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Influence of Cavity Preparation, Light-curing Units, and Composite Filling on Intrapulpal Temperature Increase in an *In Vitro* Tooth Model

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Clinical Relevance

Ten to 15 seconds of light-curing with a high-power density unit (>1200 mW/cm^2) is recommended to keep the intrapulpal temperature increase within a safe range.

SUMMARY

This study examined the effect of both the tooth substance and restorative filling materials on the increase in pulp chamber temperature when using light-curing units with different power densities.

The tip of a temperature sensor was positioned on the pulpal dentinal wall of the buccal side of a maxillary premolar. Metal tubes were inserted in the palatal and buccal root of the tooth, one for water inflow and the other for water outflow. Polyethylene tubes were connected from the metal tubes to a pump to control the flow rate. For the unprepared tooth group (group 1), the tooth was light-cured from the buccal side using two light-curing units (three curing modes): the VIP Junior (QTH, BISCO, Schaumburg, IL, USA) and the Bluephase LED light-curing units (two modes: LED$_{low}$ and LED$_{high}$; Ivoclar Vivadent, Schaan, Liechtenstein). The power densities of each light-curing unit for the LED$_{low}$, QTH, and LED$_{high}$ modes were 785 mW/cm^2, 891 mW/cm^2, and 1447 mW/cm^2, respectively. All light-curing units were activated for 60 seconds. For the prepared tooth group (group 2), a Class V cavity, 4.0 mm in width by 4.0 mm in height by 1.8 mm in depth in size, was prepared on the buccal surface of the same tooth for the temperature measurement. The light-curing and temperature measurements were performed using the same methods used in group 1.

The cavity prepared in group 2 was filled with a resin composite (Tetric N Ceram A3 shade, Ivoclar Vivadent) (group 3) or a flowable composite (Tetric N Flow with A3 shade, Ivo-

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clar Vivadent) (group 4). The light-curing and temperature measurements were performed for these groups using the same methods used for the other groups.

The highest intrapulpal temperature (T_{MAX}) was measured, and a comparison was conducted between the groups using two-way analysis of variance with a post hoc Tukey test at the 95% confidence level.

The T_{MAX} values were as follows: 38.4°C (group 1), 39.0°C (group 2), 39.8°C (group 3), and 40.3°C (group 4) for the LED_{low} mode. For the QTH mode, the T_{MAX} values were 40.1°C (group 1), 40.4°C (group 2), 40.9°C (group 3), and 41.4°C (group 4). For the LED_{high} mode, the T_{MAX} values were 43.3°C (group 1), 44.5°C (group 2), 44.7°C (group 3), and 45.3°C (group 4). The statistical analysis revealed the following: the T_{MAX} values were arranged by mode in the following manner: LED_{low} < QTH < LED_{high} ($p<0.05$) and group 1 < group 2 ≤ group 3 ≤ group 4 ($p<0.05$).

INTRODUCTION

Light-curing of composite materials is an indispensable process in many direct and indirect restorative procedures. Many dental materials, such as restorative composites, bonding agents, luting materials for indirect restorations and orthodontic appliances, pit and fissure sealants, temporary restorations, and even some bleaching agents, employ light-curing units for the polymerization or activation of the materials. High-power density light-curing units were recently released onto the market. These lights allow materials to cure in a shorter period of time. However, they also generate more heat, which can be detrimental to the vitality of the pulp tissues.[1]

Zach and Cohen[2] reported in 1965 that temperature increases of 5.5°C and 11°C resulted in necrosis rates of 15% and 60%, respectively, of the pulpal tissues when examined after three months. In that trial, the teeth in five rhesus monkeys were heated with a soldering gun at a temperature of 275°C (±50°C) for five to 20 seconds. However, it is highly questionable as to whether the values obtained in the monkeys can be applied to humans. In a clinical study on human patients,[3] a 9-15°C temperature increase did not cause histologically confirmed pulpal necrosis after three months. In that study, heat was applied to the occlusal surface of six premolars and six molars with individually fitted supports until the subjects complained of toothache. The contralateral tooth was extracted, and the temperature increase in the pulp was measured using the same parameters as were used under the *in vivo* conditions. After three months, the other teeth were extracted and examined histologically. The results suggested that the pulpal tissues could tolerate a temperature rise above 5.5°C without damage. In that study, the elevated temperature was only sustained for a short duration. There was no evidence of a critical temperature rise that would cause irreversible damage to the pulpal tissues after exposure to heat-generating processes. Therefore, it is important to be cautious and accept 5.5°C as a cutoff value, knowing that the pulp can in all likelihood withstand greater increases in temperature without irreversible damage.

The increases in pulpal temperature can be affected by the dentin thickness,[4-6] the duration of light exposure, and the type of light-curing device used in the curing process.[7-9] The role of the tooth substance in the temperature rise during the light-curing process has not been studied systematically. Although many composites are placed without or with only little cavity preparation, there is no information available on the differences in the temperature increases produced by light-curing units in a prepared vs a nonprepared cavity.

Placing composites into a cavity and curing them with light-curing units has been reported to increase the pulpal temperature.[4,7,8,10-17] However, the temperature increases in only the tooth alone caused by light-curing units should be measured separately to determine the increase in pulpal temperature separately from that of the composite itself during the course of the light-curing process. There is limited information available regarding the increase in specific pulpal temperature as a result of the light-curing process of composites themselves.

