Temperature Rise in Resin Composite Samples Polymerised with Different Curing Modes of LEDs

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Objective: *To investigate the influence of two new generations of light-emitting diode (LED) curing lights with different curing modes on the temperature rise in resin composite samples during their polymerisation.*
Methods: *Bluephase C8 and Bluephase 16i (Ivoclar Vivadent) LED curing units with different curing programmes (high intensity programme [HIGH], low intensity programme [LOW], and soft-start programme [SOF]) were used for two types of resin composite polymerisation (Tetric Ceram, Tetric EvoCeram; Ivoclar Vivadent). The temperature was measured and recorded at the beginning and at the end of illumination using the ELV Pyroscan (ELV Elektronik) thermometer.*
Results: *Regardless of the resin composite material used, there was a statistically significant difference between the temperature rise in polymerisation with Bluephase C8 and Bluephase 16i LED curing lights under the LOW programme (P = 0.022) and SOF programme (P = 0.033). However, no statistically significant difference was found in polymerisation with Bluephase C8 and Bluephase 16i LED curing lights under the HIGH polymerisation programme.*
Conclusion: *Results from this study showed that the polymerisation programme, not the type of curing light used, was related to the rise in temperature.*
Key words: *LED curing unit, polymerisation curing mode, temperature*

The most widely used light-curing source for resin composite photopolymerisation was previously the conventional halogen curing unit[1]. Halogen curing units produce light by heating the tungsten filament and primarily filtering the white light into blue light, which is needed for resin composite photopolymerisation. A large amount of produced energy is manifested as heat, while a very low percentage of energy is emitted as light appropriate for curing. Conventional halogen curing units, therefore, require heat-absorbing filters to reduce the passage of infrared energy from the source to the vital tooth tissue. Unfiltered infrared energy can result in heat generation that leads to pulp injury[2], and can also be harmful to the eyes of the operator as well as the patient. Light intensity emitted from halogen curing units has the tendency to decrease over time. This is caused by different factors such as fluctuation in line voltage, deterioration of the light bulb and the reflector or filter, contamination of the light guide, effects of disinfection procedures on the transmission of light through the light guide, and malfunction of the photoconductive fibres in the light guide.

Currently, light-emitting diode (LED) curing units are the most popular curing units used for photopolymerisation of light-cured materials. These units emit a narrow light wavelength (455 to 468 nm) that correlates with the

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spectral absorbance range of camphorquinone (CQ), the most commonly used photoinitiator in composite materials[3]. The outputs of the first LED curing units were limited, and the temperature rise during photopolymerisation of resin composite materials was also very low compared with standard halogen curing units[4,5]. Electroluminescence was used by LED curing units to produce light, and to enable more useful light with minimal heat production. Also, these curing units primarily produce blue light, versus the white light primarily produced by halogen units. Therefore, LED units do not require any filters. Three generations of LEDs have been developed to increase light intensity without a significant increase in temperature. The new generation of LED units produces high light intensity. However, the temperature increase during photopolymerisation has not been studied.

Among the other factors, the dentine thickness between the cavity floor and the pulp chamber also influences the increase in temperature of the material placed in that cavity[6]. Depending on the magnitude of the temperature increase and the duration of the applied heat, varying degrees of pulpal injury can result from applying external heat to a tooth. In experiments using monkey teeth, Zach and Cohen[7] showed that an increase of 5.5°C in the pulp caused considerable damage, resulting in complete loss of vitality in 15% of tested teeth. Temperature increase during the curing of light-activated dental materials relates to both the exothermic polymerisation of the material and the heat output from dental curing units, and temperature rises with increasing radiation time and decreasing material thickness[3]. Thermal transfer to the pulp is affected not only by residual dentine thickness, as previously mentioned, but also by material shade, thickness, resin composite porosity, curing time, and curing unit quality (e.g. quality of light filter and output intensity)[8]. Also, differences in light guides, such as the diameter, material composition or curing distance, may have various effects on the power density and focusing effect[9].

Different results have been reported, and the level of temperature increase has related to the methods used for measuring the temperature. An increase of temperature up to 20°C or more was measured within resin composites while hardening using halogen curing units[10]. Hussey et al[11] measured a maximum temperature rise of 12°C in the composite *in situ* during polymerisation, although this may only be for a short period. Hartanto et al[12] also noted the possibility of high temperatures observed in the polymerisation of most resin composites and their adverse effects on pulp tissue. Knezevic and coworkers compared the temperature increase in the polymerisation of resin composite materials with halogen, plasma and a first generation LED curing unit[13,14]. The results showed less heating in the case of LED polymerisation of resin composites.

