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In vitro pulp chamber temperature rise from irradiation and exotherm of flowable composites

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Objective. The aim of this study was to investigate the pulpal temperature rise induced during the polymerization of flowable and non-flowable composites using light-emitting diode (LED) and halogen (quartz–tungsten–halogen) light-curing units (LCUs).

Methods. Five flowable and three non-flowable composites were examined. Pulpal temperature changes were recorded over 10 min in a sample primary tooth by a thermocouple. A conventional quartz–tungsten–halogen source and two LEDs, one of which was programmable, were used for light curing the resin composites. Three repetitions per material were made for each LCU.

Results. There was a wide range of temperature rises among the materials ($P < 0.05$). Temperature rises ranged between 1.3 °C for Filtek Supreme irradiated by low-power LED and 4.5 °C for Grandio Flow irradiated by high-power LED. The highest temperature rises were observed with both the LED high-power and soft-start LCUs. The time to reach the exothermic peak varied significantly between the materials ($P < 0.05$).

Conclusions. Pulpal temperature rise is related to both the radiant energy output from LCUs and the polymerization exotherm of resin composites. A greater potential risk for heat-induced pulp damage might be associated with high-power LED sources. Flowable composites exhibited higher temperature rises than non-flowable materials, because of higher resin contents.

Introduction

Improvements in restorative materials with the growing demand for more aesthetic and conservative treatments by patients have supported the development of a vast number of direct tooth-coloured resin-based materials in paediatric dentistry[1]. Resin composite formulations with greater fluidity have been introduced to the marketplace in recent years[2]. These flowable composites are claimed to offer higher flow, better adaptation to the internal cavity wall, and easier insertion than previously available products providing a variety of clinical uses[3]. However, the possible damaging effect of temperature increases on the pulp tissue induced from light-curing unit (LCU) irradiations and the exotherm of resin-based materials is still a matter of concern to dentists[4].

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Dentine has a low thermal conductivity. But in deeper preparations, the potential for pulp damage is greater as the tubular surface area increases[5]. Previous studies have assessed *in vitro* temperature change in resin composites and surrounding tissues during polymerization using differential scanning calorimetry[6], differential thermal analysis[7], and thermocouple techniques[8] in addition to the ThermoVision 900 infra-red Scanning System for *in vivo* measurements[9]. Observations have indicated temperature rises of between 10 and 18 °C within resin composites and adjacent tooth structures. Temperature increases up to 20 °C have been measured during light polymerization within resin composites[10], although their effects depend upon the mass of the material used.

Curing lights differ in irradiance and range from less than 200 to 1000 mW/cm^2 or more[11]. Quartz–tungsten–halogen (QTH) lights are the most often used light sources for composite photo-polymerization, yet their major disadvantage is heat generation[12]. Recent developments have focused on providing units

Table 1. Resin composites investigated: product batch number, code, and manufacturer's information.

Resin composites	Code	Batch number	Manufacturer
Revolution Formula 2	RF	3-1190	Kerr, Orange, CA, USA
Point 4 Flowable	PF	305A23	Kerr
Tetric Flow	TF	B42157	Ivoclar Vivadent, Schaan, Liechtenstein
Grandio Flow	GF	361443	Voco, Cuxhaven, Germany
Filtek Flow	FF	3EP	3M ESPE, Seefeld, Germany
Filtek Z250	Z250	1KH	3M ESPE
Filtek Supreme	FS	2AW	3M ESPE
Tetric Ceram	TC	E50727	Ivoclar Vivadent

featuring various irradiation protocols, such as step curing and ramp curing. These soft-start curing modes may have the advantage of reducing polymerization contraction stress[13].

Light-emitting diodes (LEDs) are highly efficient light sources because of very narrow spectral ranges. Their spectral irradiance depends on the chemical composition of the semiconductors used. The curing efficiency of LEDs is explained by the better match of their emission spectra[14] with the standard photoinitiator, camphorquinone, than the broad spectra of halogen LCUs. Light-emitting diode technology promises comparable curing abilities to conventional halogen LCUs[15] at lower polymerization temperatures[16].

