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Temperature changes influenced by different types of light curing units during polymerization of resin-based dental composite materials

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ABSTRACT

Purpose: of this study was to evaluate the influence of LCU type on temperature changes during polymerization of two resin-based composites with different matrices (silorane-based and methacrylate-based).

Design/methodology/approach: The light-curing units (LCUs) selected for this study included three various LEDs (LED 55, LED 10W and Radii Plus) and a QTH (Elipar Highlight). Two different resin-based composites (RBCs) were used in this study. The silorane-based composite Filtek Silorane and methacrylate-based composite Filtek P60. Temperature changes were measured during polymerization with LCUs working in various curing modes. Empty mold, Filtek Silorane RBC and Filtek P60 RBC were cured from a distance of 0 mm, 2.5 mm and 5 mm.

Findings: Regardless the type of RBC, every time the highest temperature was reached with LED 55 light-curing unit. Comparing Filtek Silorane and Filtek P60 RBCs, the temperature of Filtek Silorane RBC was significantly higher with LED 55 (35.4±4.9), Radii Plus (33.5±5.5) and Elipar Highlight LCUs (31.2±3.1), and significantly lower with LED 10W LCU (28.5±7.5). For Filtek P60 the measured temperatures of polymerization were 32.7±3.2 for LED 55 LCU, 29.9±5.6 for LED 10W LCU, 31.0±2.4 for RadiiPlus LCU and 30.2±1.8 for Elipar Highlight LCU.

Research limitations/implications: The research was carried out for two groups of composite materials used for teeth restoration in modern dentistry. The experiment should be repeated on a broader group of resin-based composite dental materials and should take into account more light-curing units. The study could be also done in situ on a real tooth model.

Practical implications: This research gives an insight into the range of temperatures that are generated during polymerization process of dental composite materials. The results of the study are of a great value during choosing the restorative composite material for particular application in the oral cavity, selecting the right light-curing-unit and adjusting the curing parameters

Originality/value: The results of the study allow to conclude that the temperature values vary for each resin-based material, according to light-curing-unit type and the distance of curing seemed to have least influence on temperature changes during polymerization.

Keywords: Dental restorative material; Resin-based dental composite; Light-curing unit; Polymerization temperature

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PROPERTIES

1. Introduction

Today, almost all commercial dental composites utilize photopolymerization reactions initiated by blue visible light. Light curing units (LCUs) based on different physical principles, such as quartz-tungsten-halogen (QTH) bulbs, laser, plasma arc lights, and light emitting diodes (LEDs) are available. Nevertheless, LED LCUs are currently the standard devices in most modern dental practices [1].

Halogen lamps use a tungsten filament heated up to 3000°C, which emits a white light covering a large range of wavelengths including the infrared. Thus, QTH light must be filtered to eliminate unwanted wavelengths outside the 400 to 500 nm (blue light) range, and only a small fraction of the light produced from this source is used for polymerization and a large amount of energy is transformed into heat [2]. Heat has been shown to degrade light filters and bulbs and consequently the efficiency of QTH curing units over time [3].

Among the different light-curing systems available today, LEDs seem to present the best technology for several reasons: their narrower spectrum is better centered on the peak of maximum absorption of the main composite photoinitiator, camphorquinone (CQ), which increases irradiation efficiency [4]. Second, the low power consumption of LED LCUs enables the use of batteries, which have led to significant ergonomic improvement [5] and smaller, better-adapted fans or other heat dissipating devices.

While first generation LED lights did not meet with general approval due to their low power density [5,6], new generation lights are now increasingly used by practitioners. These newer LED lights have been shown to have produced material properties similar to QTH lights [7,8]. Moreover, several publications have highlighted the potential of these lights as reducing irradiation time without a significant loss of mechanical properties [7, 9-14]. In contrast with QTHs, LEDs do not need filters to diminish the infrared energy flux. Consequently, advantages such as long lifetime, constant irradiance, low heat generation and higher efficiency in converting energy to light could be claimed for LEDs [15].

