EFFECT OF COMPOSITE TYPE, LAYERING METHOD, AND CURING LIGHT ON TEMPERATURE CHANGES IN TOOTH CAVITIES DURING PHOTOPOLYMERIZATION

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Abstract

Objectives. The purpose of this study was to investigate temperature change in the composite and the pulpal side of dentin of a restored cavity under various restoration conditions, including the use of different composite types, layering methods, and curing lights.
Methods. Occlusal cavities were prepared on 12 extracted human molars, and restored using a conventional (Z250, 3M ESPE) or a bulk-fill (BFP, 3M ESPE) composite. Z250 was incrementally layered, while BFP was incrementally layered or bulk-filled. The composites were cured with one of two different LED curing lights (470 nm), an Elipar S10 (0.76W, 3M ESPE) or a BeLite (0.69W, B&L). Each layer was light cured for 20 s, and temperatures were recorded for 120 s using thermocouples (n=3 for each group).
Results. The greatest temperature rise (ΔT_{max}, 16-27℃) was observed at the top of the cavity in all groups. ΔT_{max} decreased as the depth of the measuring points increased. Finally, 4-8℃ of ΔT_{max} was observed at the pulpal side of dentin. The Elipar S10 produced faster temperature changes and also greater ΔT_{max} at all measured points compared to BeLite.
Conclusion. The amount and initial rate of temperature increase were most affected by the radiant exposure of the light curing unit.

1. Introduction

Composites have been widely used in dental clinics because they possess superb esthetic properties with sufficient bond strength and they perform well in normal to large restorations. Despite many advantages of composites, both radiant heat from the curing light and heat from an exothermic chemical reaction of the material are generated during photopolymerization [1-3].

These external heats can be conducted throughout the remaining dentin into the soft tissues of the tooth which can lead to temperature rises within the pulp chamber. Excess temperature rise can induce thermal damage to the dental pulp [4,5]. In a classic histological study, an intrapulpal temperature rises of 5.5℃, 11.1℃ and above 11.1℃ caused 15%, 60%, and almost 100% irreversible pulpal damage in monkeys, respectively [6].

According to a recent study using thermocouples under *in vitro* condition using human teeth, a flowable bulk-fill composite showed greater temperature increase throughout the cavity depth of a tooth compared to the conventional composite using layering method [7]. However, the flowable bulk fill composites are known to have lower mechanical properties, thus requires additional capping layer of conventional composite for sufficient mechanical strength [8]. Their lower filler load and greater volume of resin matrix may have resulted in higher temperature rise due to their greater exothermic heat release [9]. Whereas, high-viscosity, restorative bulk-fill composites have been introduced to the market recently. They showed relatively greater hardness, lower polymerization shrinkage and polymerization shrinkage stress compared to flowable bulk fill composites, supporting that they can be used solely without capping layer [10,11].

A recently developed posterior bulk fill composite, Filtek Bulk Fill Posterior, claims to incorporate high molecular weight monomers in order to reduce polymerization shrinkage stress. Cavity restoration with composite containing high molecular weight monomers may produce less heat during polymerization due to its fewer carbon-carbon double bond content. However, our previous study using infrared thermograms showed that photo-curing of bulk-fill or conventional high-viscosity composites resulted in comparable temperature increases within the composites and dentin [12]. In this study, the amount and the initial rate of temperature increases were most affected by use of different LED curing lights.

To date, no studies have evaluated the temperature changes within the cavity and the pulpal side of dentin of human tooth restored with high-viscosity bulk-fill composites using thermocouples. Therefore, this study was designed to investigate the temperature rises in the composite and dentin in occlusal cavities using thermocouples in extracted human molars under different restoration conditions, including the use of different composite types, layering methods, and curing lights.

2. Materials and methods

2.1. Composites and light curing units

Two composites, Filtek Z250 (Z250, 3M ESPE, St. Paul, MN, USA) and Filtek Bulk Fill Posterior composite (BFP, 3M ESPE), were used in this study (Table 1). According to the manufacturers' instructions, BFP allows up to a 5-mm depth of cure. Two LED light curing units, Elipar S10 (3M ESPE) and BeLite (B&L Biotech, Ansan, Korea), were used for photo-curing of the composites. Based on the manufacturer's information, the Elipar S10 LED curing light emits energy over a wavelength range of 430–480 nm with a single peak at 455 nm ± 10 nm. The irradiance of this curing unit is presented as 1200 mW/cm^2, and the diameter of guide tip was 9.8 mm. BeLite is an LED curing light which emits energy over a wavelength of 430–490 nm with a single peak at 460 nm. Among several curing modes in BeLite, the general composite filling mode (Norm mode, 800 mW/cm^2) was used. The tip diameter of BeLite was 8.8 mm. The radiant power of the Elipar S10 and BeLite curing lights were 0.76 W and 0.69 W, respectively, when measured using a power detector (UP55N-300F-H12, Gentec-EO, Quebec, Canada), confirming that the output of Elipar S10 was greater than that of the BeLite.