This current study examined the effect of both the tooth substance and restorative filling materials on the increase in pulp chamber temperature when using light-curing units with different power densities.

The null hypotheses were as follows: First, pulp temperature does not increase with different power density light units. Second, pulp temperature does not increase when light-curing intact teeth, cavity-prepared teeth, or cavities filled with resin composites of different viscosities.

METHODS AND MATERIALS

The experimental design used in this study was based on a previous study by Park and others.[1]

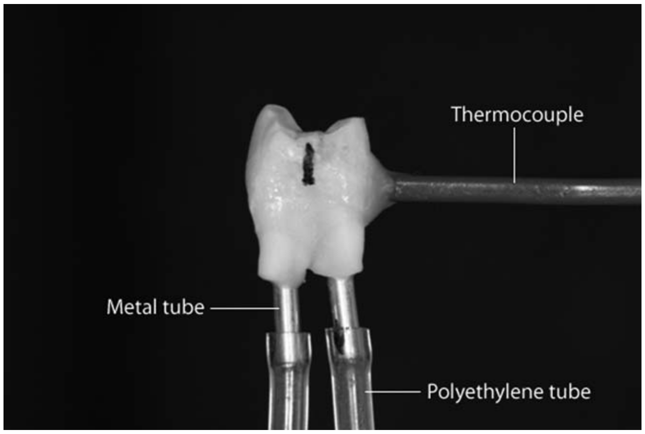

Figure 1. *The premolar connected with a thermocouple and metal tubes.*

Insertion of Thermocouples and Connection to Water Flow

Fifteen maxillary premolars with two separate roots, without caries or restorations, were used. The roots were cut to half of their length to expose the canal spaces and to allow for metal tube insertion. After confirming that the root canals were free of debris, two metal tubes (diameter, 2 mm) were inserted into the apices of both roots to a depth of approximately 2 mm and fixed into position using XP BOND bonding agent (Dentsply DeTrey GmbH; Konstanz, Germany) and Unifil LoFlo Plus flowable resin composite (GC; Tokyo, Japan). Then, two polyethylene tubes, one for water outflow and one for water inflow, were connected to the metal tubes.

On the palatal side of the premolar, a horizontal hole (diameter, 2 mm) was drilled into the pulp chamber using a cylindrical diamond bur (FG 8614, Intensiv, Grancia, Switzerland). After beveling the orifice, the enamel surrounding the hole was etched with phosphoric acid (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 30 seconds and rinsed with water. XP BOND was applied to the etched enamel, gently air-dried, and then light-cured for 10 seconds (Bluephase, 1130 mW/cm^2). A K-type thermocouple (CHAL-003; OMEGA Engineering Inc, Stamford, CT, USA) was positioned in the hole, with attention being paid to place the tip in contact with the dentin on the buccal wall of the pulp chamber. The thermocouple was fixed in position using Unifil LoFlo Plus and was light-cured for 30 seconds (Figure 1). A radiograph was taken to confirm the position of the thermocouple (Figure 2). Other thermocouples were placed in the water bath and the air above the water bath. All three thermocouples were connected to a computer via a data logger

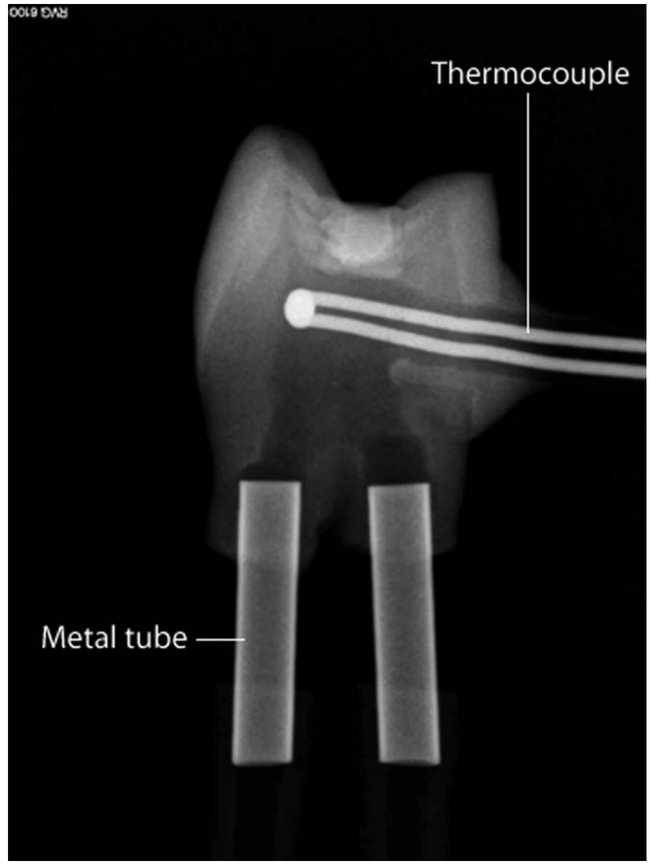

Figure 2. *X-ray of the premolar with a thermocouple and metal tubes.*

(Agilent 34970A, Agilent Tech, Santa Clara, CA, USA). Software (Agilent BenchLink DataLogger, version 1.4) was used to measure the temperatures at a frequency of 1 Hz.

A polyethylene tube was connected to the pump to serve as a water outlet, and a tube for water inflow was placed in the water bath containing deionized water (Figure 3). To mimic tooth blood flow, the flow rate of water was controlled using a regulator in the pump. The flow rate was set at 40-50 μL/min.