The new generation of LED light-curing units has been designed to increase the light energy output. However, it could also increase thermal transfer to the pulp. Therefore, the aim of this study was to evaluate the increase of temperature during photopolymerisation of composite materials with two LED curing units of different intensity.

Materials and Methods

Two resin composite materials were used in the experiments: Tetric EvoCeram® (TEC2, shade A2) and Tetric Ceram® (TC3, shade A3) (both Ivoclar Vivadent, Schaan, Liechtenstein). A plastic mould in the shape of a 2 × 2 cm square was used for the measurements. In the centre of the plastic mould, a 4 × 4 × 4 mm square opening of was made, open on the top and bottom side. The opening was filled with resin composite material, and a thermometer (ELV Pyroscan, Infrared Thermometer PF 1000, PS 140/PS 300; ELV Elektronik, Leer, Germany) was placed on the bottom side of the sample. The light source was placed on the top side of the sample (Fig 1). The composite sample was polymerised with each programme according to the manufacturer's instructions. The thermometer sensitivity range was from -20°C to +300°C.

Two LED polymerisation units, Bluephase® C8 (C8) and Bluephase® 16i (C16) (both Ivoclar Vivadent) were

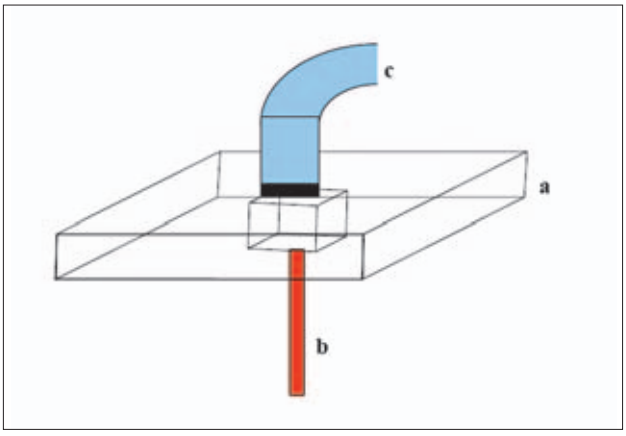

Fig 1 Experimental set up for temperature measurement. Plastic mould in the shape of a 2 × 2 cm square with a square opening of 4 × 4 × 4 mm in the central area (a). The opening was filled with composite material, a thermometer (b) was placed on the bottom side of the sample, and the light source (c) was placed on the top side of the sample.

used for resin composite sample polymerisation. Both of these curing units have wavelength ranges between 430 and 490 nm and three curing programmes: high intensity programme (HIGH), low intensity programme (LOW) and soft-start programme (SOF). The light intensity for each curing programme was as follows:

- Bluephase C8: HIGH, 800 mW/cm^2 with curing time of 20 seconds; LOW, 650 mW/cm^2 with curing time of 30 seconds (control group); and SOF, 650 mW/cm^2 for the first 5 seconds, and 800 mW/cm^2 for the next 25 seconds.
- Bluephase 16i: HIGH, 1600 mW/cm^2 with curing time of 10 seconds; LOW, 650 mW/cm^2 with curing time of 30 seconds; and SOF, 650 mW/cm^2 for the first 5 seconds, and 1600 mW/cm^2 for the next 10 seconds.

The curing lights were new and had not been used previously. Therefore, the light intensity could be considered the same as in the manufacturer's brochure.

Both the curing units are equipped with different light tips of 8 mm, 10 mm, a 13-mm large tip, and a Power-Booster tip. The Power-Booster tip, included in the package supplied from the manufacturer, was used in this study, and all the curing tips are available as accessories.

Seven samples were prepared for each polymerisation mode, resulting in a total of 42 samples for each resin composite material. The temperature was measured for each sample during the illumination process and the data were recorded initially (at the beginning when the thermometer was stable at room temperature level after each measurement) and at the end of illumination. The difference between these two values was used for statistical analysis.