The amount of light energy received in the resin composite restoration is affected by many variables, such as power density from the curing light; duration of exposure; design of the light guide; distance from the tip of the guide to the restoration; and the composition, thickness, shade, and opacity of the composite[10,17,18].

The aim of this study was to investigate *in vitro* the pulpal temperature rise induced during the polymerization of flowable and non-flowable composites using LEDs and QTH LCUs.

The specific objectives were: (i) to compare the maximum temperature rises between flowable and non-flowable composites; (ii) to compare the maximum temperature rises between light-curing units; and (iii) to investigate the time-to-exothermic-peak of temperature rises.

Materials and methods

Five flowable and three non-flowable composite materials were examined in this study. The material names, codes, batch numbers, and manufacturers are summarized in Table 1.

A small class II cavity was prepared on the proximal–occlusal surface of a freshly extracted human caries-free lower primary molar. This primary tooth was kept wet in distilled water to be used for all experimental trials. One millimetre dentin thickness was left between pulp chamber and axial wall of the proximal box as well as between the pulp chamber and occlusal cavity floor, which was assessed radiographically. The distal root was removed as well as the pulp residues, to allow the insertion of a thermocouple-exposed tip (type K, R.S Components, Corby, Northants, UK) into the pulp chamber of the sample tooth to measure the temperature changes. The thermocouple was fixed with the dentin directly underneath the prepared cavity by means of a thin layer of acrylate-based heat adhesive (R.S Components), as checked radiographically. The sample tooth was mounted in a rubber dam device supported by a wood frame in a water bath at 37 °C ± 0.5 °C, and the pulp chamber was filled with water from the bath so that just the root part of the sample tooth was inside the water bath (Fig. 1). A 2-mm layer of each resin material tested was placed in the proximal box without acid etching or bonding agent. The bonding agent was not used in order to enable easy removal of the polymerized resin material for several experimental measurements of the same sample tooth without any change in the size of the cavity.

A conventional QTH (Optilux 500, Kerr, Orange, CA, USA) and blue-phase LED LCU, of three different programmes: soft start, high, and low intensity (LED, Ivoclar Vivadent, Schaan, Liechtenstein), in addition to a con-

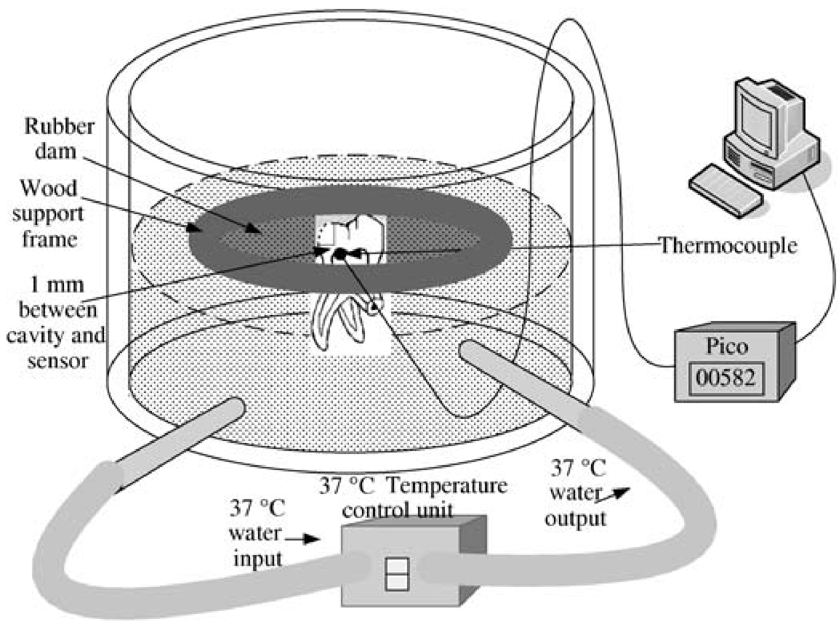

Fig. 1. Diagram of the design of apparatus used in the exothermic study.