Measuring the Power Density of the Light-curing Units

The tested light-curing units were as follows: a halogen lamp, VIP Junior (QTH, BISCO, Schaumburg, IL, USA), and a Bluephase LED light-curing unit (two modes: LED_{low} and LED_{high}, Ivoclar Vivadent). The diameter of the light-curing tip (light guide) was 9.8 mm in the VIP Junior and 9.0 mm in the Bluephase. The power density of the light-curing units was measured using an integration sphere and its software (Gigahertz-Optic GmbH, Puchheim, Germany). The integration power of the LED_{low},

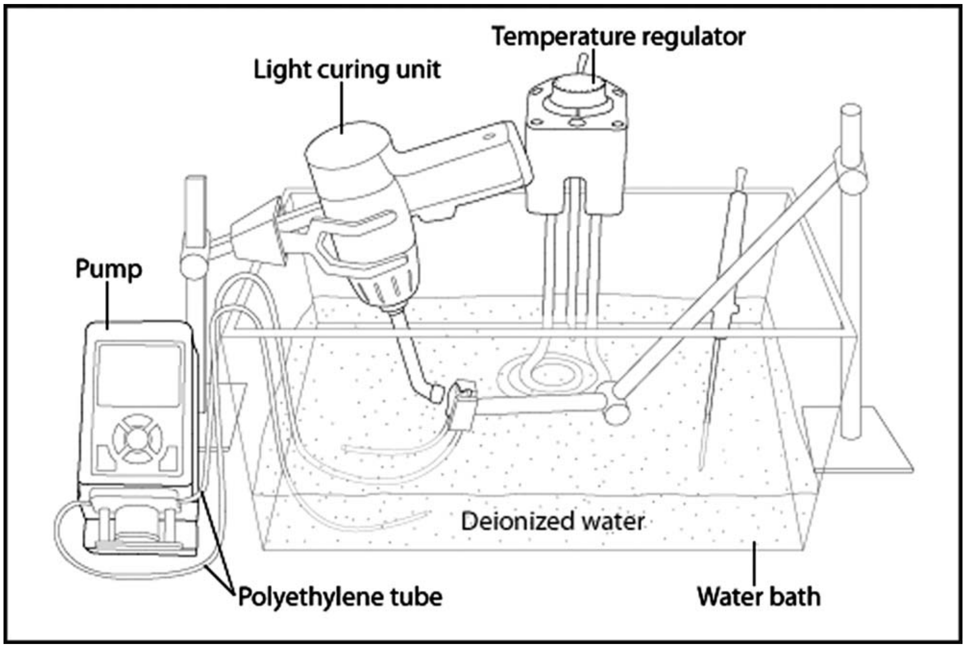

Figure 3. *Schematic diagram of experimental setup.*

QTH, and LED_{high} modes was 499.2 mW, 672 mW, and 920.4 mW, respectively, and the glass-fiber bundle area was 0.75 cm^2 in the VIP Junior and 0.64 cm^2 in the Bluephase. The power density of each light-curing unit was calculated by dividing the integration power (mW) of each light-curing unit by the fiber bundle area (cm^2). Therefore, the power densities of each light-curing unit for the LED_{low}, QTH, and LED_{high} modes were 785 mW/cm^2, 891 mW/cm^2, and 1447 mW/cm^2, respectively.

Measurement of Pulpal Temperature

Before light-curing, the temperatures in the water and air were stabilized to 39°C and 27°C, respectively.

Highest Pulp Temperature (T_{MAX}) Measurements Before Cavity Preparation (Group 1)—Fifteen maxillary premolars, which were already prepared for intrapulpal temperature measurements, were used. When the pulp temperature was stabilized at 32°C ± 0.2°C, a tooth was exposed to the three curing modes (LED_{low}, QTH, and LED_{high}).

For each light-curing unit, the distance from the light tip to the tooth was set to 4 mm using a metal spacer. All light-curing units were activated for 60 seconds. The pulp, water, and air temperature data were stored in a computer every second from the start of the light-curing procedure and for a total of three minutes.

The highest pulp temperature in each measurement was registered. The resulting 15 T_{MAX} data sets for each light-curing unit were used for a statistical comparison.

T_{MAX} Measurement After Cavity Preparation (Group 2)—For the same teeth used in group 1, a 4.0-mm (width) × 4.0-mm (height) × 1.8-mm (depth) cavity was prepared on the buccal surface of the same tooth, and the temperature of the prepared cavity was measured. After an X-ray of the tooth was taken from the proximal side, the image was digitized, and the software, Analysis FIVE (SIS, Bergisch-Gladbach, Germany), was used to measure the distance between the pulp space and cavity floor. The remaining dentin thickness was between 0.9 mm and 1.0 mm (Figure 4).

For each light-curing unit, the same procedures as described in group 1 were repeated for the pulp temperature measurement. The resulting 15 T_{MAX} data sets for each light-curing unit were used for statistical comparison.