2.2. Preparation of tooth specimens

Twelve extracted, caries-free human molars stored in 0.5% chloramine-T solution were used. The occlusal surface of each tooth was ground to a flat surface and occlusal cavities of 6 mm (L) x 4 mm (W) x 3 (D) were prepared using a flat-end cylindrical diamond bur. The prepared specimens were embedded in plastic cylinders (15 mm in diameter and 15 mm in height) below the cemento-enamel junction. Temperature measurement sites were assigned according to the position of the thermocouples (Fig. 1): P1, top center of the cavity; P2, middle center of the cavity; P3, center of the cavity floor; P4, 1 mm apical to pulp from P3.

To adjust thermocouples (K-type, diameter of 0.3 mm) within the cavity, a horizontal groove was prepared at the occlusal surface, and horizontal tunnels were prepared at 1.5 mm apical from the occlusal surface, at the cavity floor, and at 1 mm apical to pulp from the cavity floor using a diamond bur through buccal or lingual wall of the tooth. Flowable composite (Denfil Flow, Vericom Co. Ltd., Chuncheon, Korea) was applied within the groove and tunnels and light cured for 20 s to secure the thermocouple wires. Thermocouples were connected to a thermocouple conditioner (AD8495, Adafruit Industries, New York, NY, USA). The thermocouple data were stored on a computer with a data acquisition board (DAQ PCI6014, National Instruments Co, TX, USA) and software (LabVIEW, National Instruments).

2.3. Temperature measurement during photo-curing of composites

The specimens were divided into four groups (n=3 per group) with regard to the type of composite, layering method, and light curing unit (Table 2). In Group 1, cavities were filled with Z250 using two incremental layers (1.5 mm thick) followed by light curing with Elipar S10 (Z-I-E). In Group 2, cavities were filled with BFP using two incremental layers followed by photopolymerization with Elipar S10 (B-I-E). In Group 3, cavities were bulk filled with BFP and light-cured with Elipar S10 (B-B-E). And in Group 4, cavities were bulk filled with BFP and light cured with BeLite (B-B-B).

Single Bond Universal adhesive was applied in each cavity with a rubbing motion (20 s), and light cured for 10 s before restoration. The tip of the curing light was positioned 2 mm above the occlusal surface of the cavity center. At environmental temperature of 30 ± 0.5℃, composite was filled as assigned and each layer was light cured for 20 s. In the incremental group, a half of the thermocouple at P2 was embedded within the 1st increment, and the other half of the thermocouple at P2 was included within the 2nd increment. 2nd increment in the incremental group and single layer of the bulk filling group incorporated the thermocouple at P1 site. Temperatures were recorded for 120 s, including a 20-s baseline.

The mean maximum temperature rises (ΔT_{max}) and time (s) to reach ΔT=5℃ were analyzed according to the differences in material, layering method, and curing light using independent Student's t-tests. In each group, the values for each temperature measurement site (P1-P4) were analyzed by using one-way ANOVA and Tukey's post hoc comparisons (SPSS version 23.0, SPSS Inc., Chicago, IL, USA) (α= 0.05).

Table 1. Composites used in this study

Composite (Code)	Type	Composition	Filler	Shade	Manufacturer
Filtek™ Z250 (Z250)	Micro-hybrid Conventional Universal	BisGMA BisEMA UDMA	82 wt% (60 vol%)	A2	3M ESPE, St. Paul, MN, USA
Filtek™ Bulk Fill Posterior (BFP)	Nano-hybrid Bulk Fill Posterior	AUDMA AFM UDMA DDDMA	76.5 wt% (58.4 vol%)	A2	3M ESPE

Bis-GMA, Bisphenol-A-diglycidyl ether dimethacrylate; Bis-EMA, Bisphenol-A-polyethylene glycol diether dimethacrylate; UDMA, Urethane dimethacrylate; AUDMA, Aromatic urethane dimethacrylate; AFM, Additional fragment monomers; DDDMA, 1, 12-Dodecanediol dimethacrylate.

