The parameters influencing the increase in pulp chamber temperature when using light-curing devices: Cavity preparation, composite filling and power density of curing lights

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(Directed by Prof. Sungho Park, D.D.S., M.S.D., Ph.D.)

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감사의 글

부족한 제가 본 논문을 잘 마무리할 수 있도록 아낌없는 지도와 편달을 하여 주신 박성호 교수님께 마음속 깊이 진심 어린 감사를 드립니다. 또한 지금의 제가 있을 수 있도록 지도해 주신 이찬영 교수님, 이승종 교수님, 노병덕 교수님, 김의성 교수님, 정일영 교수님, 박정원 교수님, 신수정 교수님과 김경남 교수님, 김광만 교수님께도 깊은 감사를 드립니다.

아울러 바쁜 와중에도 제가 어려움을 겪을 때마다 많은 도움을 주신 신유석 교수님, 방난심 교수님께 감사를 드립니다. 논문이 무사히 나올 수 있도록 여러 면에서 많은 도움을 주신 이미영 원장님을 비롯한 치과 식구들, 특히 주말을 마다하지 않고 늦게까지 남아서 실험을 도와준 조중헌, 김현화 선생과 채지환 과장님께 감사의 말을 전합니다.

끝으로 참되고 올바른 삶을 살아나가도록 끊임없는 사랑과 정성으로 뒷바라지 해주신 아버님, 어머님, 누님과 친자식처럼 아껴주시는 장인어른, 장모님, 늘 묵묵히 사랑으로 도와주는 영원한 동반자인 사랑하는 아내 희재와 아영이, 원영이에게 이 논문을 바칩니다.

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Abstract

The parameters influencing the increase in pulp chamber temperature when using light-curing devices: Cavity preparation, composite filling and power density of curing lights

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 2 curing lights (3 curing modes): the VIP Junior (QTH, BISCO, Schaumburg, USA) and the Bluephase LED curing lights (2 modes: LED_{low} & LED_{high}; Ivoclar Vivadent, Schaan, Liechtenstein). All curing lights were activated for 60 seconds. For the prepared tooth group (group 2), a class V cavity, 4.0 mm (width) X 4.0 mm (height) X 1.8 mm (depth) in size, was excavated on the buccal surface of the same tooth for the temperature measurement of the prepared cavity. 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 resin composite with A3 shade (Tetric N Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) (group 3) or flowable composite with A3 shade (Tetric N Flow, Ivoclar Vivadent, Schaan, Liechtenstein) (group 4). The light curing and temperature measurements were performed for these groups using the same methods used in the other groups.

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

The T_{MAX} was 38.35 ℃ (group 1), 38.97 ℃ (group 2), 39.75 ℃ (group 3) and 40.31 ℃ (group 4) for the LED_{low} mode. For the QTH mode, the T_{MAX} was 40.06 ℃ (group 1), 40.39 ℃ (group 2), 40.93 ℃ (group 3) and 41.42 ℃ (group 4). For the LED_{high} mode, the T_{MAX} was 43.29 ℃ (group 1), 44.54 ℃ (group 2), 44.67 ℃ (group 3) and 45.33 ℃ (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 in ($p<0.05$).

Keywords: pulp temperature, curing light, composite filling, flowable composites, cavity preparation

The parameters influencing the increase in pulp chamber temperature with light-curing devices: Cavity preparation, composite filling and power density of curing lights

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I. Introduction

Light curing is an indispensable process in direct adhesive restorations. Many dental materials, such as restorative composites, bonding agents, luting materials, pit and fissure sealants, temporary restorations and even some bleaching agents employ curing lights for polymerization or activation of the materials. High−power density curing lights 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 (Park et al., 2010).

Zach and Cohen (Zach and Cohen, 1965) reported that temperature increases of 5.5 ℃ and 11 ℃ resulted in a necrosis of 15% and 60%, respectively, of the pulpal tissues when examined after 3 months. In that trial, the teeth in 5 rhesus monkeys were heated with a soldering gun at a temperature of 275 ℃ (±50 ℃) for 5 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, a 9 − 15 ℃ temperature increase did not cause histologically confirmed pulpal necrosis after 3 months (Baldissara et al., 1997). In this study, heat was applied to the occlusal surface of 6 premolars and 6 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 those under 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 ℃ 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 cut−off 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 (Loney and Price, 2001; Vandewalle et al., 2005; Yazici et al., 2006), the duration of light exposure and the type of light−curing device used in the curing process (Danesh et al., 2004; Ozturk et al., 2004; Yap and Soh, 2003). 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 curing lights in a prepared vs. a non−prepared cavity.