T_{MAX} Measurement After Cavity Filling with Composites (Group 3)—Using the 15 teeth that had been used in group 2, the cavities were coated with a glycerine-based liquid strip gel (Ivoclar Vivadent) to allow easy removal of the composite from the cavity after curing and filled with a resin composite (RC, Tetric N Ceram, A3, Ivoclar Vivadent). After insertion of the composite it was light-cured, and the temperature was recorded using the same proce-

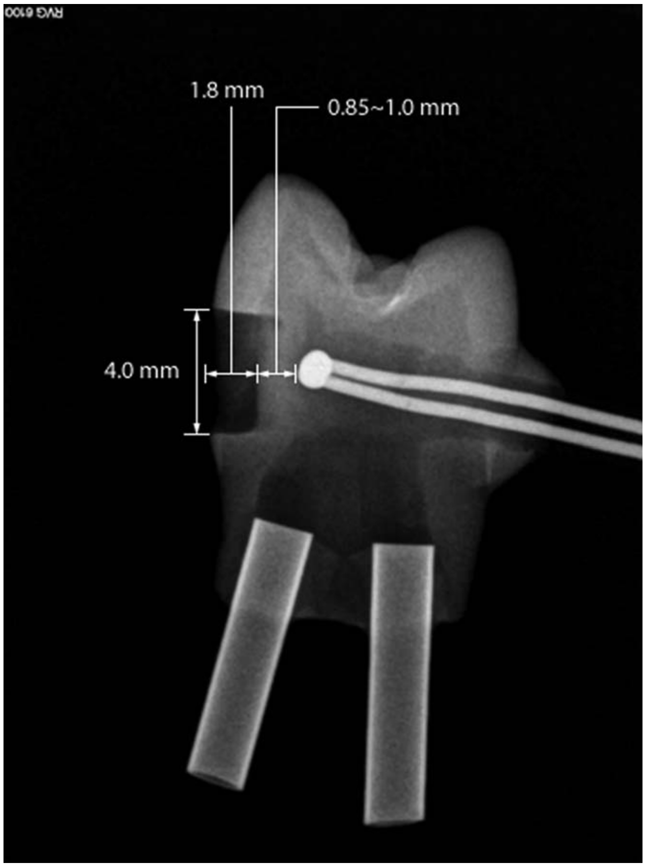

Figure 4. *X-ray of the prepared premolar with a thermocouple and metal tubes.*

dures as described for group 1. After each measurement, the cured composites were removed from the cavity, and the gel was washed out from the tooth surface with water. After the tooth surface had been rapidly air-dried, a liquid strip gel was applied again to the cavity surface for another composite filling. In this way, the same tooth could be used for different experiments. The resulting 15 T_{MAX} data sets for each light-curing unit were registered and used for statistical analysis.

T_{MAX} Measurement After Cavity Filling with Flowable Composites (Group 4)—For the 15 teeth used in group 3, the composite fillings were removed from the cavities using an explorer and hand instrument, and the cavities were coated with a glycerine-based liquid strip gel. Then, the cavities were filled with a flowable composite (FC, Tetric N Flow, A3, Ivoclar Vivadent), light-cured, and the temperature was recorded using the same procedures as described in group 1. After each measurement, the cured composites were removed from the cavities and new composites were filled into the cavities for different light-curing units using the

Table 1: *Summary of Study Design*[a]

	Cavity Preparation	Composite Filling	Light-Curing	Temperature Recording, min
Group 1	X	X	LED_{low} (60 s)	3
			VIP Junior (60 s)	3
			LED_{high} (60 s)	3
Group 2	O	X	LED_{low} (60 s)	3
			VIP Junior (60 s)	3
			LED_{high} (60 s)	3
Group 3	O	Tetric N Ceram	LED_{low} (60 s)	3
			VIP Junior (60 s)	3
			LED_{high} (60 s)	3
Group 4	O	Tetric N Flow	LED_{low} (60 s)	3
			VIP Junior (60 s)	3
			LED_{high} (60 s)	3

[a] *Cavity dimension: 4.0 mm (width) × 4.0 mm (height) × 1.8 mm (depth). LED_{low}: Bluephase low power, 785 mW/cm^2; QTH: VIP Junior, 891 mW/cm^2; and LED_{high}: Bluephase high power, 1447 mW/cm^2.*

same methods as described for group 3. The resulting 15 T_{MAX} data sets for each light-curing unit were registered and used for statistical analysis.

The study design is summarized in Table 1.

Statistical Analysis

The T_{MAX} for each light-curing unit and the T_{MAX} for groups 1, 2, 3, and 4 were compared using two-way analysis of variance (ANOVA) and post hoc Tukey test using a 95% confidence level.

RESULTS

Figures 5, 6, and 7 show the relationship between the pulpal temperatures as a function of time.

The results of the T_{MAX} analyses are listed in Table 2. The T_{MAX} ranged from 38.4°C (group 1) to 40.3°C (group 4) for the LED_{low} mode, from 40.1°C (group 1) to 41.4°C (group 4) for the QTH, and from 43.3°C (group 1) to 45.3°C (group 4) for the LED_{high} mode. The results of the two-way ANOVA revealed that there were significant differences in the T_{MAX} between light-curing units ($p<0.05$) and between the groups ($p<0.05$). There was no interaction among them ($p>0.05$) (Table 3). The post hoc test indicated the following orders: LED_{low} < QTH < LED_{high} ($p<0.05$) and group 1 < group 2 ≤ group 3 ≤ group 4 ($p<0.05$).