Table 2. Four experimental groups with varying composites, layering methods, and curing lights

Group	Composite	Layering Method	Curing Light
1 (Z-I-E)	Z250	Incremental (1.5 mm x 2 layers)	Elipar S10
2 (B-I-E)	BFP	Incremental	Elipar S10
3 (B-B-E)	BFP	Bulk (3.0 mm)	Elipar S10
4 (B-B-B)	BFP	Bulk	BeLite

Z-I-E, Z250-Incremental-Elipar S10; B-I-E, BFP-Incremental-Elipar S10;
B-B-E, BFP-Bulk-Elipar S10; B-B-B, BFP-Bulk-BeLite.

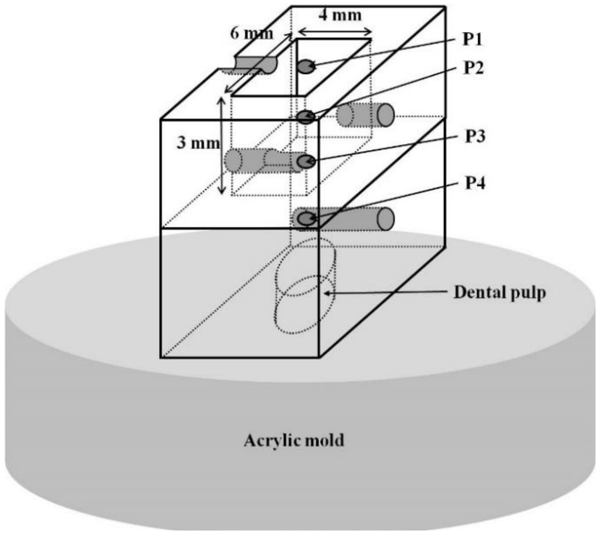

Figure 1. Schematic diagram of prepared tooth specimen showing the cavity design and the location of thermocouples. P1, top center of the cavity; P2, middle center of the cavity; P3, center of the cavity floor; P4, 1 mm apical to pulp from P3.

3. Results

The representative curves of real-time temperature changes at measuring points are shown in Figure 2. The maximum temperature rise (ΔT_{max}) were determined (Table 3, Fig. 3). The ΔT_{max} was highest at P1 and decreased with increasing the depth of the cavity (P1>P2>P3>P4, $p<0.05$) in all groups. Times (s) to reach $\Delta T = 5$℃, the parameter that indicates the initial rate of temperature increase, are shown in Table 4.

3.1. Effect of composite on temperature rise

To investigate the effects of composite type on temperature rise, Group 1 (Z250) and 2 (BFP) were compared (Tables 3 and 4). At P1 and P2, Z250 generated greater ΔT_{max} compared to BFP ($p<0.05$), but no significant differences were observed at P3 and P4 between the groups. ΔT_{max} at the center of the cavity floor (P3) was 15-16℃. At the dentin near the pulp, P4, ΔT_{max} of 6-8℃ was observed. Different composites did not influence on the initial rate of temperature rise (Table 4).

3.2. Effect of layering methods on temperature rise

Group 2 (incremental layering) and 3 (bulk filling) were compared to evaluate the effect of different layering methods on temperature rise when restored with BFP (Tables 3 and 4). ΔT_{max} of bulk filled

BFP at P1 (26.5 ± 2.0℃) was significantly greater compared to that of incremental layering at P1 (22.4 ± 0.6℃) (p<0.05). There were no significant differences of ΔT_{max} at P2, P3 and P4 between the groups. At P3, ΔT_{max} was observed as 14-16℃, while maximum 6-7℃ increased at P4. Different layering methods did not influence on the initial rate of temperature increase (Table 4).

3.3. Effect of curing lights on temperature rise

The effect of the different curing light on the temperature rise when curing the bulk fill composite was investigated by comparing Group 3 (Elipar S10) and 4 (BeLite) (Tables 3 and 4). At all measuring points, Elipar S10 showed greater ΔT_{max} compared to BeLite. At P3, Elipar S10 gave rise to ΔT_{max} of 14.2 ± 0.6℃, while BeLite generated ΔT_{max} of 9.2 ± 0.2℃ (p<0.05). ΔT_{max} at P4 with Elipar S10 and BeLite were 6.4 ± 0.5℃, 4.8 ± 0.2℃, respectively (p<0.05). In Group 3, the initial rate of temperature rises was significantly higher (shorter time to reach ΔT = 5℃) than in Group 4 at P1-P3.

