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Research Article

Intrapulpal Thermal Changes during Setting Reaction of Glass Carbomer® Using Thermocure Lamp

Firdevs Kahvecioglu,[1] Gül Tosun,[1] and Hayriye Esra Ülker[2]

[1] *Department of Pediatric Dentistry, Faculty of Dentistry, Selcuk University, Konya, Turkey*
[2] *Department of Restorative Dentistry, Faculty of Dentistry, Selcuk University, Konya, Turkey*

Correspondence should be addressed to Firdevs Kahvecioglu; drfirdevskahveci@hotmail.com

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Objectives. To measure the temperature increase induced during thermocure lamp setting reaction of glass carbomer and to compare it with those induced by visible light curing of a resin-modified glass ionomer and a polyacid-modified composite resin in primary and permanent teeth. *Materials and Methods*. Nonretentive class I cavities were prepared in extracted primary and permanent molars. Glass carbomer (GC) was placed in the cavity and set at 60°C for 60 sn using a special thermocure lamp. Resin-modified glass ionomer (RMGIC) and polyacid-modified composite resin (PMCR) were placed in the cavities and polymerized with an LED curing unit. Temperature increases during setting reactions were measured with a J-type thermocouple wire connected to a data logger. Data were examined using two-way analysis of variance and Tukey's honestly significant difference tests. *Results*. The use of GC resulted in temperature changes of 5.17 ± 0.92°C and 5.32 ± 0.90°C in primary and permanent teeth, respectively ($p > 0.05$). Temperature increases were greatest in the GC group, differing significantly from those in the PMCR group ($p < 0.05$). *Conclusion*. Temperature increases during polymerization and setting reactions of the materials were below the critical value in all groups. No difference was observed between primary and permanent teeth, regardless of the material used.

1. Introduction

Heat production is the most severe stress generated in the pulp by various operative procedures [1]. Thermal trauma may be induced by cavity preparation, exothermic polymerization reactions of resin-based restorative materials [2], and exothermic acid-base setting reactions of glass ionomer-based restorative materials [3] or from various light sources used for curing restorative materials [4, 5] and may eventually damage pulp tissue irreversibly if it is not controlled [6, 7].

A classic animal study by Zach and Cohen [6] established a threshold temperature for irreversible pulpal damage caused by the application of external heat to a sound tooth; a 5.5°C increase in intrapulpal temperature induced necrosis in 15% of pulp samples tested. Several in vitro studies have shown that various light sources used during the polymerization of resin-based restorative materials cause such increases in pulp temperature [4, 5].

Improvements in restorative materials and techniques, together with increased demand for aesthetic restorations, have led to the introduction of a wide range of dental materials, including compomer, resin-modified glass ionomer cements, and self-adhering composites. These materials contain variable proportions of resin matrix. As the exothermic reaction is proportional to the amount of resin available for polymerization and the degree of conversion of carbon–carbon double bonds, these materials may be expected to show different degrees of temperature increase when cured by the same light unit. In a 2005 study, Al-Qudah et al. [8] attempted to quantify the temperature increase caused by the light source alone. The variation in maximum temperature increases among these materials may be correlated with their resin content. The authors demonstrated exothermic temperature increases during the setting of resin-modified glass ionomer (RMGIC) and polyacid-modified composite resin

(PMCR) [8]. Polymerization of photo-activated resin composites can result in an intrapulpal temperature increase due to the exothermic reaction process and the energy absorbed during irradiation [9, 10].

Glass carbomer (GC), another newly developed material, is a glass ionomer-based restorative material. GC is distinguished from glass ionomer by its nanosized powder particles and fluorapatite crystals. The addition of fluorapatite was based on the belief that glass ionomers turn into fluorapatite-like material over time [11]. The advantages of GC over conventional glass ionomer cements include significantly better mechanical and chemical properties (e.g., strength, shear, and wear) [12–14]. The clinical application of GC is similar to that of conventional glass ionomer cement, except that heat application (60°C, 60 sn) with a special thermocure lamp is recommended during the setting reaction. The beneficial effects of heat on glass ionomers have been documented in recent studies [14–16]. However, the effects of these materials on intrapulpal temperature increase during the setting reaction are not known.

The objectives of this study were (1) to measure the temperature increase induced during thermocure lamp setting reaction of an GC and compare it with those induced by visible light curing of an RMGIC and an PMCR and (2) to compare temperature increases in primary and permanent teeth during setting and curing of these three materials. We hypothesized that temperature increases in pulp chambers during the setting of GC, RMGIC, and PMCR materials would be similar and that temperature increases in the pulp chambers of primary and permanent teeth would be similar.