Placing composites into a cavity and curing them with curing lights has been reported to increase the pulpal temperature (Danesh et al., 2004; Daronch et al., 2007; Goodis et al., 1990; Hannig and Bott, 1999; Knezevic et al., 2001; Loney and Price, 2001; Martins et al., 2006; Ozturk et al., 2004; Powell et al., 1999; Ratih et al., 2007; Weerakoon et al., 2002). However, the temperature increases in only the tooth alone caused by curing lights should be measured separately to determine the increase in pulpal temperature as separate from the composite itself during the course of the light curing process. There is limited information available on the increase in specific pulpal temperature as a result of the light curing process of composites itself. Composites that produce an exothermic reaction can contribute significantly to the increase in pulpal temperature.

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 null hypothesis was as follows:

First, there is no significant difference in the increase of pulp temperature among the curing lights with different power density.

Second, there is no significant difference in the increase of pulp temperature among intact teeth, cavity prepared teeth, and cavities filled with resin composites of different viscosities.

II. Materials and Methods

The experimental design used in this study was based on a previous study by Park, Roulet and Heintze (Park et al., 2010).

1. 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 by half of their length to expose the canal spaces and allow metal tube insertion. After confirming the root canals were free of debris, two metal tubes (diameter 2 mm) were inserted into the apices of both roots, approximately 2 mm, and fixed into position using XP BOND (Dentsply DeTrey GmbH; Konstanz, Germany) and Unifil LoFlo Plus (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 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 Total Etch (Ivoclar Vivadent) for 30 s and rinsed with water. XP BOND was applied to the etched enamel, gently air-dried and then light-cured for 10 s (Bluephase, 1130 mW/cm^2). A K-type thermocouple (CHAL-003;

OMEGA Engineering, INC. Stamford, Connecticut, USA) was positioned in the hole with attention being paid to place the tip in contact with the dentin opposed to the buccal cavity. The thermocouple was fixed in position using Unifil LoFlo Plus and light−cured for 30 s (Fig. 1). A radiograph was taken to confirm the position of the thermocouple (Fig. 2). Other thermocouples were placed in the water bath and the air above the water bath. All 3 thermocouples were connected to a computer via a data logger (Agilent 34970A, Agilent Tech, Santa Clara, California, USA). Software (Agilent BenchLink DataLogger, version 1.4) was used to measure the temperatures at a frequency of 1 Hz. A radiograph was taken to confirm the position of the thermocouple.

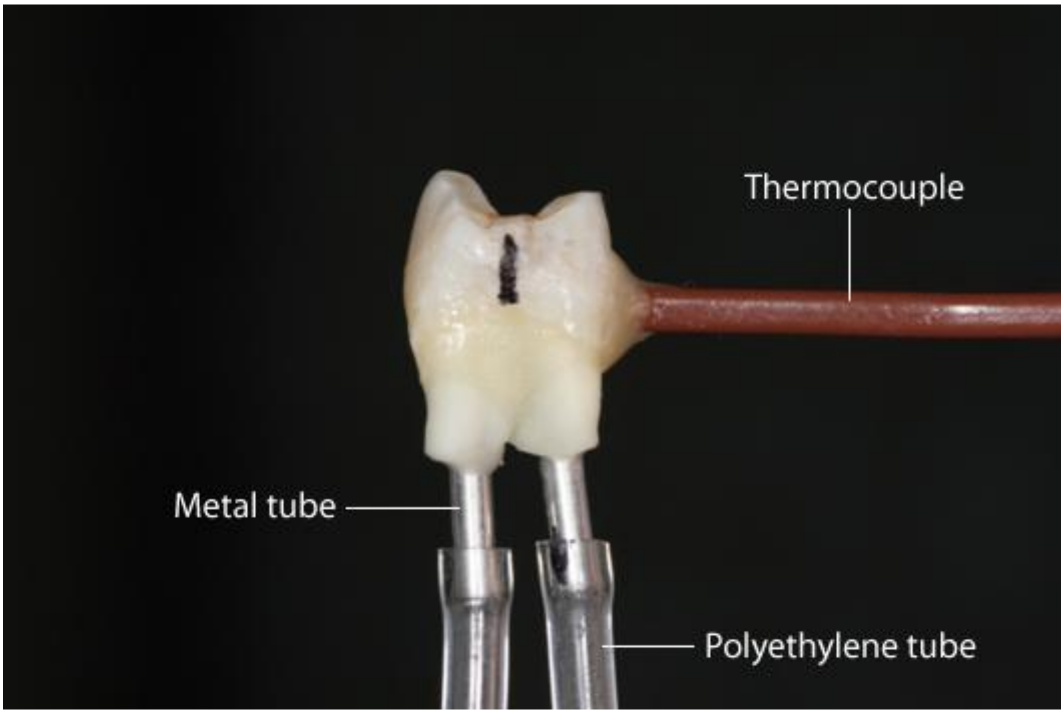

Fig. 1. The premolar connected with a thermocouple and a metal tube.