The aim of this study was to evaluate the influence of LCU type on temperature changes during polymerization of two resin-based composites with different matrices (silorane-based and methacrylate-based).

2. Material and methods

2.1. Light-curing units

The light-curing units (LCUs) selected for this study included three various LEDs (LED 55, LED 10W and Radii Plus) and a QTH (Elipar Highlight). Radii Plus and Elipar Highlight LCUs were operating only in Standard curing mode, whereas LED 55 and LED 10W LCUs were operating in three curing modes (Fast, Pulse, Ramp). The characteristics of LCUs are shown in Table 1.

Table 1.
Characteristics of Light-Curing-Units used in the study

Light source	LED 55	LED 10W	Radii Plus	Elipar Highlight
Type	LED	LED	LED	QTH
Manufacturer	TPC	Apoza Enterprise	SDI	3M ESPE
Output intensity, mW/cm^2	1250	2700	1500	750
Wavelength range, nm	430-490	430-490	440-480	400-500
Curing modes	Fast, Pulse, Ramp	Fast, Pulse, Ramp	Standard	Standard
Exposure times, s	40, 60	4, 8	40, 60	40, 60

2.2. Composites

Two different resin-based composites (RBCs) were used in this study. The silorane-based composite Filtek Silorane and methacrylate-based composite Filtek P60. Both composites contain camphorquinone as the major photoinitiator. The characteristics of RBCs are shown in Table 2.

2.3. Photocuring

The materials were cured in specially prepared silicone mold with a chamber for curing with dimensions of 3 mm length, 3 mm width and 2 mm depth. At the bottom of the chamber the tip of K-type thermocouple was placed. Temperature changes were recorded using a TES-1307 electronic thermometer.

Temperature changes were measured during polymerization with LCUs working in various curing modes. Empty mold, Filtek Silorane RBC and Filtek P60 RBC were cured from a distance of 0 mm, 2.5 mm and 5 mm.

2.4. Statistical analysis

All calculations were performed with the use of StatSoft Inc. statistical software STATISTICA, version 12.0. and Excel calculation sheet.

Quantitative variables were expressed by: mean, standard deviation, median, minimal and maximal value (range) and 95% CI (Confidence Interval). The qualitative variables were expressed by numerical values.

The W Shapiro-Wilk test was used to check if the quantitative variable came from normally distributed population. The Levene's (Brown-Forsythe) test was used to check the hypothesis on equal variances.

The difference significance between two groups (independent variables model) was tested using significance differences test: t-Student or U Mann-Whitney test. Significant differences between more than two groups were tested with F (ANOVA) or Kruskal-Wallis test (in case of not complying with ANOVA test requirements), followed by Tukey's or Dunn's tests when differences between groups were statistically significant.

The strength and direction of correlation between variables was tested using correlation analysis calculating Pearson and/or Spearman correlation coefficients. The statistical significance level was set at $p=0.05$.

3. Results

The mean temperatures, the ranges (minimum and maximum values) and the medians were measured during polymerization of two different composites using four LCUs. The measurement was also made with empty mold, to verify the results. Findings are shown in Table 3.

The temperature values varied for each RBC, according to LCU type (Kruskal-Wallis test for empty mold: $H(3.1608)=101.60$, $p=0.0010$, Filtek Silorane: $H(3.1008)=195.58$, $p=0.0010$, Filtek P60: $H(3.708)=125.24$, $p=0.0010$).

Regardless the type of RBC, every time the highest temperature was reached with LED 55 LCU. For empty mold the temperature of curing with LED 55 LCU was significantly higher than temperature of Radii Plus and Elipar Highlight LCUs. Moreover, the temperature of LED 10W was significantly higher compared with Radii Plus LCU. For both RBCs, Filtek Silorane and Filtek P60, the temperature during polymerization with LED 55 LCU was significantly higher than temperature of LED 10W, Radii Plus and Elipar Highlight LCUs. Furthermore, the lowest temperature for both materials was noticed when LED 10W LCU was used.