2. Materials and Methods

In this study, the temperature increases induced during thermocure lamp setting reaction of a glass carbomer (Glass Fill) and induced by visible light curing of a resin-modified glass ionomer cement (Fuji II LC) and a polyacid-modified composite resin (Dyract AP) in primary and permanent teeth were investigated (Table 1).

Nonretentive class I cavities were prepared in extracted, caries-free human primary and permanent second molars. One mm dentine thickness, measured with a digital micrometer (Mitutoyo, Japan), was left between the pulp chamber and occlusal cavity floor. The roots of each tooth were ground away, and the remains of the pulpal tissue were removed. The pulp chamber was then cleaned of all organic remnants using 5.25% sodium hypochlorite solution.

The same procedure was repeated for all groups. The groups were prepared as follows:

(i) Group 1A ($n = 20$): permanent dentine + Dyract AP + LED curing light

(ii) Group 1B ($n = 20$): primary dentine + Dyract AP + LED curing light

(iii) Group 2A ($n = 20$): permanent dentine + GCP Glass Fill + GCP CarboLED thermocure lamp

(iv) Group 2B ($n = 20$): primary dentine + GCP Glass Fill + GCP CarboLED thermocure lamp

(v) Group 3A ($n = 20$): permanent dentine + Fuji II LC + LED curing light

(vi) Group 3B ($n = 20$): primary dentine + Fuji II LC + LED curing light

All measurements were performed on the same primary and permanent teeth to limit the effects of differences in tooth structure. Each tooth was attached to a novel apparatus, designed originally by Sari et al. [17] and customized for this study, to simulate pulpal blood microcirculation (Figure 1). A standard infusion set (Gemed Medical Co., Istanbul, Turkey) with a 21-gauge (green) injector needle was attached to a distilled water bottle (1000 mL). The length of the injector needle was shortened to 5 mm, and the tip of the needle (1 mm in length) was placed on a stainless-steel metal base plate through a drilled hole and used for water inflow. Another needle tip, which was connected to a freestanding infusion tube, was placed adjacent to the first tip and used for water outflow. The fluid flow rate of the system was set and kept constant at 0.026 mL/min using a digital infusion flowmeter (SK-600II infusion pump; SK Medical, Shenzhen, China), which was attached to the system. Room temperature distilled water was used to simulate blood and blood pressure (15 cm H_2O) in the pulp (Figure 1). Light curing glass ionomer cavity-liner cement (glass liner; WP Dental GmbH, Barmstedt, Germany) was used to fix the samples onto the stage of the apparatus. A narrow hole providing access to the pulp chamber was drilled into the distal surface of each crown using a diamond bur, and a J-type thermocouple wire (0.36 mm diameter; Omega Engineering, Stamford, CT, USA) was inserted through this aperture into the pulp chamber. A silicone heat-transfer compound (ILC P/N 213414; Wakefield Engineering, Beverly, MA, USA) was applied to the tip of the thermocouple wire, and the wire was fixed in a position that maintained contact with the pulp chamber using light curing calcium hydroxide cement (Calcimol LC; Voco GmbH, Cuxhaven, Germany). The same cement was used to seal the gap around the thermocouple wire, preventing leakage from the system.

RMGIC and PMCR were placed into the cavities and polymerized with an LED curing unit (Ultradent, USA) according to the manufacturer's instructions (Table 2). GC was placed in the cavities and cured for 60 s, at 60°C with a special thermocure lamp (CarboLED, 1400 mw/cm^2; GCP Dental, Netherlands). All application procedures were performed according to the manufacturers' instructions. No acid etching or dentine bonding was performed to enable easy removal of the restorative materials, thereby maintaining constant cavity size during repeated removal procedures, as suggested by Hannig and Bott [10]. The procedures were applied to primary and permanent teeth. During polymerization and setting, temperature increases inside the pulp chambers were measured with a thermocouple connected to a data logger (XR440-M Pocket Logger; Pace Scientific, NC, USA) and a computer. The data logger was set to record one sample every 2 s for the duration of recording, which started with light application and continued until the temperature began to decrease. Data collection was monitored in real time, and data in tabular and graphic forms were transferred to a

Table 1: Material, manufacturer, and composition of the materials used in study.