Table 2. Light-curing units (LCUs) used in the study.

Group	LCUs	Manufacturer	Intensity and usage
1	Blue-phase LED High power	Ivoclar Vivadent, Schaan, Liechtenstein	1100 mW/cm^2 for cure of direct restoratives and cements
2	Blue-phase LED Low power	Ivoclar Vivadent	650 mW/cm^2 for cure of adhesives, liners, and restorative materials near the pulp
3	Blue-phase LED Soft start	Ivoclar Vivadent	0–650 mW/cm^2 in 5 s and then 1100 mW/cm^2 for 35 s
4	LED, LYSTA	LYSTA, Farum, Denmark	600 mW/cm^2 for curing dental composites
5	Optilux 500	Demetron, Kerr, Orange, CA, USA	500 mW/cm^2 quartz–tungsten–halogen

ventional LED (LED, LYSTA, Farum, Denmark) were used for light curing the resin composites. Table 2 illustrates the intensity and usage of these LCUs. The blue-phase LED with different programme settings means that the operator can choose an optimum setting, especially for critical applications in paedodontics.

Five experimental groups were designated, as follows: group 1 (high-power LED), group 2 (soft-start LED), group 3 (low-power LED, group 4 (conventional LED, LYSTA), and group 5 (conventional Optilux).

Three repetitions per material were made at 15-min intervals for each LCU ($n = 3$). Temperature changes taking place during setting were recorded as a function of time over a 10-min period. The temperature rise transients from the thermocouple output were obtained by measuring the output voltage by means of a rapid-response thermocouple amplifier. The amplifier output was connected to resident data acquisition software via an analogue-to-digital converter (ADC) (PICO Technology Limited, Cambridge, UK). Temperature readings recorded in the ADC unit were converted to degrees Celsius by means of the determined calibration coefficient. Graphs representing the temperature changes over a 10-min period for each specimen were obtained (SigmaPlot8, Systat Software, San Jóse, CA, USA). The following two measurements were determined from each temperature versus time plot: (i) peak temperature (°C); and (ii) time to reach peak temperature (s).

Table 3. Mean values ($n = 3$) of peak height (°C) (pulpal temperature rise) with standard deviation in parentheses of the tested materials, where group 1: high-power light-emitting diode (LED); group 2: soft-start LED; group 3: low-power LED; group 4: conventional LED, LYSTA; group 5: conventional Optilux.

Material	Group 1	Group 2	Group 3	Group 4	Group 5
RF	3.86 (0.52)	3.54 (0.06)	1.87 (0.04)	1.78 (0.27)	1.92 (0.11)
PF	3.25 (0.20)	3.04 (0.28)	2.43 (0.20)	2.21 (0.02)	2.09 (0.22)
TF	3.99 (0.19)	3.42 (0.05)	2.26 (0.28)	2.55 (0.07)	1.54 (0.26)
GF	4.52 (0.34)	4.07 (0.10)	2.88 (0.17)	1.85 (0.27)	1.75 (0.09)
FF	4.32 (0.26)	4.03 (0.35)	2.95 (0.28)	1.81 (0.20)	2.25 (0.14)
Z250	3.33 (0.36)	2.91 (0.47)	1.89 (0.39)	2.58 (0.33)	1.76 (0.10)
FS	2.82 (0.52)	2.35 (0.21)	1.32 (0.04)	1.82 (0.10)	1.72 (0.25)
TC	3.36 (0.16)	2.60 (0.05)	1.69 (0.16)	2.27 (0.24)	1.74 (0.43)

Table 4. Mean values ($n = 3$) of time (s) to exothermic peak of pulpal (standard deviation) temperature rise of resin composites light irradiated with different units, where group 1: high-power light-emitting diode (LED); group 2: soft-start LED; group 3: low-power LED; group 4: conventional LED, LYSTA; group 5: conventional Optilux.

