Thermal Change on the Tooth Surface and in the Pulp Chamber Caused by the Illumination of Intraoral Scanners and Light-Curing Units, an In Vitro Study

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Abstract

This study investigated pulp chamber changes in temperature during high-intensity illumination from light-curing units and intraoral scanners in extracted lower first premolar teeth with alternating tooth material thickness.

Twenty extracted lower first premolars were included. The pulp tissue was removed by cutting the root off and pulling it out. Three thermocouple probes of type K (0.50 mm tip diameter) were attached to the buccal, lingual surface and inserted in the pulp chamber to measure temperature change during 30 seconds of illumination. The tips of LCU and IOSs were positioned 2.00 mm apart from the buccal surface. The signals from a thermocouple probe were amplified and recorded using a digital oscilloscope and laptop computer. The cavity was prepared at the buccal surface with a step of 0.50 mm until achieving a final depth of 2.00 mm. The depth of the cavity was measured using a digital calliper. All data were compared statistically with two-way repeated measures ANOVA, multiple comparisons, and Pearson's correlation.

The pulpal probe detected the increasing temperature by approximately 6.59±0.65°C for LCU, 1.58±0.19°C for IOS1 and 1.71±0.19°C for IOS2 when illuminated on the buccal surface. When the remaining dentin thickness was decreased from 2.77±0.44 mm to 0.76±0.44 mm, the probe detected an increasing temperature in the pulp chamber up to 8.42±0.93°C for LCU, which was significantly higher than 2.08±0.21°C and 2.45±0.23°C for IOS1 and IOS2. The increase in pulpal temperature had a positive correlation with the light intensity but a negative correlation with the remaining dentin thickness.

The high-intensity light illumination from the light-curing unit and intraoral scanners elevated the temperature in the pulp chamber and potentially caused tooth sensitivity.

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Introduction

Sensitivity to hot stimuli is reported less often than to cold stimuli. For inflamed pulp, however, the threshold for both hot and cold stimuli is decreasing while the response is increasing. Many procedures for dental treatment generate heat[1], such as the friction caused by high-speed cutting instruments, the exothermic reaction of dental materials[2], and the heat from high-intensity illumination devices. Excessive heat has the potential to activate intradental nerves or even cause damage to underlying pulp tissue[3]. Heat could stimulate the response of intradental nerves, either by a hydrodynamic mechanism that stimulates the dentinal fluid movement to activate the receptors on the surface of the dental pulp[4, 5] or by transmission through the dental structure to activate heat receptors on the surface of the pulp directly[6]. Especially in cases of having tooth defects or thin tooth substances, sensitivity during using light-curing units and intraoral scanners has been frequently reported[7].

Small battery-operated light-curing units (LCU) contain an energy-efficient light-emitting diode (LED) to provide high-intensity light. This type of LCU is widely used for polymerized dental restorative materials[8]. The light intensity at the tip

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is called tip irradiance and relates to the curing ability of the dental material. Although no infrared energy is present in the light spectra emitted by this device, a significant amount of heat may be related to its ability to generate high-power-density light[9]. The intraoral scanners (IOS) are widely used in dentistry for digital impressions contain built-in high-intensity white or blue LED light sources depending on their technology[10,11].

A blue-light intraoral scanner has a shorter wavelength or higher frequency[10], which carries more energy to raise the surface temperature than the white-light intraoral scanner, resulting in fewer limitations, more reliability and higher repeatability.

Several studies have identified the relationship between high-intensity light from the light-curing unit and heat production that is associated with the irradiance of the devices[12, 13]. The heat generated from high-intensity light illumination from LCU and IOSs on the surface of the tooth and in the pulp chamber has never been investigated fully, especially when the tooth substance was reduced from cavity preparation. Therefore, this study aimed to investigate the temperature changes in the pulp chamber during high-intensity light illumination from LCU and IOSs in extracted lower first premolar teeth as well as alternate the thickness of tooth substance by cavity preparation.

Materials and methods

Twenty caries-free lower first premolars, extracted as a part of orthodontic treatment, were included in this study under approval from the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (certificate number 53/2021). The tooth samples were cleaned and disinfected immediately after extraction, then transferred for storage in 0.5% chloramine-T solution at room temperature until tested within one week.