DISCUSSION

There were significant differences in the T_{MAX} among the light-curing units using different power

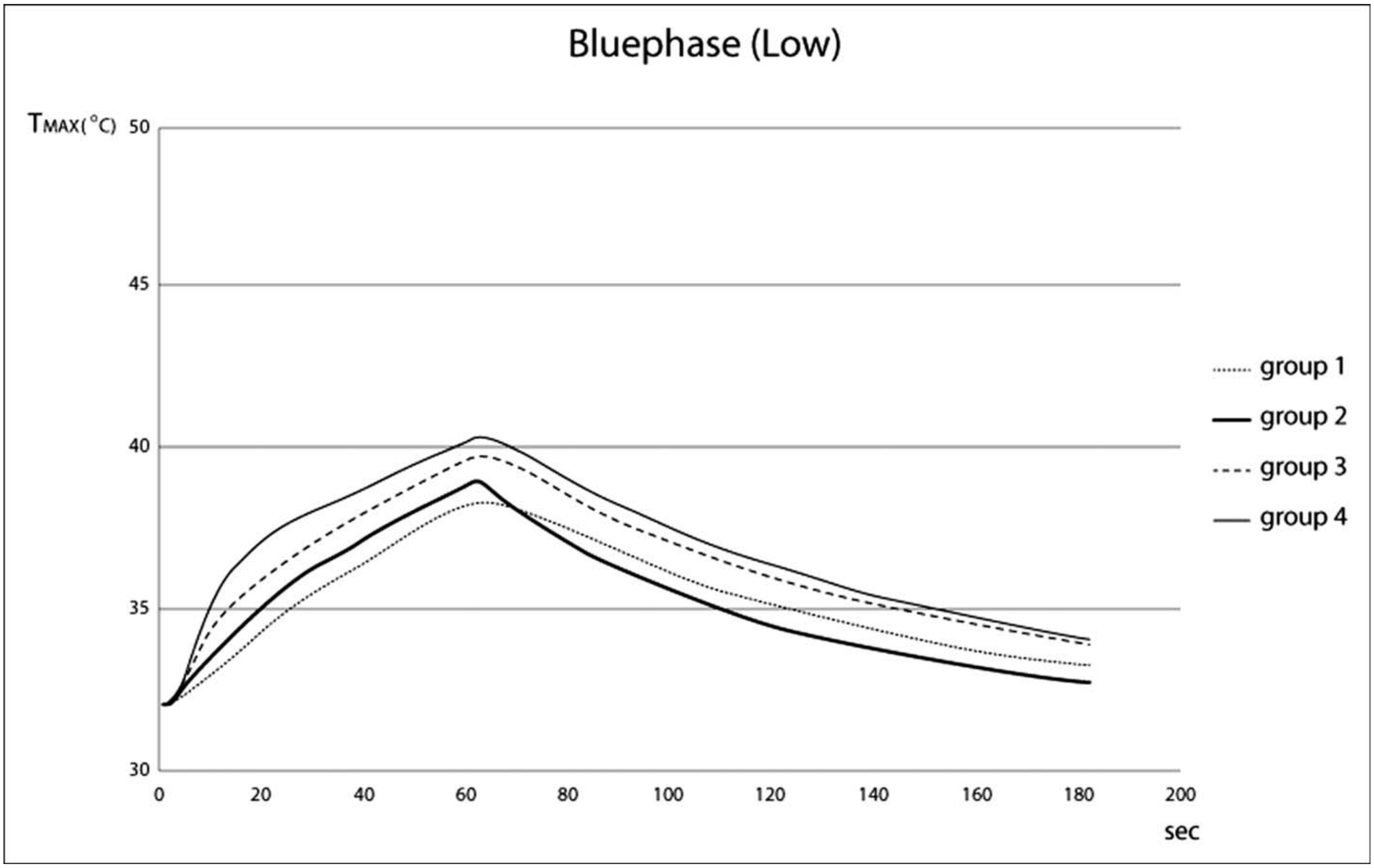

Figure 5. T_{MAX} vs time for the Bluephase in low mode.

densities. The T_{MAX} for the LED_{high} mode was highest, and the T_{MAX} for the QTH mode was higher than that for the LED_{low} mode. These results indicate that the pulpal temperature increased with the increase of the light-curing unit's power. Therefore, the first null hypothesis was rejected.

There was a significant difference in the T_{MAX} between groups 1 and 2. In accordance with the common belief that enamel and dentin are good thermal insulators,[18,19] these results indicate that the pulpal temperature increases more in a prepared tooth than in an unprepared tooth. Therefore, the second null hypothesis was also rejected. This indicates that enamel and dentin are effective thermal insulators. In clinical situations, the light-curing unit tends to be placed closer than 4 mm to the prepared surface of a tooth, which can cause the intrapulpal temperature to increase more than indicated by this present study. Therefore, it is recommended that clinicians be cautious in ensuring that they do not place the light-curing unit too close and use the light for too long in one application when working with a prepared tooth.

