

Effects of Light Curing Modes and Resin Composites on Temperature Rise under Human Dentin: An *in vitro* Study

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The influence of three curing modes of a high-powered LED curing unit on temperature rise under 2-mm-thick dentin was investigated during the polymerization of resin composite samples of Admira, Filtek P60, Premise, Tetric Flow, Tetric Ceram, and Filtek Z250. Ninety standard specimens were prepared. The bonding agents and resin composites were cured with standard, pulse, or soft-start mode (n=5 for each curing mode). Temperature rise was measured using a type L thermocouple. Data were analyzed by two-way ANOVA and Tukey's test. Soft-start curing led to statistically higher temperature rises compared than the other two modes. The highest temperature rise was observed for Admira and Tetric Flow cured with soft-start mode. The lowest temperature rise was observed for Premise cured with pulse mode. However, temperature rise did not reach the critical value that can cause pulpal damage by virtue of a prominent safety feature of the high-powered LED LCU, which ensures that no excessive heat is produced by all the three curing modes.

Key words: Temperature rise, Composites, Polymerization

Received Nov 18, 2007; Accepted Feb 23, 2008

INTRODUCTION

An important milestone in the history of modern restorative dentistry is the development of light-cured resin composites for direct procedures¹. The majority of them are based on conventional monomer systems such as 2,2-bis [4-(2-hydroxy-3-methacryloyloxy-propoxy)-phenyl] propane (Bis-GMA), urethane-ethoxydimethacrylate (UEDMA), and triethylene glycol dimethacrylate (TEGDMA), with camphorquinone (CQ) typically as the photosensitizer for free radical polymerization². These resin composites include inorganic fillers in varying degrees, of varying sizes and types. Recently, a new type of organic-inorganic hybrid dental material, known as Ormocers, was introduced as an alternative to conventional dental composites. It has been stated that the combination of organic-inorganic matrix and filler particles in high concentrations (up to 67%) in ormocers provided an improvement in some mechanical and physical properties, thereby rendering them superior to those of conventional composites³⁻⁵.

An increase in demand for esthetic dental restorations has also led to a tandem increase in the use of light sources to photocure resin composites⁶. Whereas the output of first-generation LED LCUs is limited⁷, manufacturers have recently turned their attention to high-powered LED LCUs for the polymerization of dental resins. With a high-powered light source, more photons are available per given period

of absorption by the photoinitiators. As a result, more CQ molecules are raised to an excited state. The excited CQ molecules then collide with amine molecules to form free radicals. The latter, in turn, react with the carbon-carbon double bond of a monomer molecule and initiate the polymerization process^{8,9}. These LED LCUs generally have higher power densities, thereby producing potentially higher thermal emissions and depths of cure⁹.

Regardless of the amount of infrared energy transmitted from the curing source, polymerization of resin composites always results in a temperature increase in the material caused by both the exothermic polymerization and the light energy absorbed during irradiation^{7,10,11-17}. When using high-powered LCUs, the issue of temperature increase is of particular interest. This is because the increased energy of these LCUs may also increase the potential of generating injurious temperatures in the pulp — especially when they are used in deep cavities with minimal remaining dentin thickness^{10,12}. Moreover, the concept of total adhesive bonding precludes the use of a protective cement base or cavity lining, which also means a higher potential for thermal injury to the pulp¹².

It has been stated that the released energy and maximum polymerization temperature depend on the curing mode and polymerization characteristics of the dental composite¹⁷. Traditionally, continuous cure at constant irradiance is used for the polymerization of resin composites. However, Feilzer *et al.*¹⁸

pointed out that the use of high-intensity curing light negatively affected the restoration-cavity interface. To solve this problem, several curing protocols have been suggested. The so-called “soft-start polymerization” characterized by using an initial low-power intensity of the curing light followed by higher-power intensity has been suggested to minimize internal stresses in composites and improving their marginal adaptation^{11,19}. On the other hand, Kanca and Suh²⁰ proposed “pulse-curing or pulse-delay curing”. In this curing mode, the most occlusal increment of the resin composite is activated with a short pulse of light at rather low irradiance. They have shown that the use of this curing mode provided a reduction in enamel fractures and a general improvement of marginal adaptation, especially for Class I composite restorations when compared to those cured at constant irradiance.