Material	Manufacturer	Composition
Fuji II LC (RMGIC)	GC Corporation, Tokyo, Japan	Aluminofluorosilicate glass, polyacrylic acid, 2-hydroxyethyl methacrylate, 2,2,4-trimethyl hexamethylene dicarbonate, triethylene glycol dimethacrylate
GCP Glass Fill (GC)	GCP Dental, Vianen, Netherlands	Fill: fluoroaluminosilicate glass, apatite, polyacids Gloss: modified polysiloxanes
Dyract AP (RMCR)	Dentsply, Germany	Urethane dimethacrylate (UDMA), tetracarboxylic acid-hydroxyethyl methacrylate-ester (TCB resin), alkanoyl-polymethacrylate, strontium-fluorosilicate glass, strontium fluoride, photoinitiators, butylhydroxytoluene, iron oxide pigments

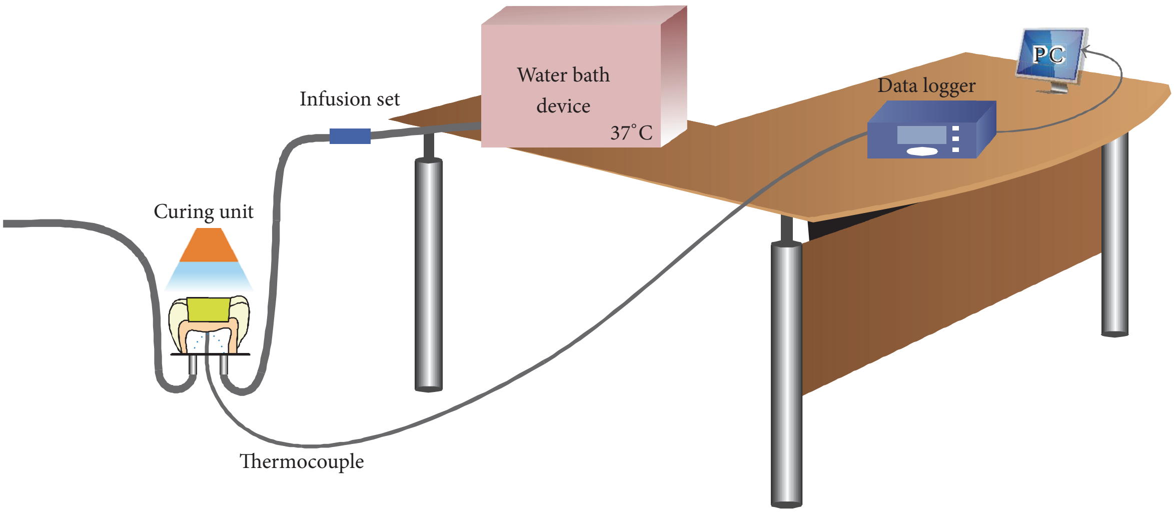

Figure 1: Pulpal microcirculation device.

computer. Differences between initial and highest temperature readings (Δt) were determined.

2.1. Statistical Analysis. Values from all groups were examined using two-way analysis of variance, after the results of Levene and Shapiro–Wilk tests had confirmed equality of variance and the assumption of normality, respectively ($p > 0.05$). Then, Tukey's honestly significant difference test for multiple comparisons was applied to determine further differences among groups. Results are presented as means, minimums, maximums, and standard deviations. The significance level was set to $p < 0.05$ for all tests. All computations were performed using the SPSS program for Windows (version 20; SPSS, Inc., Chicago, IL, USA).

3. Results

The mean and standard deviations of the temperature rise at the primary and permanent teeth for all tested materials are shown in Table 3. Temperature changes in permanent and primary teeth with PMCR were 3.04 ± 0.64°C and 3.26 ± 0.77°C, respectively ($p > 0.05$). Temperature changes in permanent and primary teeth with Fuji II LC were 3.90 ± 0.96°C and 4.22 ± 1.29°C, respectively ($p > 0.05$). The use of GC and the CarboLED lamp resulted in temperature changes in permanent and primary teeth of 5.17 ± 0.92°C and 5.32 ± 0.90°C, respectively ($p > 0.05$).

Temperature increases were the greatest in the GC group. Two-way analysis of variance revealed highly significant differences between GC group and PMCR group both permanent and primary teeth ($p < 0.001$). Results from the PMCR and RMGIC groups were similar ($p > 0.05$).

The smallest temperature increases were observed in PMCR group. No difference was observed between primary and permanent teeth, regardless of the material used ($p > 0.05$).

4. Discussion

In the present study, temperature increases induced during thermocure lamp setting reaction of an GC and visible light curing of an RMGIC and an PMCR material were evaluated in the pulp chambers of primary and permanent teeth. The first study hypothesis was partially supported, as increases in the GC group differed from those in the PMCR group in primary and permanent teeth. The second study hypothesis was supported because temperature increases in the pulp chambers of primary and permanent teeth were similar.