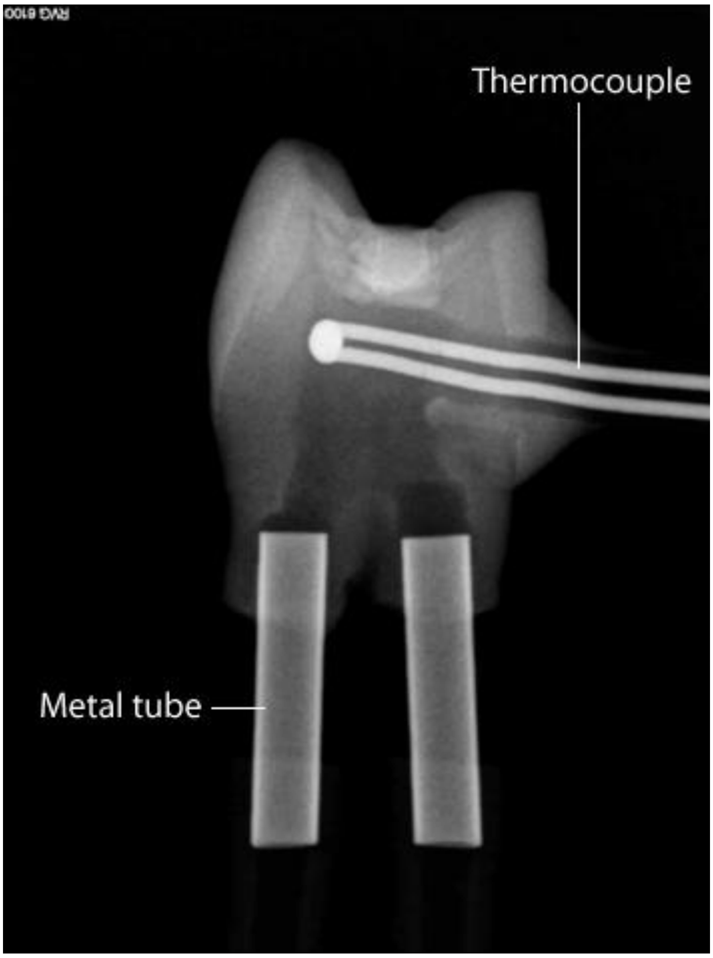

Fig. 2. X−ray of the premolar with a thermocouple and a metal tube.

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 with deionized water (Fig. 3). To mimic tooth blood flow, the flow rate of water was controlled using a regulator in the pump. The flow rate was 40−50 μL/min.

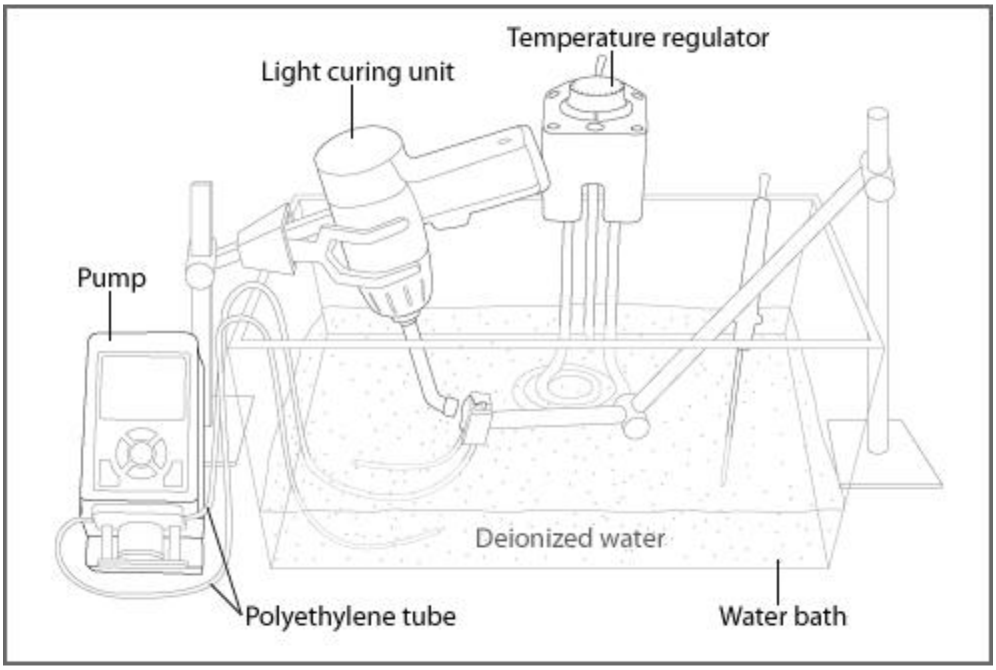

Fig. 3. Schematic diagram of water flow system.