Table 3. Mean maximum temperatures rises, ΔT_{max} (℃), measured during composite curing

Group	Temperature measurement sites			
	P1	P2	P3	P4
	ΔT_{max} in Group 1 (Z-I-E) and Group 2 (B-I-E)			
Group 1	24.4 (0.9) $^{a, A}$	21.7 (1.2) $^{a, A}$	15.5 (1.1) $^{a, B}$	8.0 (2.2) $^{a, C}$
Group 2	22.4 (0.6) $^{b, A}$	18.8 (1.0) $^{b, B}$	15.9 (1.3) $^{a, C}$	6.7 (0.4) $^{a, D}$
	ΔT_{max} in Group 2 (B-I-E) and Group 3 (B-B-E)			
Group 2	22.4 (0.6) $^{b, A}$	18.8 (1.0) $^{a, B}$	15.9 (1.3) $^{a, C}$	6.7 (0.4) $^{a, D}$
Group 3	26.5 (2.0) $^{a, A}$	19.5 (3.1) $^{a, B}$	14.2 (0.6) $^{a, C}$	6.4 (0.5) $^{a, D}$
	ΔT_{max} in Group 3 (B-B-E) and Group 4 (B-B-B)			
Group 3	26.5 (2.0) $^{a, A}$	19.5 (3.1) $^{a, B}$	14.2 (0.6) $^{a, C}$	6.4 (0.5) $^{a, D}$
Group 4	16.1 (0.6) $^{b, A}$	12.6 (0.5) $^{b, B}$	9.2 (0.2) $^{b, C}$	4.8 (0.2) $^{b, D}$

Different superscript lower-case letters indicate a statistically significant difference between two groups (within the column, p < 0.05). Different superscript upper-case letters indicate statistically significant differences among POIs (within the row, p < 0.05).

Table 4. Times (s) to reach ΔT=5℃ during composite curing

Group	Temperature measurement sites			
	P1	P2	P3	P4
	Times to reach ΔT=5℃ in Group 1 (Z-I-E) and Group 2 (B-I-E)			
Group 1	0.8 (0.1) $^{a, B}$	0.8 (0.1) $^{a, B}$	1.3 (0.1) $^{a, B}$	11.1 (6.2) $^{a, A}$
Group 2	1.0 (0.1) $^{a, B}$	1.2 (0.4) $^{a, B}$	1.5 (0.3) $^{a, B}$	15.2 (2.2) $^{a, A}$
	Times to reach ΔT=5℃ in Group 2 (B-I-E) and Group 3 (B-B-E)			
Group 2	1.0 (0.1) $^{a, B}$	1.2 (0.4) $^{a, B}$	1.5 (0.3) $^{b, B}$	15.2 (2.2) $^{a, A}$
Group 3	0.8 (0.1) $^{a, B}$	1.4 (0.1) $^{a, B}$	2.6 (0.0) $^{a, B}$	16.4 (1.7) $^{a, A}$
	Times to reach ΔT=5℃ in Group 3 (B-B-E) and Group 4 (B-B-B)			
Group 3	0.8 (0.1) $^{b, B}$	1.4 (0.1) $^{b, B}$	2.6 (0.0) $^{b, B}$	16.4 (1.7) ^{A}
Group 4	1.4 (0.1) $^{a, C}$	2.2 (0.2) $^{a, B}$	4.4 (0.3) $^{a, A}$	N/A

Different superscript lower-case letters indicate a statistically significant difference between two groups (within the column, p < 0.05). Different superscript upper-case letters indicate statistically significant differences among

POIs (within the row, $p < 0.05$).