Material	Group 1	Group 2	Group 3	Group 4	Group 5
RF	54 (3.0)	34 (1.0)	45 (4.5)	49 (1.7)	41 (3.2)
PF	41 (1.0)	40 (1.0)	40 (1.0)	40 (3.2)	52 (8.0)
TF	53 (4.0)	36 (1.0)	39 (1.0)	36 (2.3)	54 (5.5)
GF	48 (1.7)	40 (1.0)	41 (3.4)	37 (3.2)	42 (1.1)
FF	42 (1.0)	40 (2.6)	44 (4.5)	40 (4.3)	52 (2.3)
Z250	41 (2.6)	38 (6.0)	40 (5.2)	49 (1.7)	39 (6.8)
FS	65 (5.0)	49 (5.2)	45 (3.6)	56 (4.7)	41 (1.5)
TC	45 (2.0)	34 (1.0)	37 (1.0)	53 (4.1)	42 (1.5)

Peak temperature was expressed as the difference between actual maximum temperature and ambient temperature (37 °C).

Thermocouple calibration

The calibration coefficient was determined before the start of the experiments. The thermocouple connected to its amplifying unit was linked to the data acquisition system via the A/D interface. The thermocouple tip and the thermometer were positioned in the cold water bath, and data acquisition was triggered. Small quantities of warm water were added to the cold water at regular intervals, and corresponding temperatures were read off from a calibrated mercury-in-glass thermometer when the system reached equilibrium. The procedure was repeated to obtain the calibration coefficient.

Statistical analysis

One-way analysis of variance followed by Tukey *post hoc* test at the significance level of 0.05 were performed for statistical analysis.

Results

The pulp chamber temperature rises from 40 s irradiation with LED and QTH LCUs together with the exotherm of the materials in a class II of a primary tooth were obtained (Table 3). Also, the mean values and standard deviations of time to exothermic peak were also determined (Table 4). There was a wide range of temperature rises in this study. Temperature rises ranged between 1.3 °C for Filtek Supreme irradiated by low-power LED and 4.5 °C for Grandio Flow irradiated by high-power LED.

A statistically significant difference in temperature rises was found between the materials investigated ($P < 0.05$). Flowable composites exhibited higher temperature rises than non-flowable materials. Pulpal temperature rises varied significantly according to the LCUs used ($P < 0.001$). The highest temperature rises were observed with both the LED high-power and soft-start LCUs.

The time to reach exothermic peak varied significantly between the materials investigated ($P < 0.05$). The time to exothermic peak ranged from 34 s to 65 s. Also, a statistically significant difference in time to exothermic peak was found between the LCUs used ($P < 0.01$).

Discussion

This study was carried out in a representative primary tooth for all experimental groups without any change in the size of the cavity. This was achieved by placing resin composites in the tooth cavity without any dentine bonding agent. Hence, it was possible to easily replace the polymerized material during repeated measurements. The distance between the tip of the thermocouple and the cavity floor of the sample tooth was maintained at 1 mm, as checked radiographically, and by sacrifying the sample tooth after finishing the experiment. Although dentine has a relatively low thermal conductivity, it is expected that the potential for pulp damage is greater in deep cavities where the residual dentin thickness is small and the tubular surface area increases[5], especially in primary teeth[19]. Thermal transfer to the pulp is affected by the distance between the floor of the cavity preparation and the pulp (the remaining dentin thickness)[10].