2. Measuring curing light's power density

The curing lights used were as follows: a halogen lamp VIP Junior (QTH, BISCO, Schaumburg, USA) and a Bluephase LED curing light (2 modes: LED_{low} & LED_{high}, Ivoclar Vivadent, Schaan, Liechtenstein). The diameter of the light-curing tip was 9.8 mm in the VIP Junior and 9.0 mm in the Bluephase. The integration power of the curing lights was measured using an integration sphere and its software (Gigahertz-Optic GmbH, Puchheim, Germany). The integration power of the LED_{low}, 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 curing light was calculated by dividing the integration power (mW) of each curing light by the fiber bundle area (cm^2).

Therefore, the power density of each curing light for the LED_{low}, QTH and LED_{high} modes was 785 mW/cm^2, 891 mW/cm^2 and 1447 mW/cm^2, respectively.

3. Measurement of pulpal temperature

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

1) Highest pulp temperature (T_{MAX}) measurements before cavity preparation (group 1).

When the pulp temperature was stabilized between and 32 ± 0.2 ℃, the tooth was exposed to the three curing modes (LED_{low}, QTH and LED_{high}):
For each curing light, the distance from the light tip to the tooth was set to 4 mm using a metal spacer. All curing lights were activated for 60 s. 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 3 min.

The highest pulp temperature (T_{MAX}) in each measurement was registered. The resulting 15 T_{MAX} datasets for each curing light were used for a statistical comparison.

2) T_{MAX} measurement after cavity preparation (group 2).

For the same tooth used in group 1, a 4.0 mm (width) X 4.0 mm (height) X 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 digitalized and software, Analysis Five (SIS, Bergisch-Gladbach, Germany), was used to measure the distance between the pulp space and cavity floor. The depth was 0.85 − 1.0 mm (Fig. 4).

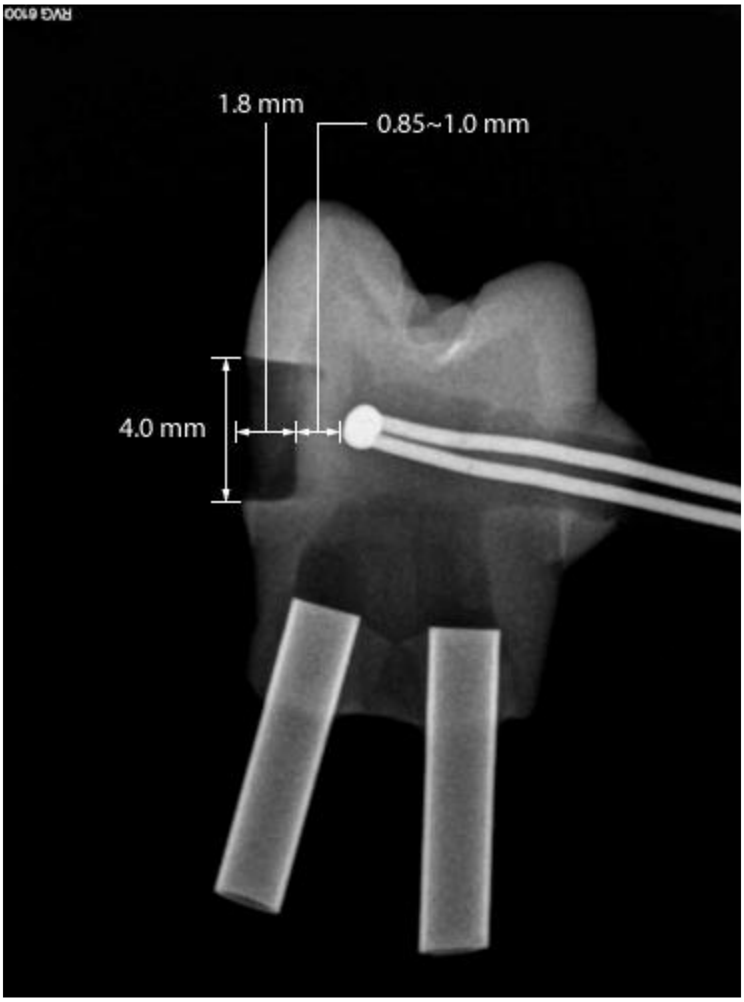

Fig. 4. X-ray of the prepared premolar with a thermocouple and a metal tube.

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

3) T_{MAX} measurement after cavity filling with composites (groups 3, 4).

Using the same tooth used in groups 1 and 2, the cavity was coated with a glycerine−based liquid strip gel (Ivoclar Vivadent, Schaan, Liechtenstein) to allow easy removal of the composite from the cavity after curing and filling with either a resin composite (RC, Tetric N Ceram, A3, Ivoclar Vivadent, Schaan, Liechtenstein) (group 3) or flowable composite (FC, Tetric N Flow, A3, Ivoclar Vivadent, Schaan, Liechtenstein) (group 4). After composite filling, the composite was light cured, and the temperature was recorded using the same procedures as in groups 1 and 2. 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 air dried rapidly, 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} for each measurement were registered and used for statistical analysis.