There was a significant difference in the T_{MAX} between groups 1 and 3 and between groups 1 and 4 for all light-curing units. This suggests that the composite generates an exothermic reaction during the light-curing process, which is consistent with the findings of previous studies.[14]

McCabe[20] reported that polymerization of a resin composite resulted in an increase in temperature caused by the exothermic reaction process and radiant heat from the light curing unit. The temperature differences in the T_{MAX} between groups 1 and 3 were approximately 1.4°C (LED_{low}), 0.8°C (QTH), and 1.4°C (LED_{high}). The differences between groups 1 and 4 were 1.9°C (LED_{low}), 1.3°C (QTH), and 2.0°C (LED_{high}). Considering that the T_{MAX} differences between groups 1 and 3 and between groups 1 and 4 were not very great between the LED_{low} and LED_{high} modes, most of the heat energy produced by the light-curing unit might be responsible for the increase in temperature of the tooth itself, and the effects on the filling material might be limited.[16,17] It is interesting to note that the T_{MAX} differences between groups 1

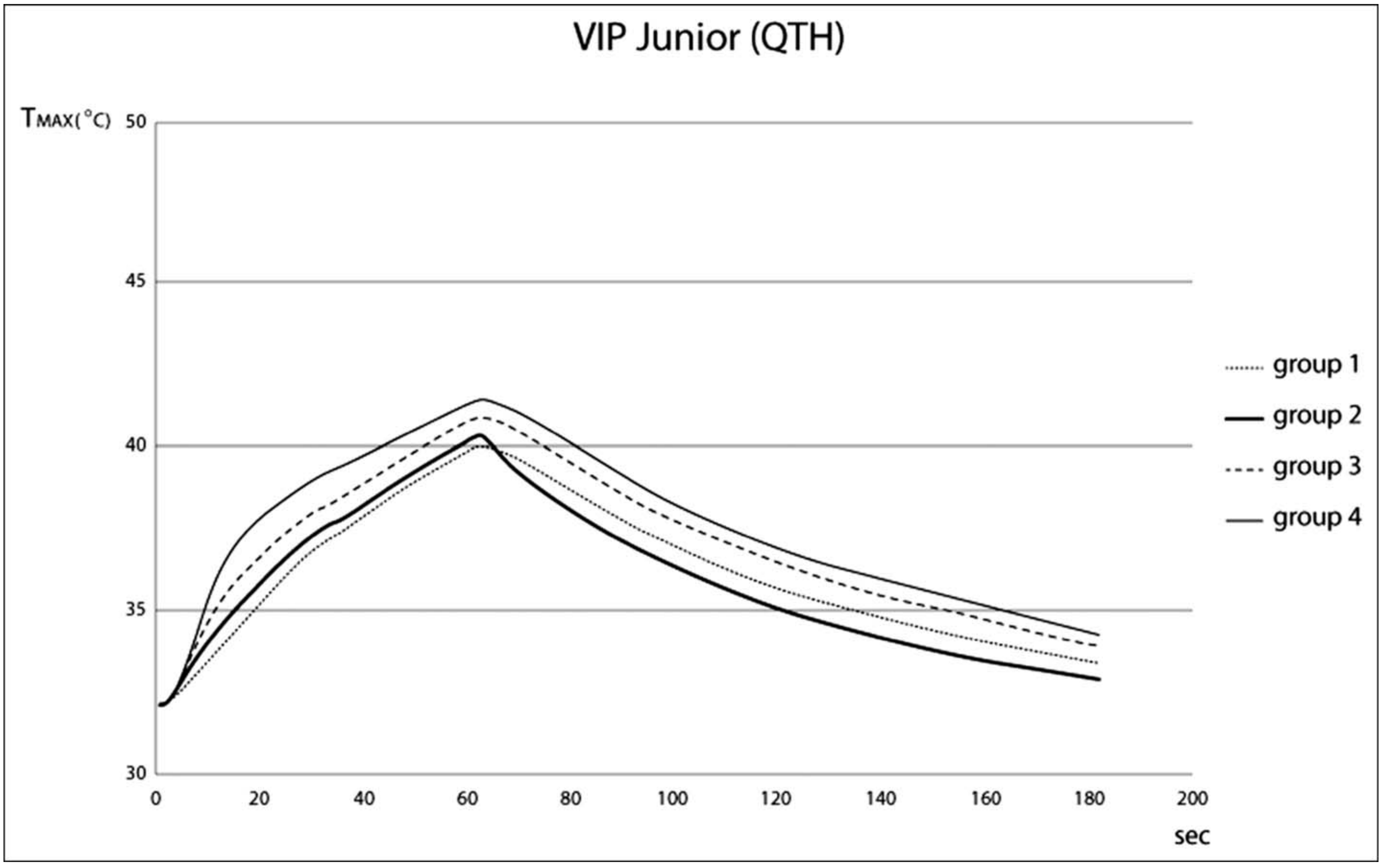

Figure 6. *T_{MAX} vs time for the VIP Junior (QTH).*

and 3 and between groups 1 and 4 were relatively lower in the QTH mode when compared with the LED_{low} and LED_{high} modes. These results might be related to the greater effectiveness of LED vs QTH modes in composite polymerization due to the efficiency in camphorquinone activation provided by the LED curing units.[21-23]

Even though the T_{MAX} for group 3 was a little higher than that of group 2, there was no significant difference between them. This indicates that even though there are exothermic reactions in composite resins, they are not remarkable or significant. It can be assumed that the composite resins functioned as a thermal insulator, so a sudden increase in pulp temperature was prevented. Previous reports[4,6] indicate that when the composite is cured, a lower increase in temperature occurs in the pulp than occurs when the remaining dentin thickness is thicker. It is recommended that more care should be taken with composite filling procedures in deep cavities to avoid an increase in the pulpal temperature.