However, few studies have been performed for the purpose of measuring temperature changes under the dentin in situations where the resin composites were cured with different curing protocols. When a high-powered LCU is used, it is important to determine the correct curing mode so as not to lead to a temperature rise which is potentially hazardous for the tooth. In light of this concern, the objective of this *in vitro* study was to evaluate the influence of different curing modes of a high-powered LED LCU on temperature rise under the dentin during the polymerization of six different composites.

MATERIALS AND METHODS

Composites

In this *in vitro* study, six different dental resin composites of shade A2 were tested for temperature rise. These composites were Admira (Voco GmbH, Cuxhaven, Germany), Filtek P60 (3M ESPE, St. Paul, MN, USA), Tetric Flow (Ivoclar Vivadent, Schaan, Liechtenstein), Tetric Ceram (Ivoclar Vivadent, Schaan, Liechtenstein), Filtek Z250 (3M ESPE, St. Paul, MN, USA), and Premise (Kerr Corp., Orange, CA, USA). The Admira composite is an ormocer consisting of additive aliphatic and aromatic dimethacrylates and Ba-Al-B-silicate glass and SiO₂ inorganic filler particles loaded in 56% by volume. Filtek P60 is a packable resin composite and Filtek Z250 is a microhybrid resin composite, whereby both are based on Bis-GMA, urethane dimethacrylate (UDMA), and bisphenol A polyethylene glycol diether dimethacrylate (Bis-EMA) resin matrix. The filler is zirconia-silica and inorganic filler loading is 61% and 60% by volume for Filtek P60 and Filtek Z250 respectively. Tetric Flow is a flowable resin composite and Tetric Ceram is a microfilled hybrid resin composite, whereby both have similar resin matrices composed of Bis-GMA, UDMA, and

TEGDMA. Their inorganic fillers are composed of barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, highly dispersed silicone dioxide, and spheroid mixed oxide in 39.7% and 60% by volume for Tetric Flow and Tetric Ceram respectively. Premise is a nanofilled hybrid composite, which has an organic resin matrix composed of ethoxylated Bis-EMA and TEGDMA. Premise incorporates a trimodal filler system consisting of prepolymerized, barium glass, and silica nano fillers. The inorganic filler loading is 69% by volume.

The bonding systems recommended by each composite manufacturer were used. Three of them were total-etching single bottle systems (Admira Bond, Adper Single Bond 2, and Optibond Solo Plus), and the other was a self-etching adhesive system (AdheSE). Table 1 shows the detailed information of the resin composites and their manufacturers, as well as information on the conditioning system and bond matrix composition of each adhesive system.

Light curing units

The composites were cured with a high-powered LED LCU (Mini LED, Satelec, Merignac, France). Output of the LED unit stated by the LED manufacturer was accepted as accurate (1100 mW/cm²), and five specimens of each composite were polymerized using one of the three curing protocols: standard (10-second exposure at full power), pulse mode (10 consecutive one-second exposures at full power), and soft-start mode (progressive cycle lasting 20 seconds). The energy produced by each polymerization mode was dependent on both the polymerization time and light intensity (total energy=light intensity×exposure time)^{11,17,21-23}. In this study, total energy was 22 J/cm² for soft-start polymerization, while it was 11 J/cm² for the other two modes. The LED unit's battery was recharged according to manufacturer's recommendation and placed in its charger following the polymerization of each specimen. Table 2 shows the details pertaining to the LED unit and its polymerization modes and profiles.

Preparation of dentin disks

Ninety noncarious, extracted human premolars were stored in physiological saline solution in an incubator. The occlusal enamel portions of the premolars were removed using a low-speed saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA) to expose the dentin by sectioning the tooth perpendicular to its long axis. Dentin disks, 2 mm thick, were then sectioned perpendicular to the long axis of the tooth, and 90 dentin disks were obtained as a result. These dentin disks were placed at the bottom of a Teflon mold cylinder of a temperature test apparatus as explained below.