Comparing Filtek Silorane and Filtek P60 RBCs, the temperature of Filtek Silorane RBC was significantly higher with LED 55, Radii Plus and Elipar Highlight LCUs, and significantly lower with LED 10W LCU.

Table 2.
Characteristics of Resin-Based-Composite materials used in the study

Material	Filtek Silorane	Filtek P60
Manufacturer	3M ESPE	3M ESPE
Resin matrix	Siloranes	Bis-GMA, UDMA, Bis-EMA
Filler type	Quartz and Yttrium fluoride	Zirconia / Silica
Average particle size, μm	0.47	0.60
Filler volume, %	55	61
Filler load by weight, %	76	80

Table 3.
Temperature values (°C) for empty mold, Filtek Silorane and Filtek P60 RBCs recorded during polymerization with four different LCUs

		LED 55	LED 10W	Radii Plus	Elipar Highlight	*P*-value
Empty mold	mean (SD)	32.2 (6.1)	30.8 (6.3)	28.9 (2.2)	29.2 (1.6)	^{1,2}0.0001 ^{3}0.0329
	range	20.8-46.1	20.7-47.6	22.4-32.8	24.6-31.4	
	median	31.1^{1,2}	30.3^{3}	28.6^{1,3}	29.4^{2}	
Filtek Silorane	mean (SD)	35.4 (4.9)	28.5 (7.5)	33.5 (5.5)	31.2 (3.1)	^{1,2,3,4}0.0001
	range	20.8-47.9	18.4-54.5	24.8-47.7	25.1-38.2	
	median	35.6^{a,1,2,3}	26.1^{b,1,4}	33.2^{c,2,4}	31.7^{d,3}	
Filtek P60	mean (SD)	32.7 (3.2)	29.9 (5.6)	31.0 (2.4)	30.2 (1.8)	^{1,2,3}0.0001
	range	21.8-37.7	19.6-43.5	25.5-35.1	25.5-32.2	
	median	33.2^{a,1,2,3}	29.8^{b,1}	30.6^{c,2}	30.6^{d,3}	
	P-value	^{a}0.0001	^{b}0.0054	^{c}0.0165	^{d}0.0001	

There were some statistically significant correlations of curing distance and temperature according to LCU type and RBC type. The results are shown in Table 4. For Filtek Silorane cured with LED 55 LCU the temperature increased with increase of curing distance (Figure 1). The temperature decreased with increase of curing distance for Filtek Silorane cured with Radii Plus LCU and for Filtek P60 cured with Radii Plus and Elipar Highlight LCUs (Figures 2-4).

Table 4.
Correlations of curing distance and temperature according to LCU type and RBC type (R – correlation coefficient)

		R	P-value
LED 55	Filtek Silorane	0.19	0.0001
	Filtek P60	-0.07	0.1809
LED 10W	Filtek Silorane	0.07	0.4542
	Filtek P60	-0.15	0.1166
Radii Plus	Filtek Silorane	-0.79	0.0100
	Filtek P60	-0.80	0.0001
Elipar Highlight	Filtek Silorane	-0.08	0.2991
	Filtek P60	-0.33	0.0002

There were statistically significant correlations of curing time and temperature according to LCU type and RBC type. Results are shown in Table 5. The temperature recorded for Filtek Silorane cured with LED 55 LCU reached the maximum value after 10 s and then slowly started to decrease (Figure 5). The temperature of Filtek Silorane cured with LED 10W LCU and Filtek P60 cured with all four LCUs was increasing with the increase of curing time (Figures 6-10).