Pediatric dental clinics provide restorative treatments for primary and permanent teeth. Thus, clear definition of

Table 2: Light curing unit used in this study.

LCU	Manufacturer	Light intensity	Curing time
VALO LED light curing unit	Ultradent Products Inc., South Jordan, UT, USA	1000 mW/cm^2	20 s
GCP CarboLED thermocure lamp	GCP Dental, Ridderkerk, Netherlands	1400 mW/cm^2	60 s

Table 3: Descriptive statistics of the intrapulpal temperature changes of all groups.

Groups	Primary			Permanent		
	N	Mean ± SD (°C)	Min–max	N	Mean ± SD (°C)	Min–max
Dyract AP	20	3.26 ± 0.77°C^{a}	2.20–4.80	20	3.04 ± 0.64°C^{a}	2.40–4.30
Fuji II LC	20	4.22 ± 1.29°C^{ab}	2.40–5.90	20	3.90 ± 0.96°C^{ab}	2.20–5.40
GCP Glass Fill	20	5.32 ± 0.90°C^{b}	2.90–8.70	20	5.17 ± 0.92°C^{b}	3.90–6.50

$p < 0.05$.
SD: standard deviation. There is no statistically significant difference between the same letters in the same column.
$p > 0.05$.

all structural differences between tooth types is important, especially when restorative materials are used to improve the quality of primary teeth. For this reason, we used primary and permanent teeth in this study.

Pulp microcirculation is an important factor in the regulation of intrapulpal temperature when heat is transferred from an external thermal stimulus to the dentine-pulp complex [18, 19]. Lack of microcirculation has been shown to cause greater changes in intrapulpal temperature [20]. Sari et al. [17] designed a novel pulp-blood microcirculation apparatus and used water circulation in the pulp chamber to simulate in vivo conditions. We also used a pulp-blood microcirculation apparatus in the present study. Dental pulp is a highly vascularized tissue, and its viability may be compromised during cavity preparation and restorative procedures [21]. These procedures can increase the intrapulpal temperature and damage the pulp tissue [22]. Zach and Cohen [6] studied the effects of heat on pulp tissue and found that a 5.5°C increase in intrapulpal temperature was associated with irreversible pulpitis in 15% of teeth tested in rhesus macaques. When the intrapulpal temperature rose to 11.1°C, 60% of teeth became necrotic [6]. In the present study, temperature increases in all groups were less than 5.5°C, the estimated critical temperature for pulp damage. To protect vital pulp from thermal damage, excess heat must be distributed or removed from the area. The major limitation of in vitro studies is the lack of pulp-blood microcirculation, which acts as a coolant by transferring excess heat away from the pulp chamber. In this study, we used a pulp-blood microcirculation apparatus to simulate the cooling effect on pulp tissue under clinical conditions.

In restorative dentistry, thermal changes have been evaluated using several approaches, such as cavity preparation, light curing, laser application, bonding, and debonding [4, 5, 23]. The thermal effect on pulp tissue depends on variations in the thickness of enamel and dentine on the pulp chamber wall [24], the dentine type [25, 26], and the choice of resin-based restorative material and light curing unit [4, 5]. The type and duration of light application during curing seem to be the most crucial factor. Familiarity with the characteristics and advantages of light sources used for curing is thus needed to gain a suitable perspective in aesthetic dentistry [27]. According to Lloyd et al. [28], the most important factor causing a temperature increase during composite photoactivation is the heat developed by the light curing unit. Yazici et al. [5] suggested that LED units reduce the risk of pulp injury because they increase the temperature less than halogen units do. The results of that study suggest that plasma-arc and LED curing units cause less temperature increase in the pulp chamber; however, assessment of the physical and mechanical properties of cured resin composites is also important [5]. For these reasons, we used an LED halogen curing unit for the photo-polymerization of two aesthetic restorative materials and a thermocure (CarboLED) lamp during the setting reaction of GC. The CarboLED lamp was developed for thermal curing to optimally enhance the excellent qualities of GCP glass carbomer products. The clinical application of GC is similar to that of conventional glass ionomer cements, except that heat application is recommended during the setting reaction. Heat can be provided by a special light curing device during the setting reaction of Glass Fill. The manufacturers of GC recommend the use of the CarboLED lamp for light curing this product and claim that this device achieves the best results. The beneficial effects of heat on glass ionomers have been documented in recent studies [14–16]. Higher temperatures during setting have been found to shorten the setting and working times [15, 16]. However, outputs indicate that the use of the CarboLED lamp results in an exothermic setting reaction that raises the temperature of the pulp tissue, thereby increasing the risk of pulpal damage. In our study, the temperature of GC was closest to the threshold temperature for irreversible pulpal damage.