Table 1 Restorative materials used in this study

Material	Admira	Filtek P60	Tetric Flow	Tetric Ceram	Filtek Z250	Premise
Manufacturer	Voco GmbH Cuxhaven, Germany	3M ESPE, St. Paul, MN, USA	Ivoclar Vivadent Schaan / Liechtenstein	Ivoclar Vivadent Schaan / Liechtenstein	3M ESPE, St. Paul MN, USA	Kerr Corporation, Orange, CA, USA
Type	Ormocer based packable	Composite-based packable	Composite-based flowable	Hybrid	Microhybrid	Nano-filled hybrid
Resin matrix	Ormocers / additive aliphatic and aromatic dimethacrylates	Bis-GMA, UDMA Bis-EMA	Bis-GMA, UDMA TEGDMA	Bis-GMA, UDMA, TEGDMA	Bis-GMA, UDMA Bis-EMA	ethoxylated Bis-EMA, TEGDMA
Filler type	Ba-Al-B-silicate glass, SiO ₂ ,	zirconia / silica	barium glass, ytterbium trifluoride, Ba- Al-fluorsilicate glass, highlydis- persed silicon dioxide spheroid mixed oxide	barium glass, ytterbium trifluoride Ba- Al-fluorsilicate glass highly dispersed silicon dioxide spheroid mixed oxide	zirconia / silica	Barium glass, non- agglomerated silica nano particles, prepolymerized filler
Average particle size	0.7 μm	0.01-3.5 μm the mean particle 0.6 μm	0.04-3.0 μm the mean particle 0.7 μm	0.04-3.0 μm the mean particle 0.7 μm	0.01-3.5 μm	barium glass: 0.4 μm, silica nano particles: 0.02 μm
Filler volume %	56	61	39.7	60	60	69
Filler weight %	78	80	64.6	79	82	84
Co-initiators absorption within<410 nm	no	no	unknown	unknown	no	unknown
Bonding Systems	Admira Bond	Adper Single Bond 2	AdheSE		Adper Single Bond 2	Optibond Solo Plus
Conditioning	Vococid (35% ortho- phosphoric acid gel)	Scotchbond etchant (35% phosphoric acid gel)	AdheSE Primer: Dimethacrylate phosphonic acid acrylate		Scotchbond etchant (35% phosphoric acid gel)	Kerr gel etchant (37.5% phosphoric acid gel)
Bond matrix	Bis-GMA, HEMA, organic acids complex, acetone three- dimensionally curing anorganic- organic copolymers	Bis-GMA, HEMA, water dimethacrylates, ethanol methacrylate functional copolymer of polyacrylic and polyitaconic acids, silica photoinitiators	AdheSE Bond: HEMA, dimethacrylate silicone dioxide		Bis-GMA, HEMA, water dimethacrylates, ethanol methacrylate functional copolymer of polyacrylic and polyitaconic acid, silica photoinitiators	Bis-GMA, HEMA, GPDM ethanol, fumed silica, barium, sodium hexa- fluorosilicate, glass, camphorquinone

*Data as disclosed by the manufacturers

Bis-GMA: Bisphenol A diglycidylmethacrylate; Bis-EMA: Bisphenol A polyethylene glycol diether dimethacrylate; UDMA: Urethane dimethacrylate; TEGDMA: Triethyleneglycoldimethacrylate; HEMA: 2-Hydroxyethyl methacrylate; GPDM: Glycerophosphate dimethacrylate; GDM: Glycerol dimethacrylate

Table 2 Details of the light polymerization unit and its polymerization modes and profiles

Unit	Light type and diameter	Wavelength of emission	Mode	Output and total time	Profile
Mini LED	LED (7.5 mm)	420-480nm	Standard	1100 mW/cm ² (10 seconds)	Continuous energy output for 10 seconds
			Pulse	1100 mW/cm ² (10 seconds)	10 successive 1-second flashes at full power pulse activation mode, with a rest period of 250 ms between flashes
			Soft start	0 to 1100 mW/cm ² +1100mW/cm ² (20 seconds)	Exponential energy output automatically increased to full energy within 10 seconds +10 seconds full energy