The root was cut off at 2.00 mm below the cementoenamel junction (CEJ) using a low-speed cutting machine with water coolant (IsoMet™ Low-Speed Precision Cutter, Buehler, Esslingen, Germany). The remaining pulp tissue in the coronal part was removed mechanically through the opening at the cutting end using barbed broach no.040.

Three type K thermocouple probes (Omega, Stamford, United States) with tip diameters of 0.50 mm were used for monitoring temperature change. One probe was inserted in the pulp chamber and positioned to touch the inner wall of the buccal surface beneath the cavity held with cotton wool soaked with 0.9% saline, while the other two probes were attached to the mid-buccal surface and the mid-lingual surface of the tooth sample, which were held with flowable composite resin. The probe tips were left uncovered. The position of all probes was confirmed by X-ray radiographs before the start of testing. The ambient temperature was maintained at 24±1 °C throughout the experiment.

Three high-intensity illumination devices, including two intraoral scanners, IOS1: Trios 3® (3Shape, Denmark), IOS2: Primescan® (Sirona, Bensheim, Germany), and one light-curing unit LCU: Bluephase N® (Ivoclar Vivadent, Lichtenstein, Germany) were alternately tested by shining light for 30 seconds. The tip of the device was held and maintained 2.00 mm apart from the buccal surface during illumination.

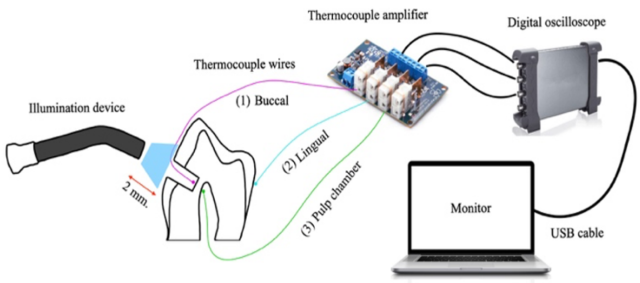

Figure 1. The diagram illustrates the experiment setup.

The temperature change was recorded using a thermocouple amplifier circuit model SEN30101/K1-5V0 (Playing with Fusion, Portland, United States) and monitored for potential differences. Data were recorded for further analysis using a 4-channel digital oscilloscope (Hantek® 6000B, Qingdao, China) and laptop computer (Figure 1). Temperature changes were monitored during the 30-second light illuminations. This method was repeated for each depth until the final depth of 2.00 mm.

After testing by illumination on the buccal surface, the cavity was cut in the same area with a step of 0.50 mm using a depth marker diamond bur (PrepMarker®, Komet Dental, Germany) on an airotor handpiece under water spray. After finishing preparation, the cutting depth was confirmed with a digital calliper from the floor of the cavity to the tooth surface.

The voltage difference in mV was calculated back to degree Celsius using the following formula.

$$T_{tc}\ (5V) = V_{out}/0.005°C$$

Whereas T_{tc} = Thermocouple temperature
V_{out} = Sensor output voltage

After the completion of recording, the tooth sample was cut along the sagittal plane through the center of the cavity using a low-speed cutting machine (IsoMet™ Low-Speed Precision Cutter, Buehler, Esslingen, Germany). The remaining dentin thickness was measured from the cavity floor and the surface of the pulp chamber using a digital calliper tip.

Changes in temperature (ΔT) during high-intensity illumination from three devices and five groups of average remaining dentin thickness were analysed using two-way repeated measures ANOVA with multiple comparisons. A P-value less than 0.05 was considered a significant difference.Moreover, Pearson's correlation was employed to investigate the relationship between light intensity and temperature change as well as between remaining dentin thickness and temperature change.

Results

The high-intensity mode of LCU produced vastly brighter illumination than IOS1 and IOS2. The intensities of LCU, IOS1 and IOS2 were 1361±12.61, 273.77±8.38, and 375.42±9.22 mW/cm^2, respectively. Moreover, the illumination from the light-curing unit that produced remarkable heat and the intraoral scanner that produced perceptible heat could be recorded continuously by three thermocouple probes and an amplifier. A significant temperature was detected on the buccal surface, which increased abruptly after starting illumination and continued to rise until reaching a maximum at the end of illumination. The illumination from IOSs showed a similar pattern of increasing temperature, but no significant change was found (Figure 3).