Differences between curing modes and resin composites were analysed using the *t* test and one-way analysis of variance with post hoc Tukey test. All analyses were performed using statistical software (SPSS v.10.0; SPSS, Chicago, Illinois, USA). An alpha level of 0.05 was considered statistically significant.

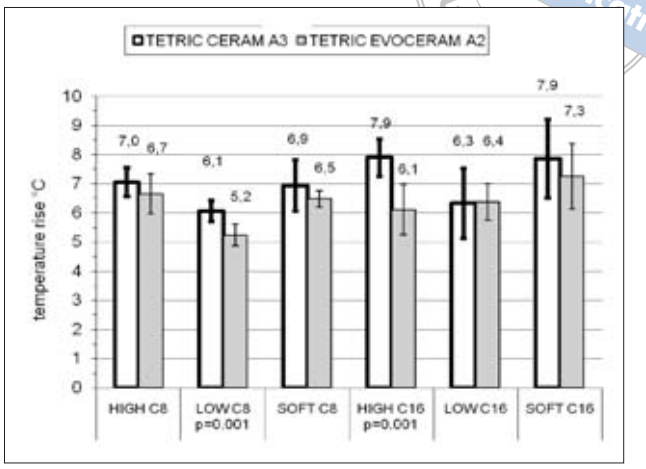

Fig 2 The increase in temperature with different materials and curing modes.

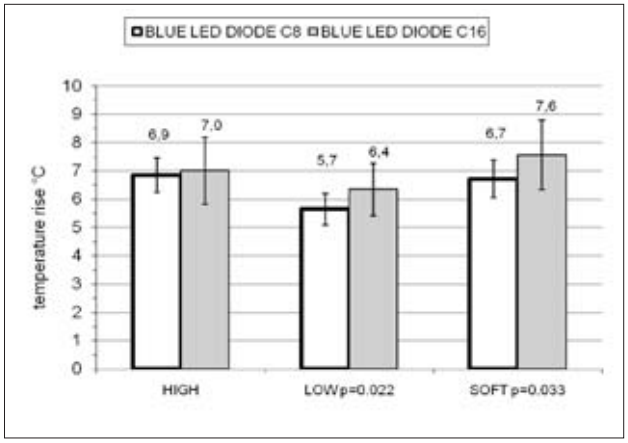

Fig 3 The increase in temperature using two LED lights in different curing modes.

Results

The results of the present study are shown in Figures 2 and 3. For each resin composite material, a statistically significant difference in the increase of temperature was found between the two polymerisation modes, for TC3 ($P = 0.014$) and for TEC2 ($P < 0.001$), in the cases of polymerisation of sample composite materials with C8 LED units. Tukey post hoc test revealed statistically significant differences in the temperature increase for both composites between SOF and LOW, and between HIGH and LOW, but there was no statistically significant difference in the increase of temperature between SOF and HIGH polymerisation modes.

In the case of sample polymerisation with C16, ANOVA showed a statistically significant difference in the temperature increase only for TC3 material ($P = 0.025$). Tukey post hoc test revealed statistically significant differences in the increase of temperature for TC3 resin composite material between HIGH and LOW ($P = 0.04$) and between LOW and SOF ($P = 0.047$), whereas no significant difference was found between polymerisation modes HIGH and SOF.

For the light source, a statistically significant difference in the temperature increase was found when using TC3 ($P = 0.042$), and the temperature increase was greater in the case of polymerisation with the C16 unit compared with the C8 unit.

For polymerisation modes, statistically significant differences in the temperature increase were found for

both resin composite materials. For the TC3 resin composite, the difference was found between HIGH and LOW ($P = 0.003$) and between LOW and SOF ($P = 0.004$) modes, whereas for the TEC2 composite, the only difference was between LOW and SOF polymerisation modes ($P = 0.004$).

When the type of resin composite material was disregarded, statistically significant differences in the temperature increase were also found between C8 and C16 LED units at LOW mode ($P = 0.022$) and SOF mode ($P = 0.033$). When the light source was disregarded, significant differences in the temperature increase were also found between HIGH and LOW modes ($P = 0.001$), and between LOW and SOF modes ($P < 0.001$).

Discussion

The potentially damaging effects of a temperature increase on the pulp tissue during resin composite restorative treatment has been a concern in dentistry for many years. Halogen-curing units were previously the most commonly used light-curing units for photopolymerisation, but they can cause a temperature increase that could be harmful for pulp tissue[8,15]. The thermal emission of LED curing units has been studied, and it was found that the thermal emission of LEDs is lower than that of halogen lights[4,5,13,14,16,17].