*Light intensity purported by manufacturer

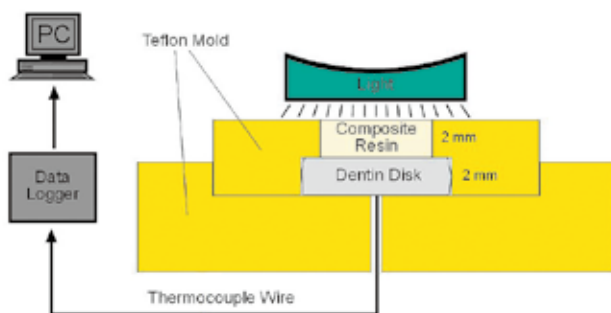


Fig. 1 Apparatus for measuring temperature changes.

Temperature test apparatus

To standardize temperature rise measurements, an apparatus was modified from that developed by Smail *et al.*²⁴ (Fig. 1). It comprised two concentric Teflon mold cylinders constructed from polytetrafluoroethylene. The top Teflon mold cylinder had a central aperture (6 mm diameter, 2 mm depth). The resin composite bulk was directly placed in this aperture onto the dentin disk treated with bonding agent. The bottom Teflon mold cylinder then formed the lateral walls of the dentin disk (8 mm diameter, 2 mm depth). The bottom portion of the apparatus had a hole (1 mm diameter) just beneath the center of the dentin disk for thermocouple wire insertion. To achieve an accurate positioning of all the dentin disks, their thicknesses were standardized at 2 mm between the tip of the thermocouple and the resin composite in each experiment.

Temperature measurement

Fifteen specimens were prepared for each resin composite, whereby five specimens (n=5) were polymerized using one of the three curing modes. All measurements were taken in a temperature-

controlled room with a constant temperature of $20 \pm 1^\circ\text{C}$. A type L Fe-constantan thermocouple (Fe-Const, Elimko Co., Turkey) connected to a data logger (E-680, Elimko Co., Turkey) was used to record temperature rise during the light-curing of bonding and resin composites. E-680 series of universal data loggers/scanners are advanced, new-generation microcontroller-based industrial instruments compatible with IEC 668 standards. Universal inputs and outputs of the device could be programmed easily by the user, and data were collected and stored in a centrally located PC loaded with software (Data Logger, ver. 5.1, Elimko Co., Turkey).

Temperature rises were recorded at the following three levels:

1. Temperature rise beneath the dentin disk without any restoration to detect whether histochemical and/or structural variables of the dentin disk affected temperature change. Temperature rise beneath all dentin disks was effected by using LED LCU for 10 seconds. The mean temperature rise was $0.24 \pm 0.04^\circ\text{C}$. Thus, it was concluded that the temperature change was not affected by any histochemical and/or structural dentin variables.
2. Temperature rise during polymerization of the visible light-cured bonding systems.
3. Temperature rise during polymerization of the resin composites. The central cylinder aperture was filled with the selected material and then covered with a Mylar strip and digitally pressed. For light curing, the LCU tip was positioned against the Teflon mold/composite.

During each measurement, the initial temperature was recorded following temperature stabilization ($20 \pm 1^\circ\text{C}$) and then the peak temperature was registered. To obtain the temperature change, the initial temperature was deducted from the final

one.

Statistical analysis

Using a SPSS statistical software program (Version 10.0, SPSS Inc., Chicago, USA), temperature change data were subjected to statistical analysis between the composites as well as among LED curing modes using two-way analysis of variance (ANOVA). Where significant differences were present, Tukey's *post hoc* test was applied to examine pairwise differences at a significance level of 0.05.

RESULTS

Table 3 lists the means and standard deviations of temperature rise measured during the polymerization of six different composites with three different modes of LED LCU. Data analysis by two-way ANOVA showed significant temperature rise differences among the curing modes both during application of bonding agent ($F=18.84$) and polymerization of resin composites ($F=119.54$).