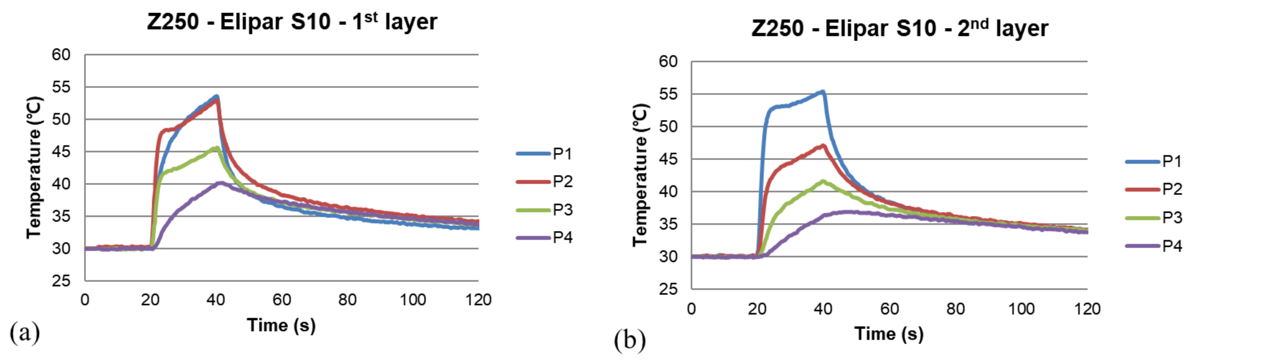

Figure 2. Representative curves of temperature change as a function of time during light curing. Photo-curing of (a) first layer and (b) second layer of Z250 using Elipar S10 in Group 1.

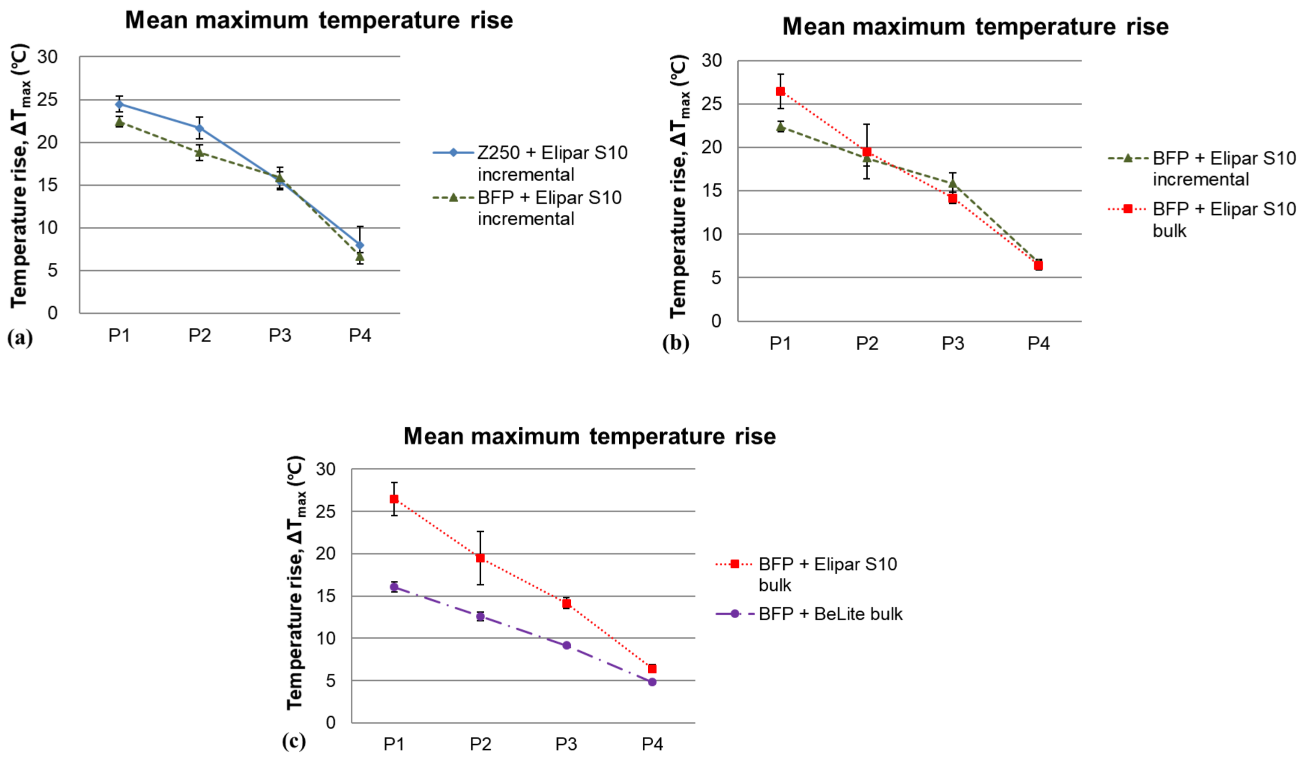

Figure 3. Mean maximum temperature rises, ΔT_{max} at different points (P1-P4) of tooth restored with different composites (a), layering methods (b), and curing lights (c).