The decisive factor for temperature rise during light-activated polymerisation of resin composites is the energy absorbed during irradiation, and the exothermic resin composite polymerisation process is of secondary importance for temperature rise. The rate of the exothermic setting reaction is a function of the irradiance of the light-curing unit, the resin composite chemical composition, and the light transmission properties of the resin composite[16,17].

With an increase in light intensity emitted from the light-curing unit, a greater temperature rise may occur, owing to the radiation energy from the curing unit. The distance between the cavity floor and light guide may vary when curing large posterior resin composite restorations[3]. The thickness of the dentine barrier is a critical factor in reducing thermal transfer to pulp. Although dentine has a relatively low thermal conductivity, the potential for pulpal damage is greater in deep cavities when the residual dentine thickness is small and the tubular surface area increases[16,17]. For an individual tooth, it is almost impossible for a clinician to predict the temperature rise that may occur when curing a resin restoration. In general, the thicker the dentine and the shorter the curing time, the smaller the temperature increase[10]. However, the most significant source of heat during polymerisation of a light-activated restorative is from the light activation unit and not the material itself[4,17]. Therefore, clinicians should be aware of the potential hazard to the pulp that might result from visible light curing of restorative materials. Special care should be taken in choosing the proper curing mode and light intensity. A thin layer of lining material should also be of great help owing to its ability to reduce the thermal transfer to the pulp. The greatest temperature rise, according to some authors, occurs during the polymerisation of the first resin composite layer. That is the reason why a polymerisation mode with a lower initial intensity should be chosen for the polymerisation of resin composites in deeper cavities. This lower initial intensity will induce a lower temperature rise during the illumination process[18]. On the other hand, this raises the problem of insufficient setting of the first layer at the deepest part of the cavity. This is because the strength of light intensity decreases with the increase in distance of the light source from the composite layer on the bottom of the cavity[18].

In the present study, the greatest temperature rise was recorded when using the HIGH mode regardless of either the type of resin composite material or polymerisation unit. Also, there was no statistically significant difference between HIGH and SOF modes regardless of the unit or the material. A statistically significant difference was found in the polymerisation of both resin composites with LOW mode compared with HIGH and SOF modes. As the temperature was recorded at the start and end of illumination, these results were expected in the case of HIGH and SOF modes. This is because both modes, except the intensity of SOF mode for the first 5 seconds, have the same intensity in the final illumination period for both C8 and C16 LED units.

Although this study focused on polymerisation units, or more correctly polymerisation modes, it is obvious that TC has greater values for temperature rise than TEC for all polymerisation modes. According to the manufacturer's instructions, TEC is composed of not only CQ, but also Lucirin® TPO (2,4,6-trimethylbenzoyldiphenylphosphine oxide; BASF, Charlotte, NC, USA), which acts as a photoinitiator with spectrum absorption from 410 to 430 nm. Since both LED units have spectra from 430 to 490 nm, Lucirin TPO's spectrum is not completely covered, which could result in worse or incomplete polymerisation. A lower level of conversion also causes a lower temperature rise, which could explain the lower results for the temperature rise for TEC in comparison with TC resin composite material.

Various reports mention the advantages of gradual polymerisation such as the SOF mode, because of the lower initial light intensity. Lower initial intensity

enables slower polymerisation, 'flowing or redistribution' of molecules within the system, and consequently reduces polymerisation shrinkage and stress. Newer units, which have a shorter illumination time and higher light intensity, leave very little time for the pregelation phase (in this case 5 seconds). More research should be carried out to discover whether this time is sufficient for proper molecule distribution and polymerisation within the pregelation phase of resin composite material, as well as to prove the efficiency of this type of polymerisation mode.

Further studies should be performed with more samples, degree of conversion measurements considered, different experimental procedures (including distinguishing the temperature produced from the curing lights or resin composite material alone during the photopolymerisation process), as well as with different dentine thicknesses between the resin composite and thermometer in order to gain more representative results.

In conclusion, it is very difficult to predict the temperature rise in any particular tooth due to multiple variables. Results from this study showed that the polymerisation programme, not the type of curing light used, was related to the rise in temperature.

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