During the application of all bonding systems, the highest temperature rise was observed with the soft-start mode and this increase was statistically different from the other two modes ($p<0.05$). Temperature rises observed with the standard- and pulse-mode curing of the bonding systems showed no statistical differences ($p>0.05$). Admira and Tetric Flow resin composites showed the highest temperature increase when they were cured with soft-start mode ($1.50\pm 0.11^\circ\text{C}$ and $1.46\pm 0.05^\circ\text{C}$ respectively), whereas pulse-mode curing of Premise resin composite led to the lowest temperature increase among the materials and curing modes tested ($0.22\pm 0.04^\circ\text{C}$).

With soft-start curing, significantly higher temperature increase was recorded for Admira, Filtek P60, Tetric Ceram, and Premise resin composites as compared to the other two curing modes ($p<0.05$). No statistically significant differences were observed for these specimens when they were cured with the standard and pulse modes ($p>0.05$). For Tetric Flow and Filtek Z250 resin composites, temperature

Table 3 Mean temperature rise values and standard deviations (SD) for the resin composite systems and light curing modes evaluated

Composite	Curing mode	Bonding Agent Application Mean \pm SD	Resin Composite Polymerization Mean \pm SD
Admira	Standard	0.26 ± 0.05	0.54 ± 0.11^a
	Pulse	0.28 ± 0.04	0.42 ± 0.08^b
	Soft start	$0.46 \pm 0.05^*$	$1.50 \pm 0.07^{*i,j,k,l}$
Filtek P60	Standard	0.24 ± 0.05	$0.38 \pm 0.08^{d,e}$
	Pulse	0.22 ± 0.04	0.34 ± 0.05
	Soft start	$0.46 \pm 0.05^*$	$0.90 \pm 0.10^{*i,m}$
Tetric Flow	Standard	0.26 ± 0.05	$0.62 \pm 0.08^{b,d,f}$
	Pulse	0.28 ± 0.04	0.38 ± 0.04
	Soft start	$0.46 \pm 0.05^*$	$1.46 \pm 0.05^{*m,n,o,p}$
Tetric Ceram	Standard	0.26 ± 0.05	$0.40 \pm 0.07^{f,g}$
	Pulse	0.28 ± 0.04	0.30 ± 0.07
	Soft start	$0.46 \pm 0.05^*$	$1.08 \pm 0.13^{*j,n,r}$
Filtek Z 250	Standard	0.26 ± 0.05	$0.62 \pm 0.08^{c,e,g}$
	Pulse	0.28 ± 0.04	0.24 ± 0.05
	Soft start	$0.46 \pm 0.05^*$	$0.98 \pm 0.13^{*k,o,s}$
Premise	Standard	0.24 ± 0.05	$0.34 \pm 0.05^{a,b,c}$
	Pulse	0.22 ± 0.04	0.22 ± 0.04^h
	Soft start	$0.46 \pm 0.05^*$	$0.76 \pm 0.05^{*l,p,r,s}$

n=5 specimens per experimental condition

By two-way ANOVA: $F=18.84$ $P=0.000$ $p<0.05$ for bonding agent application; $F=119.54$ $P=0.000$ $p<0.05$ for resin composite polymerization.

Means labelled with the same small letters in the columns are for the comparison of different resin composites cured with the same light curing mode; *:denotes the highest temperature rise values among three light curing modes of a given material. They are significantly different by Tukey's test ($p<0.05$).

change with each of the three curing modes differed ($p < 0.05$).

Tukey's test results showed that the standard mode curing led to statistically significant differences in temperature rise between Admira and Premise, Filtek P60 and Tetric Flow, Filtek P60 and Filtek Z250, Tetric Flow and Tetric Ceram, Tetric Flow and Premise, Tetric Ceram and Filtek Z250, and Premise and Filtek Z250 ($p < 0.05$). Pulse-mode curing of composites did not lead to statistically different temperature variations among all the resin composites, except between Admira and Premise which were found to be statistically different from each other at $p < 0.05$. The comparison of temperature changes of all resin composites cured with soft-start mode showed no statistically significant differences between Admira and Tetric Flow, Filtek P60 and Tetric Ceram, Filtek P60 and Filtek Z250, Filtek P60 and Premise, and Tetric Ceram and Filtek Z250 ($p > 0.05$); the others were found to be statistically different from each other ($p < 0.05$).

