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Light curing composite -a thermal risk for the pulp?

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Abstract

Introduction and objectives: Light curing has shown to be a risk for the pulp as well as for superficial tissues due to high temperatures. The aim of this study was to evaluate temperature changes in a low viscosity bulk fill composite and the temperature effect on the pulp chamber temperature during light curing using a LED light curing device (LCU). The null hypothesis stated was that the composite tested would not have a thickness dependent temperature effect on pulp temperatures during light curing.

Materials and methods: The composite used was SDR™ A mains powered LCU, Bluephase G2®, (was used for curing at high mode for 30 sec. The measurement and recordings of temperatures was performed using calibrated thermocouples. The study was divided in 3 parts (1-3) with curing cycles performed as follows: SDR™ was first cured (referred to as non-precured) and, after 5 minutes of recovery time, recured (referred to as precured). In part 1, a thermocouple was mounted in standard cylinders, filled with material and one curing cycle was performed. The curing cycles was repeated 5 times for each thickness. In part 2 the irradiance through SDR™ during curing cycles was evaluated using the same cylinders mounted on top of an irradiance tester. In part 3, evaluation of pulp chamber temperature in a caries-free 3:rd molar was done with a thermocouple inserted in the pulp chamber. A cavity was prepared close to the pulp chamber and controlled with X-ray. The root was immersed under water ($36.4 \pm 1^\circ\text{C}$), composite placed and cured according to the protocol with 5 repeated measurements for each depth. The data were statistically analyzed with a One Way analysis of Variance with an alpha value of 0.05.

Results: An increased difference in temperature between the non-precured and precured groups, with increased amount of SDR™ was shown. This was shown booth inside the SDR™ (part 1) and in the pulp chamber (part 3). Increased thickness of SDR™ placed in the cavity, lead to lower pulp chamber temperatures during light curing. Part 2 showed that the non-precured SDR™ absorbed more light than the precured SDR™.

Conclusion: SDR™ had a linear, thickness dependent effect on pulp chamber temperatures during light curing. A significant isolating effect was seen for increments above 3 mm of non-precured SDR™, and for all groups of precured SDR™. Potential tissue damaging pulp chamber temperatures were achieved when light curing was

performed in an empty cavity and when thin increments of non-precured SDR™ were tested. The irradiance of the LCU, the absorption of irradiance in SDR™, the exothermic reaction, and the conduction of heat from the material tested to the tooth, seemed to be the factors contributing to heat development in the pulp chamber during curing of the tested material.

Keywords:

Dentistry, Composite, Light curing, Pulp chamber, Temperature

1. Introduction

In modern restorative dentistry, polymer resin based materials (PRMs) are used in more than 250 million direct restorations (e.g. composite, resin based glass-ionomers etc.) annually [1]. The most common manner to initiate polymerization of those materials is by use of blue light with a wavelength between 380-500 nm and an irradiance $<450\text{mW}/\text{cm}^2$ [2]. The most used initiator is still camphorquinone/ tertiary amine (CQ/TA). When the initiator is applied sufficient light and irradiance, free radicals are created allowing the exothermic, chain polymerization reaction of the monomers to polymers occur [3].

Today, most of the light curing devices are based on the light emitting diode (LED) technique, in favor of quartz-tungsten-halogen (QHT) devices. LED have the potential of converting electricity to light with near unity efficiency while the light from QHT are accompanied by large energy losses and high temperatures in the lamp [4]. LED-curing devices has been shown to lead to lower temperatures during light curing of PRMs than the QHT-devices [5]–[7]. However, newer LED systems have irradiances emitted ten times higher than that from the first generation LED units (e.g. LUX-O-Max)[8]. With increased irradiance there is a risk of increased temperature during light curing, even with the LED technology and concerns have therefore been raised about negative effects with risk for pulp and tissue damage [5], [9]–[11]. Zach and Cohen showed that 15% of intact monkey teeth ended in pulp necrosis after exposure of a thermal increase of $5,5\text{ }^\circ\text{C}$ in the pulp [12]. In a previous study it has been shown that the risk of pulp injury increased with thin dentin thickness and increased radiant exposure [13].

In general, polymers are, however, known to be poor conductors of heat compared to other materials due to electron stability (e.g. metals). When compared to dentin, the conduction of heat in composites are less [14] [15]. It can therefore be speculated if composite resin based materials (hereafter referred to as composite) placed in a cavity can act as an isolator decreasing the risk for thermal injury on the pulp during light curing. Still, most polymer resin based materials used in dentistry (e.g. composites) are based on methacrylates. Polymerization of methacrylates is an exothermic reaction that may add to the overall temperature increase[16]. In recent years, dental PRMs manufactures has released “bulk fill” materials, which can be applied in thicker increments than conventional composites [17]–[19]. Larger increments will result in an

increased volume of material placed (e.g. more monomers) and this may lead to higher temperatures due to the exothermic reactions in the material during polymerization[16]. Low viscosity bulk fill materials contains less filler than universal composites (e.g less than 50%/vol [18] vs over 65 %/vol [20]). They may therefore have an increased exothermic potential than universal composites due to a higher monomer content[16]. It has also been shown that the translucency of low viscosity bulk fill composites is higher than universal composites[21]. Therefore, the potential of energy passing through low viscosity bulk fill materials during light curing, might be higher than for universal composites increasing the risk of thermal exposure to the pulp tissue. At present, only a few studies have evaluated the influence of the exothermic reaction of PRM and light curing on the pulp chamber temperature and only one of the studies have tried to discriminate between the influence of the exothermic reaction in the PRM and the influence from the light curing device [22]–[24]. Since there is a risk of pulp tissue damage during light curing due to radiant exposure it seems important to further investigate factors with potential of pulp damages due to temperature increase when restoring cavities.