The study design is summarized in Table 1.

Table 1. Summary of study design.

	Cavity Preparation	Composite filling	Light curing	Temperature Recording
Group 1	X	X	LED_{low} (60 sec) VIP Junior (60 sec) LED_{high} (60 sec)	3 minutes 3 minutes 3 minutes
Group 2	O	X	LED_{low} (60 sec) VIP Junior (60 sec) LED_{high} (60 sec)	3 minutes 3 minutes 3 minutes
Group 3	O	Tetric N Ceram	LED_{low} (60 sec) VIP Junior (60 sec) LED_{high} (60 sec)	3 minutes 3 minutes 3 minutes
Group 4	O	Tetric N Flow	LED_{low} (60 sec) VIP Junior (60 sec) LED_{high} (60 sec)	3 minutes 3 minutes 3 minutes

Cavity dimension: 4.0 mm (width) X 4.0 mm (height) X 1.8 mm (depth)

LED_{low}: Bluephase low power, 785 mW/cm^2

QTH: VIP Junior, 891 mW/cm^2

LED_{high}: Bluephase high power, 1447 mW/cm^2

4. Statistical Analysis

The T_{MAX} for each curing light and the T_{MAX} for groups 1, 2, 3 and 4 were compared using a two-way ANOVA with a post-hoc Tukey’s test using a 95% confidence level.

III. Results

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

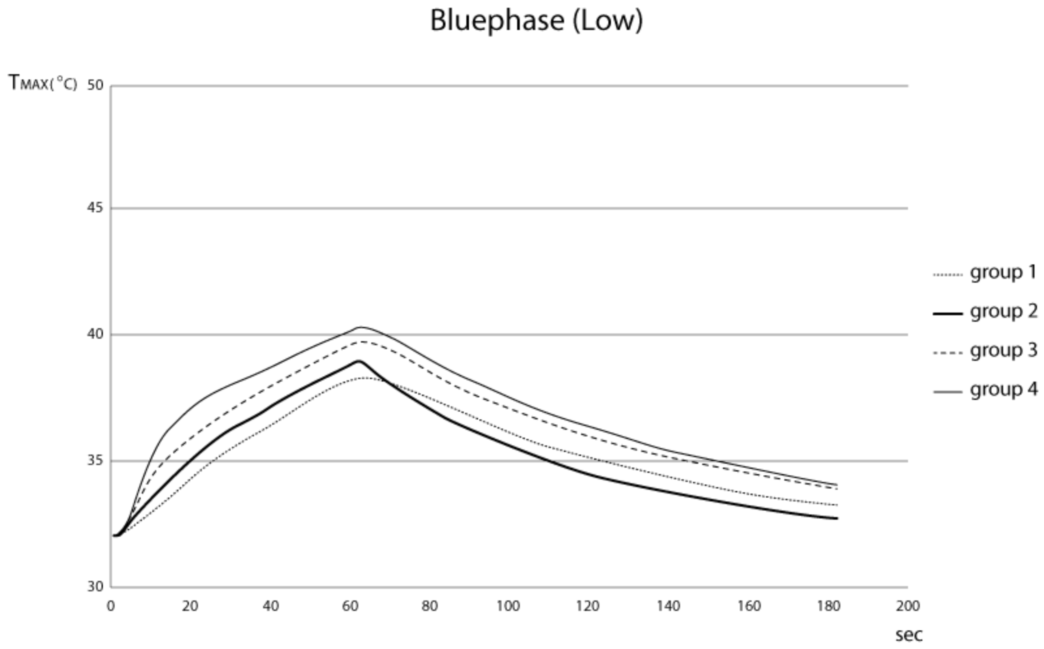

Fig. 5. T_{MAX} versus time in Bluephase low mode.