The buccal probe detected an increase of temperature by 34.79±2.52°C (Maximum) during illumination with LCU for 30 seconds, which was significantly higher than 2.34±0.34°C and 3.61±0.46°C from the illuminations of IOS1 and IOS2. The lingual probe also detected slight changes in temperature for these illuminations (3.19±0.49°C, 1.21±0.01°C, and 1.31±0.02°C, respectively). Moreover, the probe located in the pulp chamber also detected a significant increase in temperature by 6.59±0.65°C for LCU illumination, which was significantly higher than both IOS1 and IOS2 (1.58±0.19°C and 1.71±0.19°C) (Table 1).

	Temperature change (°C)		
	IOS1	IOS2	LCU
Buccal surface	2.34±0.34	3.61±0.46	34.79±2.52**
Pulp chamber	1.58±0.19	1.71±0.19	6.59±0.65**
Lingual surface	1.29±0.11	1.28±0.08	3.16±0.45**

Table 1. The mean ± SD of maximum temperature change during the 30-second illumination of a light-curing unit and intraoral scanners. **Showed a significant difference (p<0.01)

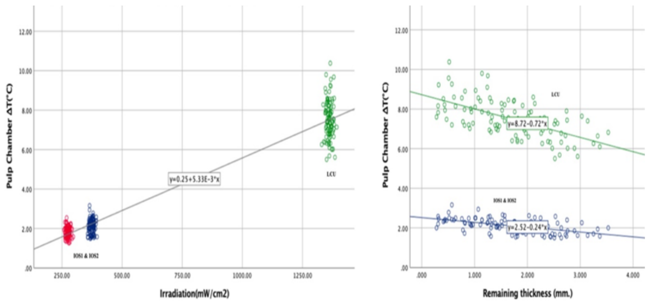

Figure 2. The scatter plot of the temperature change (ΔT) in a pulp chamber showed a strong positive correlation with light intensity during irradiation from IOS1, IOS2 and LCU (R^2 = 0.946), but showed a negative correlation with the remaining dentin thickness.

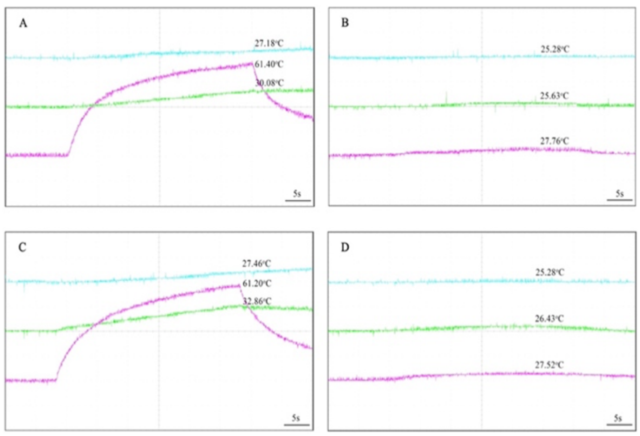

Figure 3. Examples of temperature recording from three thermocouple probes located on

lingual surface (top trace), in the pulp chamber (middle trace) and at the floor of the buccal cavity (bottom trace). The 10-second delay was performed prior to temperature recording, the buccal surface was alternately illuminated with high-intensity light from a light-curing unit (LCU) or intraoral scanners (IOSs) for 30 seconds. (A) During LCU illumination, the temperature at the buccal surface increased considerably from room temperature (24°C) to maximum of 61.40°C and returned to normal. The pulpal temperature also increased slightly to a maximum of 30.08°C. (C) The buccal probe located at the base of 2.0 mm buccal cavity showed an equivalent raising of temperature, but the pulpal temperature increased significantly to 32.86°C during LCU illumination. (B&D) Both IOS devices caused slight elevations in temperature when the buccal probe located on the tooth surface to 27.76 °C and pulpal probe to 25.63 °C while the buccal probe located at 2.0 mm floor of the cavity was 27.52 °C and the pulpal probe showed slightly higher temperature elevation to 26.43°C.