Aims

The aim of the study was two-fold; to evaluate temperature changes in a low viscosity bulk fill composite and; to evaluate the temperature effect of the composite on the pulp chamber temperature during light- curing using a LED device.

Hypotheses

The null hypothesis formulated was that the composite tested would not have a thickness dependent temperature effect on pulp temperatures during light curing.

2. Material and Methods

The light curing unit

The light curing unit (LCU) used was a mains powered Bluephase G2[®], (serial # P626170S591130) (IvoClar/Vivadent, Schaan, Lichtenstein). Evaluation of this type of unit used has showed a homogeneity concerning the irradiance at the end of the light tip[25]. All measurements were performed at high mode (1400 +/- 100 mw/cm²) for 30 sec. according to the protocol used in a previous study [13] the LCU was fixated, for reproducible placement, into a sliding roller (#55025, Edmunds Optics, Barrington, NJ) with 0.1 mm accuracy. In addition, movement between the irradiance tester, the tooth and the standard cylinders was allowed.

Irradiance testing of the LCU and irradiance testing through the composite

The irradiance of the LCU was controlled using a calibrated laboratory-grade NIST-referenced USB4000 spectrometer (Managing Accurate Resin Curing (MARC) System; Bluelight Analytics Inc., Halifax, Canada). The irradiance of the LCU was tested before the first curing and between every 5:th of the curing cycles in Part 1. Measurement of the exothermic reaction” and every third of the curing cycles in the other experiments. The same spectrometer was used to investigate the irradiance through the composite during light curing in “Part 2. Transmission of irradiance through the composite”.

Temperature recording

Measurement of temperatures was performed using thermocouples (N9002 Thermometer, Comark instruments Inc. Norwich, UK). All thermocouples used were calibrated against a certified reference thermometer. The latter was calibrated against a traceable reference source (Norwegian Standards Organization). The accuracy was 0.1 °C and all thermocouples were recalibrated routinely.

Material

All experiments were performed with the low viscosity bulk fill composite, SDR™ (LOT:1602000876) (Dentsply Sirona, Konstanz, Germany). This material has a filler loading of 45%/volume and the resin is based on a changed formula of urethan dimethacrylate (UDMA) with molecular weight of 849 g/mol compared to 513 g/mol for Bis-GMA and 471g/mol for common UDMA[26].

Curing cycles

Curing cycles was performed as follows in all experiments: SDR™ was first cured (30 sec) (referred to as non-precured) and, after 5 minutes of recovery time, recurred (30 sec) (referred to as precured). The recovery time was based on initial testing.

Part 1. Measurement of exothermic reaction

Setup

Standard cylinders from 3M/ESPE (3M Corp. St Paul, MN, US), 2, 4, and 6 mm high and 4 mm in diameter, was used. The cylinder was fixated on top of a polyethylene sheet. A small hole was punched out through the sheet using a probe. This allowed the deisolated part of thermocouple wire (1.5 mm of the tip) to enter the cylinder from the center of the bottom and reaching 1.5 mm into the cylinder. The LCU was placed and fixated, using the sliding roller, 1 mm over the center of the cylinders. This setup ensured that the LCU was placed at the same place over the cylinders before every curing cycle performed.

Procedure

The cylinder with the thermocouple was filled with composite and one curing cycle was performed. The experiment was repeated 5 times for each of the thicknesses evaluated (2, 4 and 6 mm). Between each curing cycle, the thermocouple wire was cut, the composite was removed from the cylinder and the re-calibrated thermocouple reinstalled.

Part 2. Transmission of irradiance through SDR™

To distinguish different factors contributing to heat development in the composite, the absorption of irradiance in both the non-precured and the precured composite during light curing was performed. A transparent polyethylene sheet was placed on top of the spectrometer. The same type of cylinder (2 and 4 mm was used) as in part 1. The cylinder was placed over the center of the spectrometer and the LCU was placed centrally, in its sliding roller, 1 mm over the cylinder. The arrangement allowed the light from the LCU to freely penetrate through the hole of the cylinder. Three curing cycles were performed when the 2 mm cylinder was filled with 1 and 2 mm of SDR™ respectively and when one curing cycle was performed when the 4 mm cylinder was filled with 4 mm of material. The irradiance was measured through both the non-precured and the precured composite during the light curing (30 sec) in the curing cycles. The irradiance was also checked through empty cylinders.