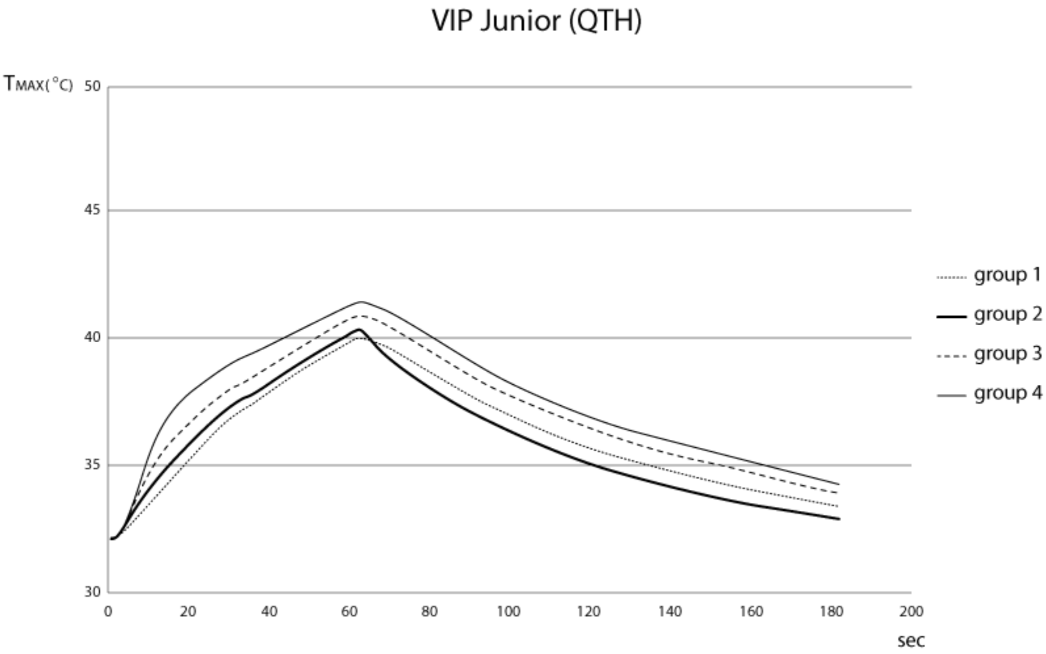

Fig. 6. T_{MAX} versus time in VIP Junior (QTH).

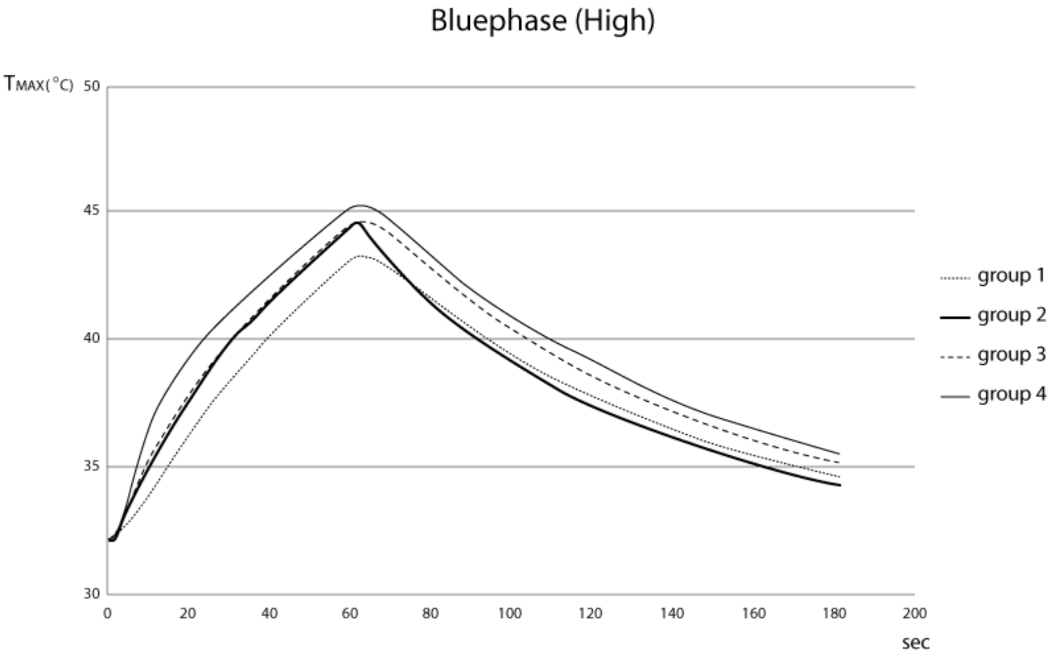

Fig. 7. T_{MAX} versus time in Bluephase high mode.

Table 2. The average value of highest pulpal temperature (T_{MAX})

Groups	1 No Cavity Preparation	2 Cavity Preparation	3 Cavity Preparation + Tetric N ceram	4 Cavity Preparation + Tetric N Flow
LED_{low}	38.35 ± 0.99	38.97 ± 0.80	39.75 ± 0.79	40.31 ± 0.89
QTH	40.06 ± 1.18	40.39 ± 1.19	40.93 ± 0.92	41.42 ± 0.86
LED_{high}	43.29 ± 1.47	44.54 ± 1.31	44.67 ± 0.94	45.33 ± 1.23

LED_{low}: Bluephase low power, 785 mW/cm^2

QTH: VIP Junior, 891 mW/cm^2

LED_{high}: Bluephase high power, 1447 mW/cm^2

Table 3. Two-way 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	.000
Groups (G)	77.726	3	25.909	22.689	.000
Interaction (C)(G)	4.836	6	.806	.706	.645
Error	191.844	168	1.142		
Total	1115.370	179			