4. Discussion

Heat generation occurs inevitably during the photo-curing of composites. Not only the radiant heat arises from the tip of curing light which transmits throughout the restoring material and dentinal tissue, but the exothermic heat develops during the polymerization process of the composite.

The experimental design of this study was as the same as our previous report [12], except that the tooth cavity was remained intact and the temperature measurement was performed using multiple thermocouples. The greatest temperature rise (ΔT_{max}, 16-27℃) was observed at the top of the cavity (P1) in all groups, and ΔT_{max} decreased as the depth of the measuring points increased. This observation is consistent with the findings that the temperature increases were greater at the top surface than at the bottom surface when thermocouples were used [7]. As the occlusal cavity was surrounded by lateral walls, relatively small amount of heat was lost when compared to ΔT_{max} in the open cavity which was obtained by using the infrared thermal camera (ΔT_{max}, 9-11℃) [12].

Z250 resulted in greater temperature increase at the top and at the middle of the cavity compared to BFP during polymerization. However, temperatures at the floor of the cavity and the pulpal side of dentin were not affected by the types of composite material. The temperature increases within the composites are closely correlated to the polymerization heat, thus they are influenced by the number of C=C double bonds and filler contents [13]. More resin matrix with less filler content would be expected to generate more polymerization heat. According to the manufacturer's literature, the filler content of BFP (76.5 wt%, 58.4 vol%) was lower than that in Z250 (82 wt%, 60 vol%). However, BFP in known to possess novel monomer type with high molecular weight which decreases the number of reactive group in resin. These factors might have influenced on the temperature rises of composites.

Bulk filling of BFP showed greater temperature rise at the top of the cavity compared to incremental filling of BFP in the second layer. Since the exothermic heat is related to the types and amount of the resin matrix of composite materials [14], greater amount of resin matrix in bulk filling group is expected to generate more heat compared to incremental group. Nonetheless, there were no significant differences between the incremental and the bulk filling groups at the regions close to the pulp chamber (P3, P4).
When two curing lights were compared, the Elipar S10 gave rise to greater temperature increase at all measuring points compared to BeLite. Furthermore, it took less time for Elipar S10 to increase by 5℃ at all measuring points, which represents that the Elipar S10 induced faster initial temperature rise than BeLite. It can be explained by the fact that the Elipar S10 (0.76W) had greater radiant power than the BeLite (0.69W). In our previous report, Elipar S10 produced greater heat compared to BeLite in both composites [12]. Therefore, it can be concluded that the light curing unit had a great influence on the amount of temperature rise and the initial rate of temperature increase, which was consistent with our previous report performed by infrared thermal camera [12].

The measuring point P4 exhibited the lowest ΔT_{max} (4.8-8.0℃). The distances from this point to pulp chamber may vary, however, the amount of heat transferred to this point can influence the condition of pulpal tissues depending on the amount of dentinal tissue remained in between. According to the classic histological study performed in monkeys, an increase of 5.5℃ in the pulp chamber was considered as a critical threshold for irreversible pulpal damage, which led to 15% of damages [6]. When composites were light cured with either curing light, the Elipar S10 led to temperature increase of 6.4-8.0℃ at P4, while BeLite generated temperature increase of 4.8℃ at the same measuring point. If the floor of the cavity was within 1 mm from the pulp chamber, the pulp tissue of the Elipar S10 group can be placed in the environment higher than the critical threshold. However, in a vital tooth, microcirculation of pulpal blood may involve in temperature control within the pulp chamber. So that the results of this study should be evaluated carefully in terms of thermal damage of pulpal tissue.

5. Conclusions

Cavity restoration using either composite, Z250 or BFP, or by using either incremental or bulk-filling method, resulted in comparable temperature increase during polymerization at the pulpal side of dentin in a tooth cavity. The intensity of radiant exposure of the curing light was the only factor that influenced the amount and initial rate of the temperature increases. Within the limitations of this *in vitro* study, when irradiation time is constant, a curing light with greater irradiance can induce relatively high thermal transfer, thereby increasing the risk of the pulpal damage.

Acknowledgments

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