Part 3. Evaluation of thermal effect in the pulp chamber

One caries free 3:rd molar extracted due to surgical reasons was used for this experiment. The tooth was cleaned and stored in 0.5% chloramine solution according to ISO/TS 11405:2015 in a refrigerator ($4 \pm 1^\circ\text{C}$) prior to use. It was used within 3 months of extraction. An approximal cavity was prepared with a turbine (GENTLESILINCE LUX 8000 B from KAVO) with a cylindrical diamond (012, Comet, GEBR. BRASSELER GmbH & Co. KG. Lemgo Germany). The cavity was prepared with diverging walls and continued out to the mesial side of the tooth. This created a preparation with three flat walls and a flat pulpal floor all the way out to the mesial side (Figure 1a and b). Adjustments were performed with a circular diamond sized 1.2 mm, (V 001 010 801, Comet, GEBR. BRASSELER GmbH & Co. KG. Lemgo Germany). The cavity was polished with a yellow composite polisher Y2 (Top Dent, DAB Dental, Upplands Väsby, Sweden). A plastic matrix-band (Hawe Neos Dental, Bioggio Switzerland) attached to a holder (Nyström, Sweden) was used to seal the cavity on the mesial side. By this design, removal of the composite from the cavity after each curing cycle was facilitated using a sharp carver (Carver N 3, Parainen, Finland). No adhesive material was used for 2 reasons. It allowed the use of the same tooth/preparation throughout the experiment and it has been

shown that bonding agent don't significantly influence the pulp chamber temperatures [27].

Prior to preparation, an x-ray was taken to determine the anatomy and position of the pulp. The thickness of the dentin was controlled with x-ray before and after preparation, with the aim of having 1 mm of dentin left between the cavity floor and the pulp chamber ceiling.

According to the protocol from a recent study from our group [13], the apex was cut and the channels prepared up to the pulp chamber with K-files #35 and #70 (K-FILE NITIFLEX, Dentsply Sirona, Ballaigues, Switzerland) to ensure correct placement of the thermocouple. The position of the latter was controlled with x-ray to ensure placement close to the dentin ceiling at the top of the pulp chamber. The pulp chamber was filled with glycerol. Sealing and fixation of the thermocouple were obtained using glass ionomer cement (Fuji I®, GC Corp. Tokyo, Japan) at the apex (Figure 1 a and b). The buccal wall of the cavity was marked with a permanent marker at 1, 2, 3 and 4 mm levels measured from the floor of the cavity to ensure thickness control when applying SDR™ with a composite applicator (Dentsply Sirona, Konstanz, Germany). To control the accuracy of the volume of the applied material in the respective depth group, the composite was removed from the cavity after the performed curing cycle and the weight of the material was checked with an accuracy of 0.0001 grams using a scale (Sartorius AG, Goettingen, Germany). The weight of the samples was used as an expression for thickness of the sample in some of the statistical analyses.

Baseline thermal evaluation

In an attempt to mimic the humidity and temperature in the oral cavity, the tooth was mounted and placed, with the root immersed under water, in a circulated water bath (AH15L HT, VWR International, Radnor, USA) ($36,4 \pm 1^\circ\text{C}$), and the coronal part in the air ($24 \pm 1^\circ\text{C}$) as described by Mouhat et al [13]. The polystyrene plate was taped to the edge of the water bath to ensure minimum movement of the tooth. Two additional thermocouples were placed: one into the bath for control of the water temperature and the other in the air close to the tooth for control of the air temperature

Procedure

The cavity was filled with SDRTM up to the respective marking. The material was allowed to flow freely out in the cavity and no instrument was used for manipulation. The LCU was placed and fixated using the sliding roller over the cavity in close contact with the cusps of the tooth and a curing cycle was performed. 3 curing cycles was performed on each of the thicknesses evaluated (1, 2, 3 and 4 mm).

After the experiment was completed, the tooth was examined by micro-CT (BRUKER SKYSCAN 1272; Bruker, Kontich, Belgium). The reason was to further assess the position of the thermocouple and dentin thickness. The scan was performed at $19.79 \mu\text{m}\cdot\text{voxel}^{-1}$ and the projections were reconstructed with filtered backprojection, using nRecon (Bruker, Kontich, Belgium). Distance measurements were performed in Dataviewer (Bruker, Kontich, Belgium)

Statistics

In part 1 the temperatures were plotted manually every 5 sec. from a video recording performed of the monitor of the thermocouple during the entire curing cycle. For part 2 and 3 temperatures were plotted each second using a temperature logger (OQ610 temperature logger) and the software SquirrelView 3.9 (Grant instruments. Cambridge, England). All the data was exported to Excel 2016 (Microsoft Corporation, Redmond, Washington). The data was grouped as non-precured or precured and of depth of SDRTM in the respective experiment (Part 1, 2 and 3). In Part 3, analyses were in addition performed using weight of the respective samples as a substitute to the thickness of the

samples. The graphs and the statistics were analyzed using Sigmaplot 13 (Systat Software, San Jose, CA, USA). Quantitative data were analyzed with a One Way analysis of Variance with an alpha value of 0.05. Normality (Shapiro-Wilk) and equal variance test (Brown-Forsythe) were performed.

Ethics

In this experiment human material was used (i.e. extracted teeth), therefore, ethical permission was asked for from the Norwegian Regional Committee for Medical and Health Research Ethics (REK). The committee concluded that such permission was not required (2015/234/REK Nord).