The results of the T_{MAX} analyses are listed in Table 2. The T_{MAX} ranged from 38.35 ℃ (group 1) to 40.31 ℃ (group 4) in LED_{low} mode, from 40.06 ℃ (group 1) to 41.42 ℃ (group 4) in QTH, and from 43.29 ℃ (group 1) to 45.33 ℃ (group 4) in LED_{high} mode. The results of the two-way ANOVA revealed that there were significant differences in the T_{MAX} between curing lights ($p<0.05$) and between the groups ($p<0.05$). There was no interaction between them ($p>0.05$) (Table 3). The post-hoc test indicated the following order: LED_{low} < QTH < LED_{high} ($p<0.05$) and group 1 < group 2 ≤ group 3 ≤ group 4 ($p<0.05$).

IV. Discussion

There were significant differences in the T_{MAX} among the curing lights using different power densities. The T_{MAX} in LED_{high} mode was highest, and the T_{MAX} in QTH mode was higher than that in LED_{low} mode. These results indicate that the pulpal temperature increased with the increase of the curing light 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 (Brown et al., 1970; Jacobs et al., 1973), these results indicate that the pulpal temperature increases more in a prepared tooth than an unprepared tooth. Therefore, the second null hypothesis was rejected. This indicates that enamel and dentin are effective as thermal insulators. In clinical situations, the curing light 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 this study indicated. Therefore, it is recommended that clinicians be cautious in avoiding placing the curing light too close and using the light for too long a duration 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 curing lights. This suggests that the composite undergoes an exothermic reaction during the light−curing process, which is consistent with previous studies (Ratih et al., 2007).

McCabe(McCabe, 1985) 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 ℃ (LED_{low}), 0.87 ℃ (QTH) and 1.38 ℃ (LED_{high}). The differences between groups 1 and 4 were 1.96 ℃ (LED_{low}), 1.36 ℃ (QTH) and 2.04 ℃ (LED_{high}). Considering the T_{MAX} difference 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 curing light might be responsible for the increase in temperature of tooth itself, and the effects on the filling material might be limited (Hannig and Bott, 1999; Martins et al., 2006). It is interesting that the T_{MAX} difference between groups 1 and 3 and between group 1 and 4 were relatively lower in the QTH mode compared with the LED_{low} and LED_{high} modes. These results might be related to the higher effectiveness of LED vs. QTH modes in composite polymerization due to efficiency in camphorquinone activation (Bala et al., 2005; Mills et al., 1999; Uhl et al., 2003).

Even though the T_{MAX} in 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 of pulp temperature was prevented. Previous reports indicate that when the composite is cured, a lower increase in temperature occurs in the pulp when the remaining dentin thickness is thicker (Loney and Price, 2001; Yazici et al., 2006). It is recommended that more care should be taken with composite filling procedures in deep cavities to not increase the temperature.

Even though T_{MAX} in group 4 was a little higher than that of group 3, there was no significant difference among them for all curing lights. This is inconsistent with a study by Al−Qudah et al. (Al−Qudah et al., 2005), which reported that the temperature rise with a flowable composite was significantly higher than with hybrid or packable composites. The researchers reported that a flowable composite with a higher proportion of resin available for polymerization can explain the higher temperature rise than other types of composites. This difference between the present study and their study may be due to the differences in the composition of the test materials.

According to Zach and Cohen (Zach and Cohen, 1965), the critical threshold temperature increase to cause a pulp problem was 5.5 ℃. As the initial temperature in the pulp was 32 ℃ in the present study, the amount of the temperature increase in group 4 was approximately 8.31 ℃, 9.42 ℃, 13.3 ℃ for the LED_{low}, QTH and LED_{high}, modes, respectively, after 60 sec of light activation. When we refer to Fig. 5 a, b and c, the critical threshold of 5.5 ℃ was reached after 35 sec for the LED_{low} mode, 27 sec for the QTH mode and 20 sec for the LED_{high} mode in group 3. Park et al. (Park et al., 2010) suggested that curing devices with a high power density (>1200 mW/cm^2) should only be activated for a short duration (<15 sec) 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 ℃ after 24 sec, 18 sec and 14 sec using the LED_{low}, QTH and LED_{high} light curing modes, respectively (Fig. 5 a, b and c).

It would also be meaningful to examine what proportion of the intrapulpal temperature increases after the 30 seconds of light curing commonly used in clinical procedures.

The data of T_{30sec} are listed in Table 4.