DISCUSSION

Temperature rise during polymerization is a consequence of both the exothermic reaction process and the radiant heat from the light curing unit. The contribution from the material depends on material composition, material depth, and ambient temperature, whereas contribution from the light depends on exposure time and characteristics of the light source¹⁴. This *in vitro* study sought to evaluate the effect of three different polymerization modes of a latest high-powered LED LCU on temperature rise under human dentin during the polymerization of different resin composite systems. A stringently standardized dentin thickness (2 mm) was used with a view to eliminating any possible variation in thermal transfer. Further, a composite specimen size of 2 mm thickness was selected as it was considered to be clinically realistic¹⁶. Many manufacturers quote 2-mm-thick specimens when recommending radiation times. On the shade of resin composite specimens, shade A2 was selected to minimize the effects of colorant on light polymerization²¹.

Temperature increases up to 20°C have been measured during light-induced polymerization of composite resins^{19,25}. According to Zach and Cohen²⁶, a temperature rise of 5.5°C in the pulp is the limit that permits the pulp to recover from thermal damage. In the current study, temperature changes were measured during the operation of a high-powered LED LCU with a starting temperature of 20±1°C as previously suggested^{7,27}. Temperature increases under dentin were continuously measured up to the point where the temperature began to fall. The peak values registered during the curing of all

the tested materials with each of the three modes were lower than this previously reported critical value. This below-critical-value temperature rise could be attributed to a prominent feature of this high-powered LED LCU, in that there was basically no infrared light transmission to the tooth—and hence no excessive heat was produced²⁷. Based on the data obtained in this study, it may be suggested that this LED light source could be used safely in similar clinical situations.

Resin composites were used with their own bonding agents in order to simulate clinical use. The same curing mode made no statistically significant differences among the bonding agents, which was probably due to the same irradiation time. Ozturk *et al.*²⁸ have compared the temperature changes under 1-mm-thick dentin using total-etch and self-etch adhesive systems and polymerization using a LED LCU. They obtained a higher temperature rise (1.61°C) for both types of adhesives systems than those found in the current study. The use of different dentin thicknesses might explain this. Knezevic *et al.*²⁹ have reported higher temperature increases with increased irradiation time and decreased material thickness. During the application of all the bonding systems in this study, the highest temperature rise was observed with the soft-start mode of LED LCU at a value of 0.46±0.05°C. The reason for this result could stem from the irradiation time of soft-start mode being approximately two times longer than the other curing modes. Furthermore, the absence of remarkable temperature changes in this study supported the suggestion by Shortall and Harrington¹⁶ that greater thermal insult might occur when polymerizing bonding resins prior to restorative resins.

The soft-start mode was introduced to reduce shrinkage stress of dental composites, to achieve smaller marginal gaps, and to increase marginal integrity³⁰⁻³². However this technique requires long cure times and consequently increases the energy produced, raising the temperature of resin composites and the surrounding dentin¹¹. In the current study, the temperature rise induced by each curing mode did not exceed a previously reported critical value. In this respect, the thermal insulation provided by a relatively thick dentin⁷ might be effective. However, in deep cavities where the residual dentin thickness is smaller and the tubular surface area increases¹⁷, soft-start mode should be used cautiously to avoid excessively heating the pulp. This is because during the polymerization of all the tested resin composites, the highest temperature increase under dentin was consistently recorded with soft-start mode. Conversely, the pulse mode yielded the lowest temperature rise for all the tested resin composites.

These data were in agreement with those of

Aguiar *et al.*¹¹⁾, who evaluated the effect of five polymerization modes and the presence of resin composite on temperature rise in human dentin of different thicknesses. They found that conventional and high-intensity polymerization modes presented lower temperature rise than soft-start mode in all conditions. However, the values obtained were higher than those of the current study, which could be due to the test conditions and light source used. According to Loney and Price³³⁾, the difference in energy produced by the light curing units was an important factor for different temperature rises in different polymerization modes. Therefore, the differences in energy produced by the three curing modes might be responsible for the differences in the observed temperature changes.