3. Results

Part 1. Measurement of the exothermic reaction

Temperatures and temperature differences between non-precured and precured composite after 30 sec of light curing in the standard cylinders are shown in table 1. The temperature difference between the non-precured and the precured SDR™ after 30 sec. of light curing in the 2, 4 and 6 mm group was 10.1 °C, 12.9 °C and 13.3 °C, respectively. The differences were significant. Figure 2 shows temperature development inside the composite during light curing. The maximum temperatures measured inside of the composite were 60.8°C, (30 sec.), 59.9°C (35 sec.), and 45.6°C (40 and 45 sec.), for the non-precured groups and 50.7°C (30 sec.), 42.3°C (40 sec.), and 34.9°C (55 sec.), for the precured groups of 2, 4 and 6 mm respectively. The non-precured composite showed a rapid increase in temperature the first 6-7 sec. while the precured material showed a linear temperature increase until end of light curing.

Part 2. Transmission of irradiance through the composite

In figure 3 representative result of transmission of irradiance is presented. They showed that the non-precured SDR™ absorbed more energy (i.e. had a lower transmission of irradiance) the first 6-7 sec. before the transmission reach a point where leveling of irradiance occurred (i.e. steady state until end of cure). The transmitted irradiance through the precured SDR™ reached on the contrary a higher level in less than 0.25 sec with a slow increase until end of cure. The same differences in behavior between non-precured and precured composite were observed for the 1 mm and 4 mm samples. Increased thickness (1, 2 and 4 mm) of SDR™ lead to a decrease in irradiance measured. For the sample with 4 mm of non-precured SDR™ the irradiance through was less than 120 mW/cm².

Part 3. Evaluation of thermal effects in the pulp chamber

Table 1 presents the mean maximum temperatures in the respective groups after 30 sec. of light curing. When the factor of thickness between each group was compared, a

significant difference was displayed between the empty cavity group and the non-precured groups of 3 and 4 mm. This was also seen in all the precured groups, regardless thickness. In addition, a significant difference between the non-precured and the precured for all thicknesses except for the 1 mm group was evident. The weight of the removed SDR™ showed that the variance in each of the groups was appreciable. Figure 5 shows that maximum pulp chamber temperature decreased with increased thickness (the weight of the removed composite) of SDR™. The precured SDR™ displayed improved isolating effect compared to non-precured material. A linear correlation between weight and the increased difference in pulp chamber temperature between non-precured and precured SDR™ was shown (Figure 4). The increased difference in pulp chamber temperature was weight dependent. When the empty cavity was irradiated, the pulp chamber temperature increased with 7.2 °C, from 35.4 °C (initial temperature) to 42.6°C.

The micro-CT examination of the tooth after the experiment showed a distance from the cavity floor to the thermocouple and to the sealing of the pulp was 1.31 mm and 0.87 mm respectively.

4. Discussion

The results of the present study showed that the main cause for increase of pulp chamber temperature was the irradiance. The composite had an isolating effect independent of whether the material was precured or not. The null hypothesis stated that the composite tested would not have a thickness dependent temperature effect on pulp temperatures during light curing was rejected. The tests performed on the tooth showed that presence of SDR™ in the cavity lead to a temperature decrease with increased thickness of the material (i.e. isolating effect). The study showed a correlation between weight of the material in the cavity and the difference in pulp chamber temperature between non-precured and precured materials.

Placement of the thermocouple and composite in cylinders was performed in a standardized manner in an attempt to accurately evaluate temperature changes due to the exothermic reactions inside the composite tested. The position of calibrated

thermocouple was constant in the cylinder leading to small variations. Still, the result from part 2 showed that the absorption of energy (e.g. irradiance) of SDR™ was increasing with increasing depth of the material. Therefore, to avoid the effect of differences in absorption of light affected by thickness, the depth should have been kept constant and the volume changed by variations of diameter of the mould. By that measurements of the exothermic effect may have been more accurately evaluated. The results from part 2 showed a similar trend between the non-precured and the precured composite. Variation in irradiance was seen in replicates from the same group (e.g. 1 mm) (Figure 3). Those variations could be due to slight difference in composite thickness placed.

The method using extracted teeth for measurements of temperature changes in the pulp chamber have been used in several studies[5], [22], [28], [29]. When the tooth was prepared and restored, thin dentin was left between the cavity floor and the pulp sealing, simulating the clinical situation when preparing and restoring deep carious lesions with SDR™. The use of a calibrated thermocouple placed in the pulp chamber allowed accurate measurement of local temperature increase close to the pulp sealing, during light curing. The aim was that the placement of the thermocouple should be as close as possible to the pulp ceiling to investigate the worst case scenario of local temperature increase. The micro CT- scan performed after the experiment showed that the thermocouple in fact was 0.44 mm from the pulp ceiling. This indicated a potential of a local temperature increase that might be even higher than that shown in the present study. In modern dentistry, it has been recommended to leave some carious dentin (e.g. partial caries removal) close to the pulp when restoring deep carious lesions[30]. In the present study only caries free dentin was left in the cavity prepared, and thus, the effect of carious dentin could not be evaluated. However, it can be speculated if carious dentin can affect the absorption and transmission of energy with effects on the pulp chamber temperature.