Even though the T_{MAX} in group 4 was a little higher than that of group 3, there was no significant difference between these values for all light-curing units. This is not in line with the findings of a study by Al-Qudah and others,[24] which reported that the temperature rise with a flowable composite was significantly higher than that found with hybrid or packable composites. Those researchers reported that a flowable composite with a higher proportion of resin available for polymerization can explain the higher temperature rise (compared to what is observed with other types of composites). This difference between the present study and the previous study may be due to the differences in the composition of the test materials and/or the test setup.

According to Zach and Cohen,[2] the critical threshold temperature increase to cause a pulp problem was 5.5°C. As the initial temperature in the pulp was 32°C in the present study, the amount of the temperature increase in group 4 was approximately 8.3°C, 9.4°C, and 13.3°C for the LED_{low}, QTH, and

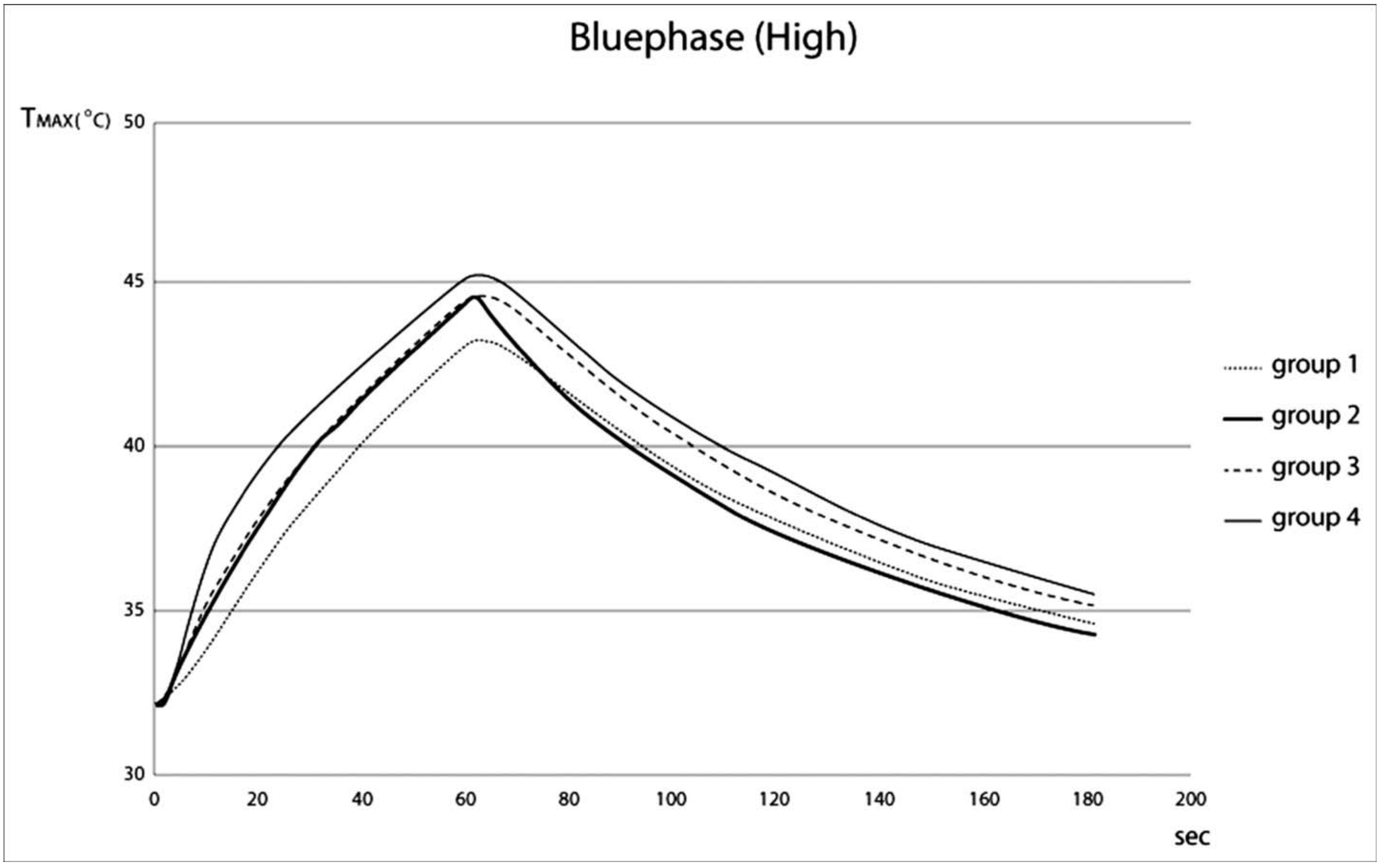

Figure 7. *T_{MAX} vs time for the Bluephase in high mode.*

LED_{high} modes, respectively, after 60 seconds of light activation. Figure 5, 6, and 7 indicate that the critical threshold of 5.5°C was reached after 35 seconds for the LED_{low} mode, after 27 seconds for the QTH mode, and after 20 seconds for the LED_{high} mode in group 3. Park and others[1] suggested that curing devices with a high power density (>1200 mW/cm^2) should only be activated for a short duration (<15 seconds) to reduce the risk of a potentially detrimental increase in pulpal temperature, even in teeth without a cavity preparation. In group 4, the temperature increased more than 5.5°C after 24 seconds, 18 seconds, and 14 seconds using the LED_{low}, QTH, and LED_{high} light-curing modes, respectively (Figure 5a-c).