With regard to material composition, Shortall and Harrington¹⁶⁾ have concluded that temperature rise is also related to the light transmission characteristics of resin composition. Masutani *et al.*³⁴⁾ suggested that the exothermic reaction of the resin during polymerization had a greater influence on temperature rise *vis-à-vis* the light source. This suggestion was supported by our results where the temperature rise was very specific to a given composite due to its unique combination of filler, resin characteristics and formulation. While the highest temperature increase was observed for ormocer (Admira) and flowable (Tetric Flow) resin composites with soft-start curing, the lowest temperature rise was observed for nanofilled hybrid resin material (Premise) with pulse curing. It should be highlighted that all the composites tested had different volume fractions of the organic resin matrix. This appeared to be effective in influencing the extent of exothermic reaction during the polymerization process, and thus the differences in temperature change.

Under the same light-curing conditions, the different thermal conductivity values of composites and the different patterns of energy density distribution along time²⁷⁾ could help explain the results in this study. The ormocer material possessed a modified organic matrix, formed by monomers with a single polymerizable end. The other end was formed by an alkoxy group, resulting in an inorganic area, bonded to other monomers by a chemical reaction of condensation, converting the monomer precursors in a polymeric inorganic condensate — via sol-gel processing — to create a complex structure with the formation of the Si-O-Si chain in the inorganic area of the polymer^{3-5,35)}. The significantly greater temperature rise with the ormocer compared to the other products presumably resulted from the different monomer compositions, given the relatively low light transmittance of this product.

Although Filtek Z250 and Filtek P60, and Tetric

Ceram and Tetric Flow had the same molecules in their organic matrices and the same types of fillers, they showed different temperature rises. According to the data given by the manufacturers, the majority of TEGDMA was replaced with a blend of UDMA and BisEMA in Filtek Z250 when compared to Filtek P60. On the other hand, Tetric Ceram had a higher amount of inorganic filler than Tetric Flow. Taking these differences into consideration, they could have thus led to a decrease in temperature rise during polymerization. Tarle *et al.*³⁶⁾ found higher temperature rises with standard-mode curing of hybrid composite Tetric Ceram (2.2°C) and microhybrid composite Filtek Z250 (1.5°C) than those found in the current study for the same materials (0.40°C and 0.62°C respectively). It should be highlighted that in their experiment³⁶⁾, they used one of the early commercial blue LED LCUs giving an exposure profile of 10 seconds at 50 mW/cm², then 30 seconds at 150 mW/cm². Differences in the curing protocol might help to explain the differences in results between the two studies using the same products.

Premise, which is a nanofilled resin composite, has been highly rated for handling, polishability, esthetics, and shade matching by clinical evaluators³⁷⁾. Its manufacturer claimed that this resin demonstrated only moderate polymerization shrinkage caused by changes in dimensions as the resin was being cured. The temperature measurements under all conditions revealed the lowest temperature rise with this product and affirmed its safe use in clinical situations.

In this study, final temperature increases during polymerization with the high-powered LED LCU appeared to be below the critical value that can cause pulpal damage, thereby indicating its safety. In the current study, temperature change was evaluated under human dentin of 2 mm thickness. At this juncture, it should be put into perspective that for heat-related pulpal injury, the remaining dentin thickness is a critical factor that influences the amount of heat reaching the pulp. Therefore, further studies should be performed to confirm the effects of different curing modes on temperature change during the polymerization of composites placed over a thinner dentin. This would then mimic a more realistic clinical situation.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions were drawn:

- (1) The high-powered LED LCU caused minimal temperature rise under dentin during the polymerization of all resin composite systems.
- (2) Soft-start curing led to significantly higher

temperature increases under dentin than the standard and pulse modes.

- (3) Temperature rise was found to be material-dependent. The differences were found to be statistically significant among all the materials tested.
- (4) Highest temperature rise was observed for the soft-start curing of Admira and Tetric Flow.
- (5) Pulse curing of Premise gave the lowest temperature rise among the materials tested.

ACKNOWLEDGEMENTS

Special thanks go to Assoc. Professor Ali Fazal Yenidünya, Cumhuriyet University, Faculty of Science and Arts, Department of Biology, for his invaluable contribution in the preparation of this manuscript for submission.

This work was supported by CUBAP, Project Nr. DIS-043.

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