The placement of the tooth in the circulated water bath ensured initial temperatures and humid conditions comparable to the conditions in the oral cavity. The model lacked however, circulation of liquor in the pulp. Thus, it can be argued if circulation is limited when restoring a natural tooth by the vasoconstrictions of the local anesthesia due to

the effects of epinephrine [31], [32]. That may still motivate the clinical relevance of the design of the method use.

In this study, markings were made on the buccal wall of the cavity to guide the insertion of composite. Weight were used as a pseudo-variable for thickness to increase the accuracy of the correlation analysis between the difference in pulp chamber temperatures between precured and non-precured composite.

The risk of pulp damage when only thin dentin is left and light curing with an irradiance $>1200 \text{ mW/cm}^2$ has been showed in a previous study [13]. That risk may be increased by placement of a composite having an exothermic reaction [16]. In the present study, the highest temperature inside of the composite was obtained in samples with less volume of material (table 1). If such high temperatures can be achieved close to the pulp, the risk of tissue damage is evident [12]. However, PRMs are known to be poor conductors of heat [14]. Measurements of temperature inside of the composite supported that. The time to reach the maximum temperature increased with increased thickness of material (30, 35 and 40/45 sec. respectively for the non- precured groups and 30, 40 and 55 sec for the precured groups). In addition, the time to reach maximum temperature increased when the distance from the LCU to the thermocouple trough SDRTM increased (0.5 mm, 2.5 mm and 4.5 mm of SDRTM), and also when the material was precured.

Apart being a poor conduction of heat, these results can additionally be explained by absorption of energy within the composite: To our knowledge, only L. Andretta et al. [22] has attempted to discriminate and explaining the influence of the exothermic reaction in PRMs and the influence from the light curing devices on pulp chamber temperatures. They considered the temperature related to the exothermic reaction as the difference in temperature between the first and the second curing, thus not including the factor of differences in absorption of irradiance between the non-precured and the precured material [22].

In the present study, a large proportion of irradiance was absorbed in the superficial layer of the material. Of the irradiance of $\approx 1400 \text{ mW/cm}^2$ measured from the LCU, only $<600 \text{ mW/cm}^2$ (1 mm) and $<120 \text{ mW/cm}^2$ (4 mm) (not shown), was transmitted through the material. The non-precured SDRTM absorbed more irradiance compared to

the precured and the absorption increased with increased depth. Based on those results, it can be argued that the higher temperature measured inside the non-precured SDR™, and in the pulp chamber in the non-precured groups (shown in Table 1), were a result of higher absorption of irradiance, and not only the exothermic reaction. Together, the absorbance and the exothermic reaction explain the rapid increase in temperatures inside SDR and the pulp chamber during the first 8 seconds of polymerization.

The curing of non-precured SDR™ always lead to higher temperatures inside composite and in the pulp chamber than precured SDR™. The difference was higher for larger volumes of composite and can be explained by the fact that the heat released from the resin primarily increases with an increasing number of vinyl groups[33]. The material used in this study has a high volume of resin [26], and therefore, a relevant material for evaluation of the temperature effect due to the exothermic reaction. The study showed that the maximum pulp chamber temperature reached was slightly lower in a filled cavity compared to an empty cavity (table 1) showing the isolation effect of the composite.

A correlation between increasing amount of SDR™ and a decreasing pulp chamber temperature indicates that an increased thickness of material in the cavity increase the isolation effect (Figure 5). A significant difference in pulp chamber temperature was recorded between the non-precured and the precured SDR™ for all groups with one exception (i.e. the 1 mm group) (Table 1). The precured composite tested achieved improved isolating effect in comparison to the non-precured. This finding is in accordance with results obtained by Andreatta et al [22].

A potential of local increase in temperature in the pulp was shown in the present study. That can be of clinical relevance in terms of pulp vitality and long term prognosis after deep cavity restorations[12]. No significant difference in pulp chamber temperature between empty cavity and the 1 and 2 mm group of non-precured SDR™ was shown. A plausible explanation is that the isolating effect of thin layers of SDR™ is similar to the heat generated in the exothermic reaction and the absorption of irradiance in the material.

In this model a molar was used. A molar has a larger mass than other teeth, and could therefore potentially have a higher heat buffering potential than teeth with less mass. This could potentially be investigated in further studies. Even though the results obtained showed the importance of the exothermic reaction and absorption of energy, common features for methacrylate based polymers the results should be interpreted with some caution. Only one representative composite was tested and therefore more research on other PRMs used to restore deep cavity preparations seems needed to confirm the patterns observed. Still, the irradiance of the light curing device seems to be the most important factor for pulp chamber heat development.

Conclusions

Within the limitations of the present study it can be concluded:

- The composite tested had a linear, thickness dependent effect on pulp chamber temperatures during light curing. A significant isolating effect was seen for increments above 3 mm of non-precured materials, and for all groups of precured materials.
- Potential tissue damaging pulp chamber temperatures were achieved when light curing was performed in an empty cavity and when thin increments of non-precured composite were tested.
- The irradiance of the LCU, the absorption of irradiance in the material, the exothermic reaction, and the conduction of heat from the material to the tooth, seemed to be the factors contributing to heat development in the pulp chamber during curing of the tested material.