Cavity depth (mm.)	Remaining dentin thickness (mm.)	Pulp chamber temperature change (°C)		
		IOS1	IOS2	LCU
0.00	2.77±0.44	1.58±0.19	1.71±0.19	6.59±0.65*
0.50	2.27±0.44	1.68±0.18	1.93±0.24	7.01±0.93*
1.00	1.76±0.43	1.84±0.19	2.20±0.28*	7.55±0.64**
1.50	1.26±0.44	1.93±0.23	2.25±0.29*	7.93±0.71**
2.00	0.76±0.43	2.08±0.21*	2.45±0.23**	8.42±0.93**

Table 2. The mean ± SD of pulp chamber temperature change during the 30-second illumination of a light-curing unit and intraoral scanners.
Note: Values in elevation of pulp chamber temperature column marked with * are significantly different with p<0.05 and values succeeded with ** are significantly different with p<0.001.

With a step of 0.5 mm cavity preparation, the buccal thermocouple probe, which always relocated to the floor of the cavity, showed no significant temperature change for the same devices (Table 2), while the probe on the lingual surface also showed no significant temperature change throughout the experiment for the same device as the depth of buccal cavity changed.

The pulpal probe detected the elevation of pulpal temperature almost immediately after starting the LCU illumination, and the temperature continued to rise to maximum until the end of illumination, but at a slower rate than buccal temperature which did not occur when using IOSs. During LCU illumination, the pulp chamber probe detected significant increase in temperature (from 6.59±0.65 to 8.42±0.93°C) when the depth of the buccal cavity increased or the remaining dentin thickness decreased (Table 2). In addition, the illumination of IOS2 produced slightly higher temperature changes than illumination from IOS1, but a significant difference was not found. The example in Figure 3A showed that the maximum pulpal temperature reached 30.08°C or elevated by 6.08°C during the illumination of LCU on the buccal surface. After preparation of the 2.0 mm depth cavity, the maximum temperature reached 32.86°C, or 8.86°C higher than room temperature.

Pearson's analysis suggested that the increase in temperature in the pulp chamber had a strong positive correlation with the light intensity from illumination devices ($R^2 = 0.946$, $p < 0.05$), but a negative correlation with the remaining dentin thickness ($R^2 = 0.371$, $p < 0.05$ for LCU and $R^2 = 0.304$, $p < 0.05$ for IOS1&IOS2) (Figure 2).

Discussion

The heat generation from LCU, IOS1, and IOS2 depended upon light intensity, the wavelength of light, duration of illumination, and distance from the source[8, 14]. In this study, the duration of illumination and the distance from the tip of devices were controlled, but the light intensity and wavelength were varied based on their technology and specifications. The LCU caused a significantly higher temperature than IOS1 and IOS2 on both the tooth surface and cavity floor, as well as in the pulp chamber, similar to other studies[7, 15] and correlated with the high-intensity irradiance of this device[3, 13].

Heat perception and tooth sensitivity were reported during LCU irradiation[7]. Similar to other hot stimuli, heat can either activate an inward movement of dentinal fluid to stimulate the mechanoreceptor of nerve fibers on the surface of the pulp according to the hydrodynamic theory[16, 17] or transmit through semi-insulated dentin to activate specific heat receptors on nerve fibers directly on the surface of the pulp[18]. The intraoral scanner can elevate the temperature of the cavity floor by 2-3°C, which is usually insufficient to promote dentin sensitivity. However, it can cause dentin sensitivity in certain individuals with a lower sensitivity threshold.

The thickness of the tooth substance, together with the properties of tooth structures, determined the thermal conductivity and the diffusivity of heat from the surface to the pulp chamber[19]. The higher proportion of organic matrix of like dentin resulted in lower thermal conductibility than enamel[20, 21]. Similar to previous literatures[22, 23], the results showed an inverse relationship between tooth thickness and pulp chamber temperature. This showed that heat could easily be transmitted through thin dentin to pulp tissue[24], which substantially increased the potential of pulpal damage [25], particularly for LCU illumination.