Temperature rise during the polymerization of light-activated restorative materials is attributed to both the polymerization exotherm of materials and the energy absorbed during irradiation from LCUs[20,21]. Temperature rises recorded in previous published studies, ranged from 1.5 °C to more than 4 °C in the pulp chamber of extracted teeth during light curing of resin composites[22,23]. Zach and Cohen (1965) reported that 15% of the teeth in rhesus monkeys developed necrosis when the healthy pulp was exposed to a temperature increase of only 5.5 °C[24]. These results as well as the findings of Pohto and Scheinin (1958) indicate that the critical temperature for irreversible damage to the pulp begins at 42–42.5 °C[25]. Even though the real value of the critical temperature rise that causes pulp damage is still controversial, it can be concluded that the pulp temperature rise should be kept as low as possible during the polymerization of dental resin restoratives to avoid any risk of harming the pulp[26].

In this study, the measured temperature increase of the light-cured materials was between 1.3 °C and 4.5 °C from a starting temperature of 37 °C. Even the highest temperature increase was less than 5.5 °C which is the estimated critical temperature for damaging the pulp. Furthermore, these temperature rises are less than those ones recorded in other studies[24–27].

Even though this exotherm study was designed to simulate closely the clinical situation of pulp temperature rise during the polymerization of resin materials in primary teeth, heat conduction could occur within the tooth during composite resin polymerization because of the effect of blood circulation in the pulp chamber and fluid motion in the dentinal tubules. In addition, the surrounding periodontal tissues could play an important role in further limiting pulp temperature rise[27].

Flowable composites exhibited higher temperature rises than non-flowable composites, which could be related to their lower filler loading and higher resin content, which should increase the exothermic reaction. Several previous investigators concluded that a change in exotherm was caused by differences in the materials' composition[7,10,20]. The highly exothermic nature of the setting reaction of flowable composite produced substantial temperature rise.

Both Grandio Flow and Filtek Flow showed the greatest temperature rises, whereas the lowest value was found with Filtek Supreme. This also indicates that the materials' composition is an important variable in determining the magnitude of temperature rise.

The temperature rises varied significantly according to the LCU used. The highest pulp temperature rises were found with high-power LED. This might be related to the intensity of high-power LED compared to other LCUs[21,27,28]. The soft-start mode was introduced to try to reduce shrinkage stress of dental composites, to achieve smaller marginal gaps, and to increase marginal integrity[29]. The soft-start mode could slow the temperature rise within the composite which results in a lower temperature maximum. Reducing the speed of a traumatic event to the pulp may play an important role because the tissue has more time to adapt itself and compensate for the trauma[26]. However, this study did not demonstrate a statistically significant difference in temperature rise between soft-start LED and high-power LED.

The results demonstrated an almost instantaneous temperature rise for all tested materials, occurring as soon as the light source was activated. The temperature peak time was reached, generally, just after finishing the exposure time. This finding coincided with that of other authors who showed that the temperature continues to rise almost linearly while the light is on[10]. The results suggest that minimum irradiation times should be used when curing resin composites in deep cavities where residual dentine thickness is limited. Significant differences in time to exothermic peak were associated with LCUs. The longest period needed to reach the exothermic peak was with the high-power LED. This was associated with the highest temperature rise recorded with this high-intensity mode of LED unit. These results showed that powerful LED sources can induce considerable temperature increases within dental composites, and hence, in the dental tissues.

In the clinical situation, consideration should be given to the choice of light-curing units when curing flowable composites in deep cavities close to the pulp. A reduced amount of a resin composite or/and a light-curing unit with lower intensity would be necessary to reduce the thermal stress on the pulp, especially in primary teeth.

What this paper adds

- Information on pulp chamber temperature rise in primary teeth during the polymerization of light-activated restorative materials.
- Knowledge of the effect of a material's composition and LCUs on pulpal temperature rise.

Why this paper is important to paediatric dentists

- Paediatric dentists should be aware of the possible potential risk for heat-induced pulp damage associated with high-power LED.
- Clinically, the paper raises awareness of the influence of prolonged exposure time upon increase in the pulp temperature.

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