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6. Appendix Figure 1-5 and Table 1

Figure 1a and 1b:

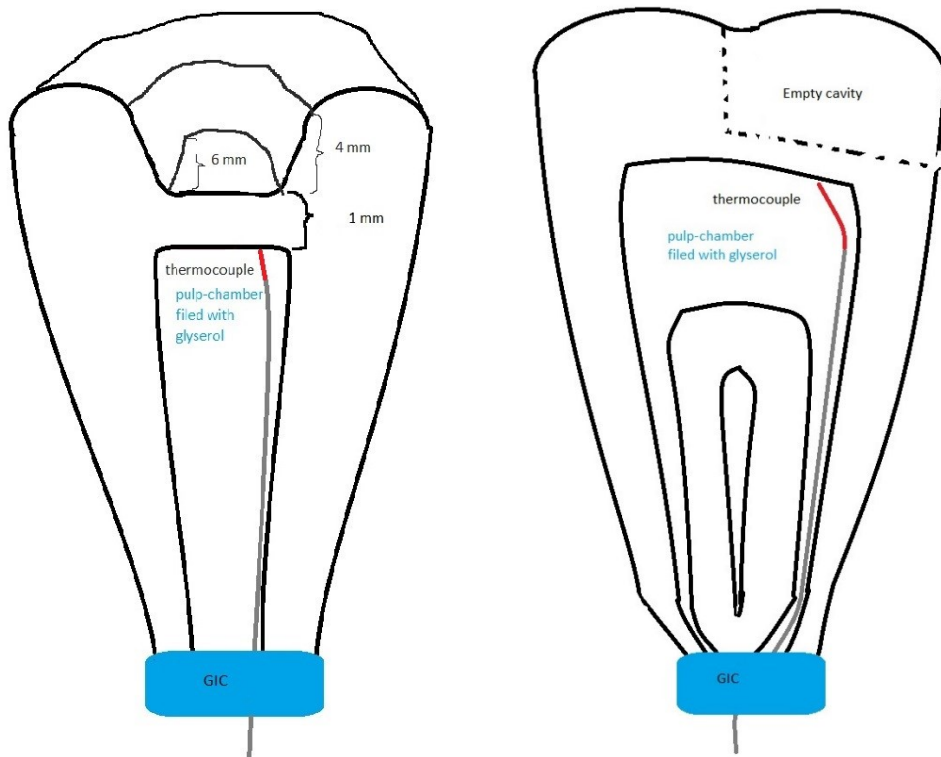


Figure 1a. Cross section of the tooth. Mesial view.

Figure 1b. Cross section of the tooth. Bucco- lingual view.

Figure 2:

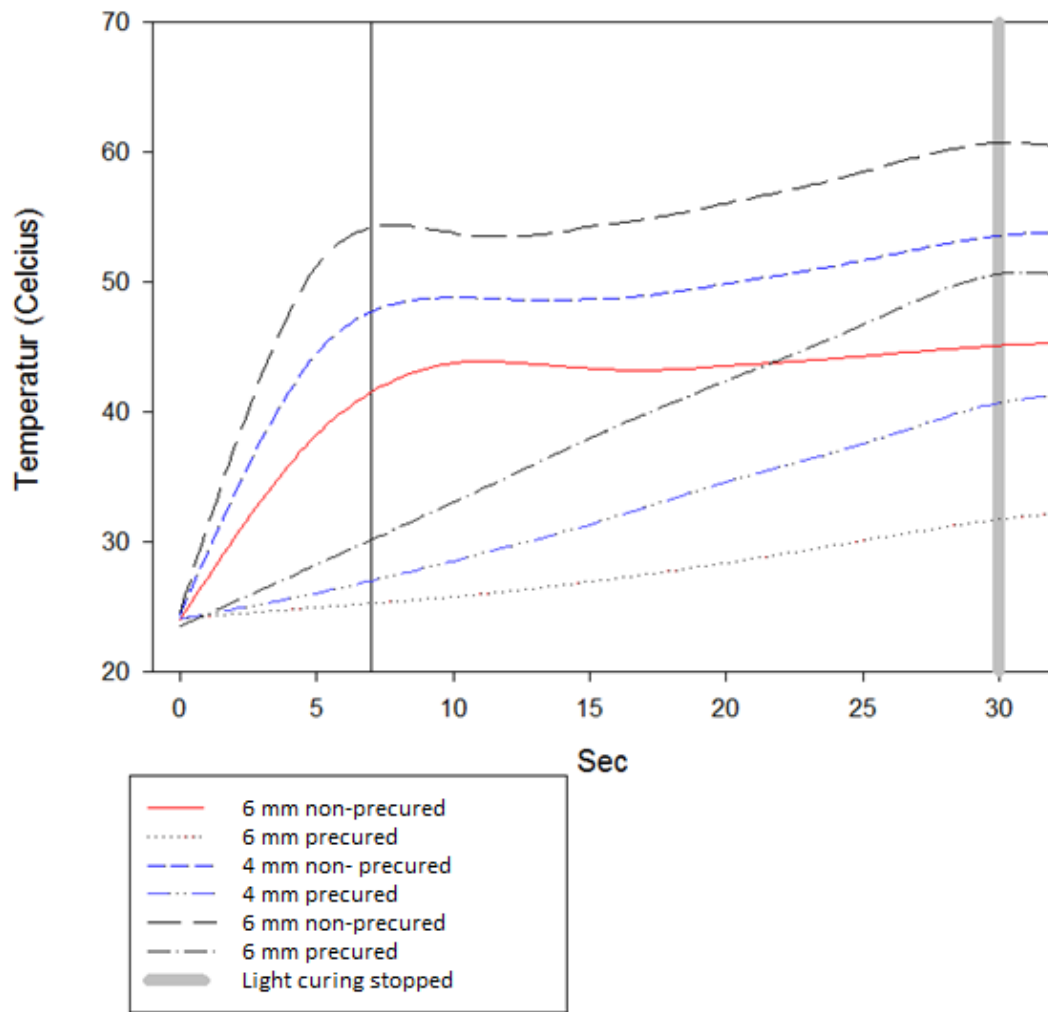


Figure 2. Mean temperature (n=5) inside of SDR™ during curing of each group. At 30 seconds, all measurements between the groups were significant different ($p < 0.05$).

Figure 3:

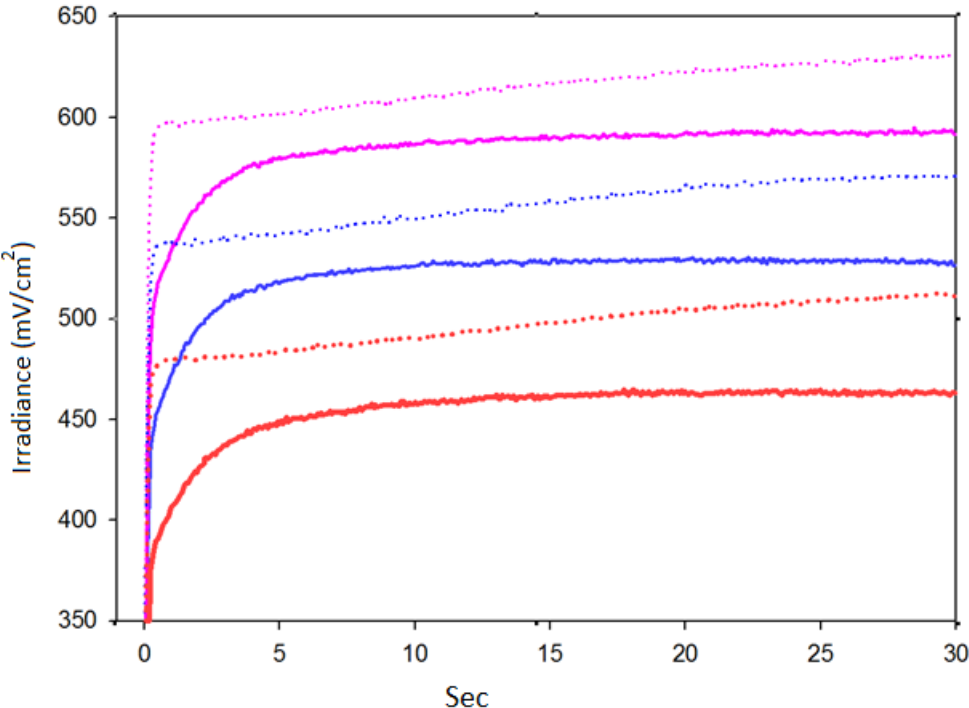


Figure 3. The irradiance measured through 3 samples of 1 mm of non-precured (lines) and precured composite (dots). The same color indicates the same sample.

Figure 4:

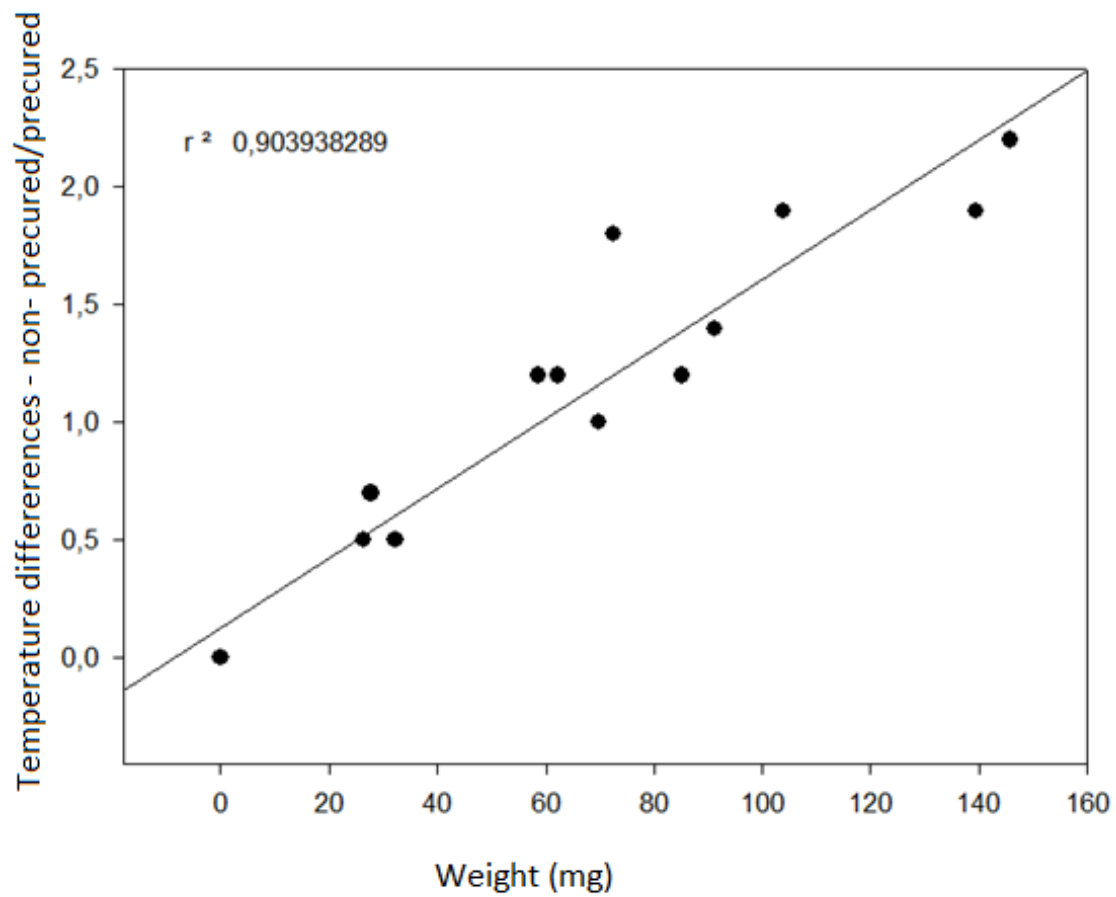


Figure 4. The differences in pulp chamber temperature between the non-precured and the precured SDR™ after 30 sec. of light curing, plotted against the weight of the composite sample.

Figure 5:

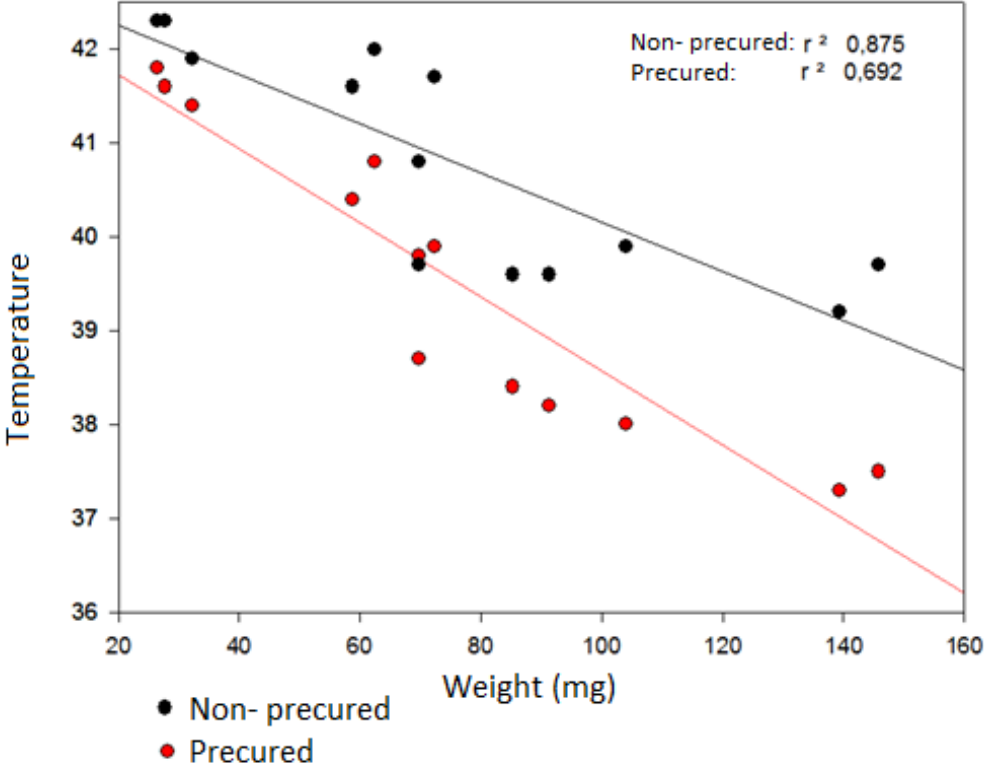


Figure 5. The decrease in pulp chamber temperature (Y-axis) plotted against weight/thickness of the composite (X-axis).

Table 1:

Group	Pulp chamber temperature			Temperature inside the composite		
	Non- precured	Precured	Temp. Δ	Non- precured	Precured	Temp. Δ
Empty cavity	42.6					
1 mm	42.2	41.6*	0.6			
2 mm	41.5	40.2*	1.3**	60.8	50.7	10.1**
3 mm	39.6*	38.4*	1.2**			
4 mm	39.6*	37.6*	2**	53.6	40.7	12.9**
6 mm				45.1	31.8	13.3**

Table 1. Mean temperatures after 30 sec of light curing and differences between non-precured and precured groups are shown. * Indicate a significant difference ($p < 0.05$) between the group respectively and the empty cavity. **Indicate a significant difference ($p < 0.05$) between non-precured and precured within the same group.