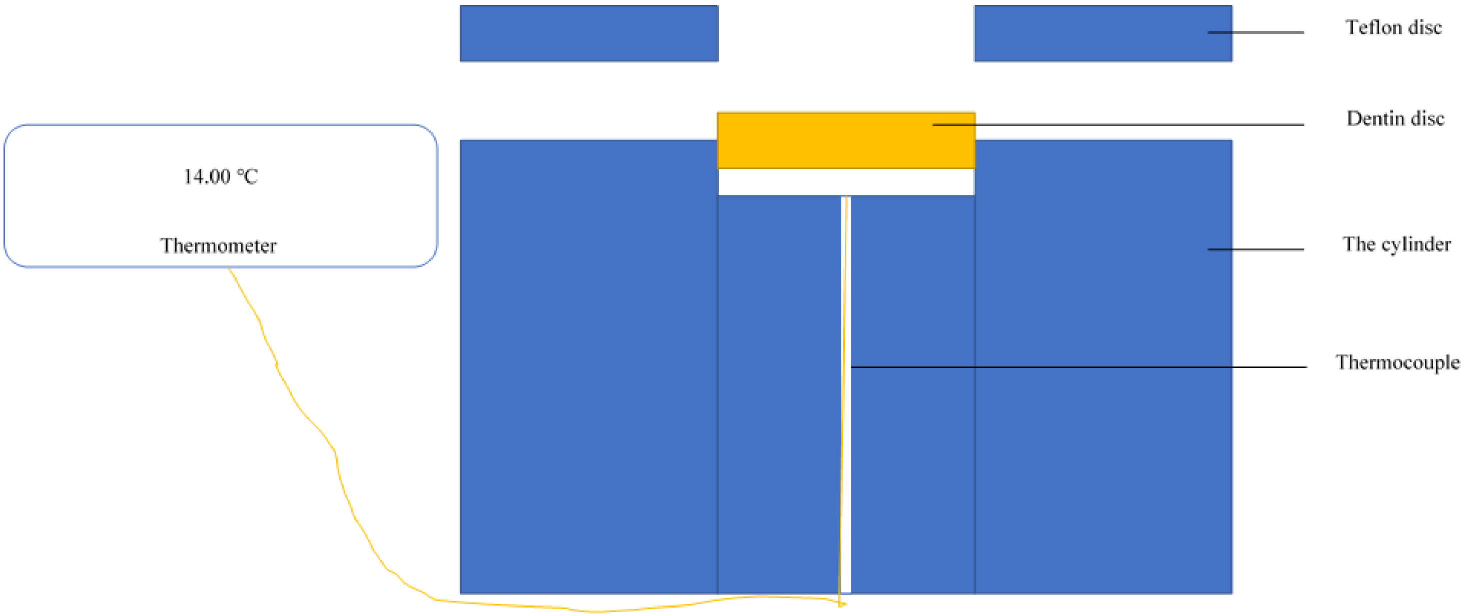

Figure 1

Temperature test apparatus

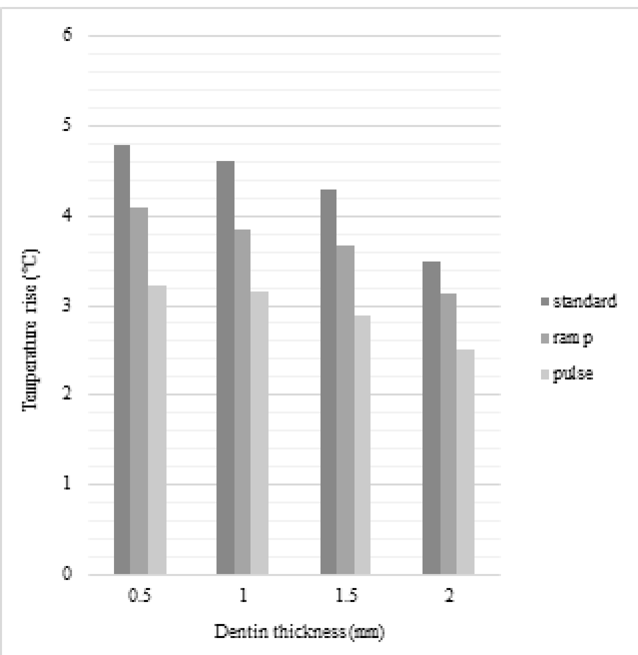

Figure 2

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

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