Frequently referred to the literature, Zach and Cohen[26] suggested in an animal study in 1965 that raising the pulpal temperature by 5.5°C could induce irreversible pulpitis. However, a study found that transiently increasing temperature (between 8.9 and 14.7°C) did not cause permanent damage to the dental pulp[27]. The results of this study found that the illumination of LCU for 30 seconds to the deepest cavity at 2.0 mm could elevate the highest temperature change in the pulp chamber by 8.42±0.93°C, lower than that range. In other words, the heat generated from the illuminations of all tested devices in this study was in the safe range for clinical use. However, the high-intensity LCU should be used with caution in the case of severe loss of tooth structure and thin dentin covering the pulp, which has a certain degree of inflammation and lower pain threshold.

In vital pulp, the high rate of pulpal blood flow could dissipate hot stimuli to surrounding supporting tissue[28, 29]. However, it is impossible to insert a thermal sensing device into the normal pulpal tissue under normal physiologic conditions to measure the pulp temperature without inducing error[30]. Moreover, any intense stimuli that activates neural response could also induce neurogenic inflammation to enhance blood circulation in the pulp chamber via vasoactive neuropeptide release[29]. This circulation was not considered in this in vitro study. This in vitro model could provide some reasonably crucial information on how much heat diffused through different remaining dentin thicknesses could reach the pulpal chamber. The rising temperature during high-intensity illumination in this study should be interpreted and used with caution. Thus, the results of the present study may help clinicians develop a better understanding of the potential adverse consequences and gain awareness of the potential thermal damage to the pulp which may result from the use of high-intensity light from both IOS and LCU in a deep cavity or thin remaining tooth structure.

Conclusion

Within the limitations of this study, the illuminations of high-intensity light from the light-curing unit and intraoral scanners produced an elevation of temperature on the tooth surface, the cavity floor, and the pulp chamber. The increasing temperature had a strong positive correlation with light intensity while increasing pulp chamber temperature negatively correlated with remaining dentin thickness. The increasing temperatures revealed in the experiment for the current study were within the safety range for clinical use.

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Declaration of Interest

All authors declare that they have no conflicts of interest.

References

1. Mjör IA. Pulp-dentin biology in restorative dentistry. Part 7: The exposed pulp. Quintessence Int. 2002;33(2):113-35.
2. Tjan AH, Grant BE, Godfrey MF, 3rd. Temperature rise in the pulp chamber during fabrication of provisional crowns. J Prosthet Dent. 1989;62(6):622-6.
3. Oberholzer TG, Makofane ME, du Preez IC, George R. Modern high powered led curing lights and their effect on pulp chamber temperature of bulk and incrementally cured composite resin. Eur J Prosthodont Restor Dent. 2012;20(2):50-5.
4. Brannstrom M, Linden L-Ak, Johnson G. Movement of Dentinal and Pulpal Fluid Caused by Clinical Procedures. Journal of Dental Research. 1968;47(5):679-82.
5. Zarpellon DC, Runnacles P, Maucoski C, Gross DJ, Coelho U, Rueggeberg FA, et al. Influence of Class V preparation on in vivo temperature rise in anesthetized human pulp during exposure to a Polywave® LED light curing unit. Dental Materials. 2018;34(6):901-9.
6. Matthews B. Responses of intradental nerves to electrical and thermal stimulation of teeth in dogs. J Physiol. 1977;264(3):641-64.
7. Natongkham P, Banthitkhunanon P, Wanachantararak S.