Resin-modified glass ionomer cements and polyacid-modified resin composites were developed to overcome the problems of traditional restorative materials, such as moisture sensitivity and reduced early strength, while maintaining the clinical advantages of command setting, adhesion to tooth structures, adequate strength under occlusal loading, fluoride release, and aesthetics [3]. Taking into account the advantages and clinical characteristics of GC, it appears to be an extremely suitable alternative to conventional restorative materials [14]. It may also have a particular role in the restoration of primary teeth.

The setting reaction of RMGIC has a dual mechanism. The usual glass ionomer acid-base reaction begins when the material is mixed, and this is followed by a free radical polymerization reaction, which may be generated by photoinitiators and/or chemical initiators [29].

Restorative materials such as PMCR can be hardened only through photo-polymerization. This setting reaction has two stages. The first stage is dominant free radical polymerization, identical to that occurring in resin composite. Upon light curing, the polymerizable molecules are interconnected in a three-dimensional network that is reinforced by the filler particles included in the material. After initial setting, with the addition of water, Dyract AP contains all ingredients needed to initiate an ionic acid-base reaction, as occurs with glass ionomers [30]. Setting reactions of all recently marketed compomers are also based on dominant light-initiated free radical polymerization, followed by an acid-base reaction [3].

Al-Qudah et al. [8] suggested that the resin content of dental materials was an important factor affecting temperature increase. Greater resin filler content was associated with a lesser temperature increase and thus a smaller proportion of resin available for polymerization. Fillers are chemically inert and do not contribute to the heat of a reaction. In our study, we used PMCR and RMGIC. According to the manufacturers, PMCR has 73% filler content, and RMGIC has 66% filler content. In our study, temperatures were higher in specimens prepared with RMGIC than in those prepared with compomer because of the dual-cure setting mechanism and the lower filler content.

Light curing units for dental applications were developed to initiate photo-polymerization of resin composites, adhesives, sealants, and resin cements [31, 32]. The rise in temperature which accompanies visible light curing of resin materials is caused by both the exothermic reaction process and the radiant heat from light source. In addition, various factors, such as the light intensity of the light curing units, the amount of remaining dentin thickness, the composition of the restorative materials, the distance between light curing units and material surface, the position of light curing units, and exposure time, can affect the extent of the increase in temperature during the polymerization process [33–35]. Among these factors, the light intensity of the light curing units arises as an important factor for the temperature rise intrapulpal during polymerization. In the current study, we used two different light curing units according to manufacturer's instructions. The highest temperature increase was observed in GCP Glass Fill group. The GCP Glass Fill has got a special thermocure lamp. The reason for this large intrapulpal temperature rise is probably related to the greater power output of the laser lamp, which at 1400 mW/cm^2/60 sn is considerably greater than the other lamp (Table 2).

In this study, temperature increases in primary and permanent teeth prepared with the three tested materials were compared. Some chemical and morphological properties of dentine structures differ between primary and permanent teeth. Primary teeth have fewer dentinal tubules, which have smaller diameters and are located at distances of 0.4–0.5 mm from the pulpal surface; the peritubular dentine is two to five times thicker than in permanent teeth [36, 37]. In the present study, temperature increases were greatest in primary teeth in all groups, but differences from permanent teeth were not significant. However, the primary teeth used in the present study were nearing exfoliation. These teeth had been in occlusion for about 8-9 years, which may have reduced the permeability of the primary dentine due to the apposition of additional peritubular dentinal matrix [36]. Dentinal tubules may become partly or completely obturated by growth of the peritubular dentine [38]. These structural changes may have effect on increases in temperature.

The thickness of remaining dentine may be reduced under clinical conditions. The potential risk of pulp damage is expected to be greater in deep cavities with thin layers of residual dentine, especially in primary and young permanent teeth. In such cases, a simple and highly effective way to protect the pulp is to apply a cement base or lining material.

Although the actual critical temperature that causes pulp damage remains controversial, increases in pulp temperature should be minimized during the polymerization of resin-based dental restorative materials to avoid the risk of pulp damage.

5. Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. The use of glass carbomer in combination with the CarboLED lamp resulted in the greatest intrapulpal temperature increases in primary and permanent teeth.
2. The smallest temperature increases were observed in teeth treated with polyacid-modified composite resin.
3. No difference was observed between primary and permanent teeth, regardless of the material used.
4. Temperature increases during polymerization and setting of the materials were below the critical value in all groups.

Competing Interests

The authors declare that they have no competing interests.

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