Table 4. The average value of pulpal temperature at 30 sec (T_{30sec})

Groups	1	2	3	4
	No Cavity Preparation	Cavity Preparation	Cavity Preparation + Tetric N ceram	Cavity Preparation +Tetric N Flow
LED_{low}	35.67	36.4	37.26	38.15*
QTH	37	37.38	38.05*	39.12*
LED_{high}	38.58*	40.03*	40.08*	41.25*

* represents the intrapulpal temperature increase more than 5.5℃

Temperature increases over the critical threshold of 5.5 ℃ after light curing for 30 seconds were observed in group 4 for the LED_{low} mode, in groups 3 and 4 for the QTH mode and in all groups for the LED_{high} mode. According to the results for the QTH and LED_{high} mode, light−curing for over 30 seconds is not recommended. Recently, high intensity curing lights 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 curing lights for a long duration.

Operational measures that may be helpful in reducing the temperature increase include the use of base materials (Danesh et al., 2004) and modulation of the light intensity (Huang et al., 2006), as well as the curing tip design and diameter (Loney and Price, 2001). Another variable would be the distance of the light tip to the tooth. In the present study, the distance from the light tip to the tooth was set to 4 mm.

Further studies are needed to determine if a temperature change of more than 5.5 ℃ 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.

Liquid strip was used as a separating medium. It has a negligible thickness and can be washed out with simple water irrigation from the tooth surface. 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 composites were placed into the cavity without the strip. However, this was not because it was not possible to remove the composites from a cavity without damaging the tooth structure without the liquid strip.

V. Conclusion

The intrapulpal temperature increased more when using the high intensity curing light treatment. The intrapulpal temperature in the prepared tooth presented a larger increase than the unprepared tooth. The intrapulpal temperature in the prepared tooth with the resin composite or flowable composite presented a larger increase than the unprepared tooth.

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국문 요약

광중합기에 의한 치수강 내 온도 증가에 영향을 미치는 변수 : 와동 형성, 복합 레진 충전과 광중합기의 출력 밀도

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본 연구에서는 출력 밀도가 다른 광중합기를 사용하였을 때, 치질과 수복물이 치수강 내 온도 증가에 미치는 효과에 대하여 조사하였다.

실험 방법으로는 온도감지기의 끝부분을 상악 소구치의 치수 내 협측 상아질 벽에 위치시킨 후, 치근의 협근과 구개근 각각에 금속관을 삽입하여 한쪽은 물이 유입되도록, 다른 한쪽은 물이 유출되도록 하였다. 금속관은 펌프에 연결하여 유량을 조절하도록 하였다.

모든 그룹들은 협측에서 광조사를 시행하였으며, 두 가지 광조사기를 사용하였다. 사용된 광조사기는 VIP Junior (QTH, BISCO, Schaumburg, USA)와 Bluephase (2가지 모드: LED_{low}, LED_{high}, Ivoclar Vivadent, Schaan, Liechtenstein)이다. 모든 광조사기들은 60초간 적용하였다.

그룹 1은 와동이 형성되지 않은 치아상태에서 광조사를 시행하였다. 그룹 2는 와동을 형성한 치아로서, 너비 4.0 mm, 높이 4.0 mm, 깊이 1.8 mm의 5급 와동을 같은 치아의 협측에 형성한 후 그룹 1에서와 같은 방법으로 광조사를 시행하였다. 그룹 2에서 형성된 와동에 복합 레진(A3 shade, Tetric N Ceram, Ivoclar Vivadent, Schaan, Liechtenstein)으로 충전한 것을 그룹 3로, 플로어블 레진(A3 shade, Tetric N Flow, Ivoclar Vivadent, Schaan, Liechtnstein)으로 충전한 것을 그룹 4로 하여, 동일한 방법으로 광조사한 후 온도를 측정하였다.

치수 내 최고 온도(T_{MAX})를 측정하여, 95% 신뢰수준의 two-way ANOVA (with post-hoc Tukey)로 각각의 광조사기와 그룹별로 비교하였다.

실험의 결과, T_{MAX} 값은 LED_{low}의 경우, 그룹 1에서 38.35도, 그룹 2에서 38.97도, 그룹 3에서 39.75도, 그룹 4에서 40.31도를 나타내었다. QTH는, 그룹 1에서 40.06도, 그룹 2에서 40.39도, 그룹 3에서 40.93도, 그룹 4에서 41.42도를 보였다. LED_{high}의 경우는, 그룹 1에서 43.29도, 그룹2에서 44.54도, 그룹 3에서 44.67도, 그룹 4에서 45.33도로 나타났다. 통계분석 결과, 광조사기에서는 LED_{high}, QTH, LED_{low} 순서로 T_{MAX}가 높게 나타났으며 각각 유의성 있는 차이를 보였다($p<0.05$). 광조사 단계인 그룹별 비교에서는 그룹 4, 그룹 3, 그룹 2, 그룹 1의 순서로 높게 나타났으며, 그룹 2와 그룹 3, 그룹 3와 그룹 4 사이에는 유의할 만한 차이를 보이지 않았다($p<0.05$).

핵심 되는 말: 치수 온도; 광조사기; 복합 레진 충전; 플로어블 복합 레진; 와동 형성