Dentine sensitivity caused by illumination of intraoral scanner and light curing unit. J Clin Exp Dent. 2022;14(5):e420-e5.
8. Mouhat M, Mercer J, Stangvaltaite L, Ortengren U. Light-curing units used in dentistry: factors associated with heat development-potential risk for patients. Clin Oral Investig. 2017;21(5):1687-96.
9. Rueggeberg FA, Giannini M, Arrais CAG, Price RBT. Light curing in dentistry and clinical implications: a literature review. Braz Oral Res. 2017;31(suppl 1):e61.
10. Jeon JH, Choi BY, Kim CM, Kim JH, Kim HY, Kim WC. Three-dimensional evaluation of the repeatability of scanned conventional impressions of prepared teeth generated with white- and blue-light scanners. J Prosthet Dent. 2015;114(4):549-53.
11. Jeon JH, Lee KT, Kim HY, Kim JH, Kim WC. White light scanner-based repeatability of 3-dimensional digitizing of silicon rubber abutment teeth impressions. J Adv Prosthodont. 2013;5(4):452-6.
12. Yap AU, Soh MS. Thermal emission by different light-curing units. Oper Dent. 2003;28(3):260-6.
13. Gomes M, DeVito-Moraes A, Francci C, Moraes R, Pereira T, Froes-Salgado N, et al. Temperature increase at the light guide tip of 15 contemporary LED units and thermal variation at the pulpal floor of cavities: an infrared thermographic analysis. Oper Dent. 2013;38(3):324-33.
14. Santini A, Watterson C, Miletic V. Temperature rise within the pulp chamber during composite resin polymerisation using three different light sources. Open Dent J. 2008;2:137-41.
15. Goodis HE, White JM, Andrews J, Watanabe LG. Measurement of temperature generated by visible-light-cure lamps in an in vitro model. Dent Mater. 1989;5(4):230-4.
16. Linsuwanont P, Palamara JE, Messer HH. An investigation of thermal stimulation in intact teeth. Arch Oral Biol. 2007;52(3):218-27.
17. Vongsavan N, Matthews B. The relationship between the discharge of intradental nerves and the rate of fluid flow through dentine in the cat. Arch Oral Biol. 2007;52(7):640-7.
18. Matthews B. Sensory mechanisms in dentine. Proc R Soc Med. 1972;65(5):493-5.
19. Yazici AR, Müftü A, Kugel G, Perry RD. Comparison of temperature changes in the pulp chamber induced by various light curing units, in vitro. Oper Dent. 2006;31(2):261-5.
20. Craig RG, Peyton FA. Thermal Conductivity of Tooth Structure, Dental Cements, and Amalgam. Journal of Dental Research. 1961;40(3):411-8.
21. Lancaster P, Brettle D, Carmichael F, Clerehugh V. In-vitro Thermal Maps to Characterize Human Dental Enamel and Dentin. Front Physiol. 2017;8:461.
22. Doğan A, Hubbezoğlu I, Dogan O, Bolayır G, Demir H. Temperature rise induced by various light curing units through human dentin. Dental materials journal. 2009;28:253-60.
23. Tjan AH, Dunn JR. Temperature rise produced by various visible light generators through dentinal barriers. J Prosthet Dent. 1988;59(4):433-8.
24. Dange BS, Mootha A, Madhav V, Kale S, Nevrekar S, Attargekar V. Comparison of temperature rise within pulp chamber during light curing of composite restoration. Journal of Applied Polymer Science. 2021;138(37):50946.
25. Hannig M, Bott B. In-vitro pulp chamber temperature rise during composite resin polymerization with various light-curing sources. Dent Mater. 1999;15(4):275-81.
26. Zach L, Cohen G. PULP RESPONSE TO EXTERNALLY APPLIED HEAT. Oral Surg Oral Med Oral Pathol. 1965;19:515-30.
27. Baldissara P, Catapano S, Scotti R. Clinical and histological evaluation of thermal injury thresholds in human teeth: a preliminary study. J Oral Rehabil. 1997;24(11):791-801.
28. Kodonas K, Gogos C, Tziafas D. Effect of simulated pulpal microcirculation on intrapulpal temperature changes following application of heat on tooth surfaces. Int Endod J. 2009;42(3):247-52.
29. Mahant RH, Chokshi S, Vaidya R, Patel P, Vora A, Mahant P. Comparison of the Amount of Temperature Rise in the Pulp Chamber of Teeth Treated With QTH, Second and Third Generation LED Light Curing Units: An In Vitro Study. J Lasers Med Sci. 2016;7(3):184-91.
30. Sulieman M, Addy M, Rees JS. Surface and intra-pulpal temperature rises during tooth bleaching: an in vitro study. Br Dent J. 2005;199(1):37-40; discussion 32.