According to the total energy concept, the energy density should be approximately 16,000 mW/cm^2 to obtain good curing results in resin-based composites.[25] At an energy density >17,000 mW/cm^2, no further improvements in mechanical properties were found. In the present study, the power densities of each light-curing unit for the LED_{low}, QTH, and LED_{high} modes were 785 mW/cm^2, 891 mW/cm^2, and 1447 mW/cm^2, respectively. Therefore, the proper curing time, based on the total energy concept, would be about 11 seconds for LED_{high}, 18 seconds for QTH,

Table 2: *The Average Value of Highest Pulpal Temperature, °C (T_{MAX})[a]*

Groups	1 No Cavity Preparation	2 Cavity Preparation	3 Cavity Preparation + Tetric N Ceram	4 Cavity Preparation + Tetric N Flow
LED_{low}	38.4 ± 1.0	39.0 ± 0.8	39.8 ± 0.8	40.3 ± 0.9
QTH	40.1 ± 1.1	40.4 ± 1.2	40.9 ± 0.9	41.4 ± 0.9
LED_{high}	43.3 ± 1.5	44.5 ± 1.3	44.7 ± 0.9	45.3 ± 1.2

[a] *LED_{low}: Bluephase low power, 785 mW/cm^2; QTH: VIP Junior, 891 mW/cm^2; and LED_{high}: Bluephase high power, 1447 mW/cm^2.*

Table 3: *Two-way Analysis of Variance (ANOVA) of Curing Lights and Steps*

Source	Sum of Square	df	Mean Square	*F*	*p*-Value
Curing_Light (C)	840.963	2	420.482	368.220	0.000
Groups (G)	77.726	3	25.909	22.689	0.000
Interaction (C)(G)	4.836	6	0.806	0.706	0.645
Error	191.844	168	1.142		
Total	1115.370	179			

and 20 seconds for LED_{low}. In Table 4, the results of intrapulpal temperature after the 10 seconds (T_{10sec}), 20 seconds (T_{20sec}), and 30 seconds (T_{30sec}) of light-curing are listed. When considering the results of this current study and the total energy concept, 10-15 seconds of light-curing would be recommended for LED_{high}, with approximately 20 seconds for the LED_{low} and QTH.

Recently, high-intensity light-curing units have been used more frequently, but a downside to this instrument is that the pulpal temperature may increase significantly. Therefore, care should be taken when using high-intensity light-curing units for a long duration.[1]

Operational measures that may be helpful in reducing the temperature increase include the use of base materials[7] and modulation of the light intensity,[26] as well as the curing tip design and diameter.[4] Another variable would be the distance between the light tip and the tooth. In the present study, the distance from the light tip to the tooth was set at 4 mm.

Further studies are needed to determine if a temperature change of more than 5.5°C is detrimental to the pulp tissue. This is because the light-curing time often exceeds 60 seconds in many clinical cases of indirect restorations, and there have been no clinical reports yet that indicate that such a light-curing procedure harms the pulp tissue. Pulp damage is also of concern in terms of bleaching procedures. To achieve bleaching effects of teeth in a shorter period of time, an acceleration of the degradation of hydrogen peroxide is needed, and light sources, such as halogen, LEDs, and lasers, have been used to activate the hydrogen peroxide. Existing studies reveal that activation of bleaching agents by heat, lights, or laser may have an adverse effect on pulpal tissue due to an increase in intrapulpal temperature exceeding the critical value of 5.5°C.[27] However, there is no clear evidence regarding whether application of heat increases the frequency and severity of postoperative tooth hypersensitivity in vital bleaching procedures since randomized, controlled clinical studies addressing this question are still lacking.[27]

Liquid strip was used as a separating medium. It has a negligible thickness and can be washed out from the tooth surface with simple water irrigation. In the pilot study, the effect of the liquid strip on the temperature increase was tested, and it was confirmed that it did not affect the results. To prove its inertness, it would have been more preferable to place one group in the study design in which

Table 4: *The Average Value of Pulpal Temperature at 10, 20, and 30 s (T_{10sec}, T_{20sec}, and T_{30sec})*

Time	Groups	1 No Cavity Preparation	2 Cavity Preparation	3 Cavity Preparation + Tetric N Ceram	4 Cavity Preparation + Tetric N Flow
T_{10sec}	LED_{low}	33.24	33.79	34.77	35.68
	QTH	33.73	34.41	35.14	36.07
	LED_{high}	34.13	35.33	35.62	36.95
T_{20sec}	LED_{low}	34.52	35.23	36.15	37.35
	QTH	35.57	36.10	36.92	38.07[a]
	LED_{high}	36.51	37.91[a]	38.05[a]	39.53[a]
T_{30sec}	LED_{low}	35.67	36.40	37.26	38.15[a]
	QTH	37.00	37.38	38.05[a]	39.12[a]
	LED_{high}	38.58[a]	40.03[a]	40.08[a]	41.25[a]

[a] *Represents an intrapulpal temperature increase more than 5.5°C.*

composites were placed into the cavity without the strip. However, this was not done because it would not be possible to remove the composites from a cavity without damaging the tooth structure without the liquid strip.

CONCLUSIONS

The intrapulpal temperature increased more when using the higher intensity light-curing unit. Composite curing by light-curing units increased intrapulpal temperature. The light-curing time should be controlled depending on the power density of light-curing units to limit the intrapulpal temperature increase to within a safe range.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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