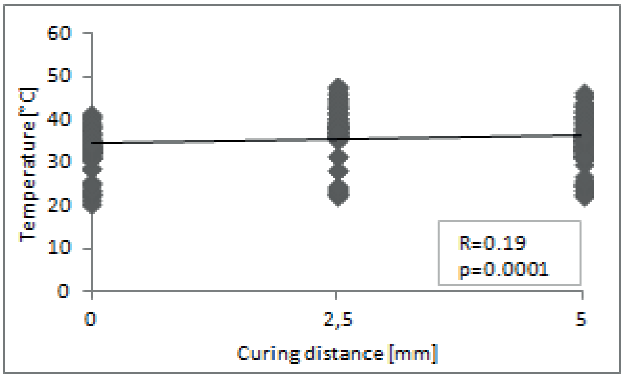

Fig. 1. Correlation of curing distance and temperature for Filtek Silorane cured with LED 55 LCU

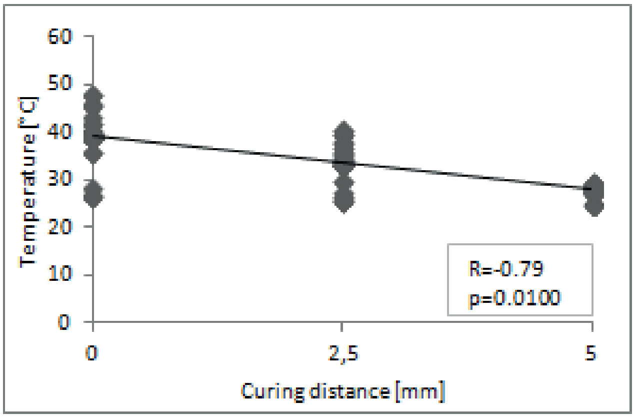

Fig. 2. Correlation of curing distance and temperature for Filtek Silorane cured with Radii Plus LCU

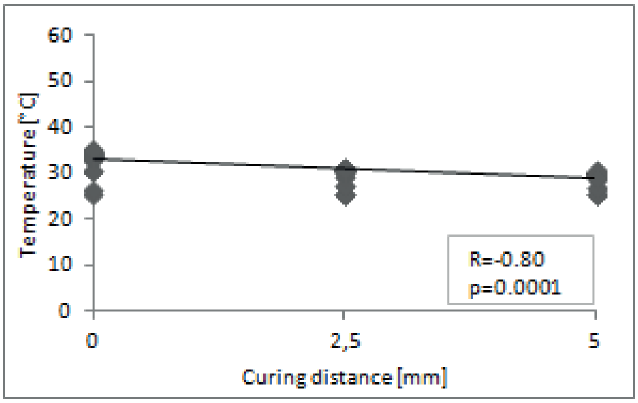

Fig. 3. Correlation of curing distance and temperature for Filtek P60 cured with Radii Plus LCU

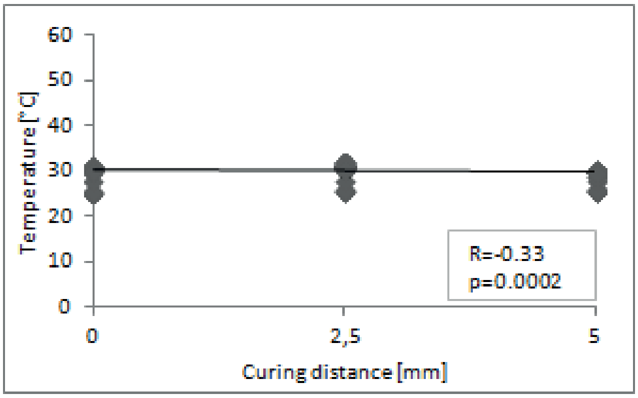

Fig. 4. Correlation of curing distance and temperature for Filtek P60 cured with Elipar Highlight LCU

Table 5.
Correlations of curing time and temperature according to LCU type and RBC type (R – correlation coefficient)

		R	P-value
LED 55	Filtek Silorane	-0.34	0.0082
	Filtek P60	0.95	0.0001
LED 10W	Filtek Silorane	0.64	0.0001
	Filtek P60	0.60	0.0001
Radii Plus	Filtek Silorane	-0.24	0.0620
	Filtek P60	0.91	0.0001
Elipar Highlight	Filtek Silorane	0.11	0.4122
	Filtek P60	0.48	0.0001

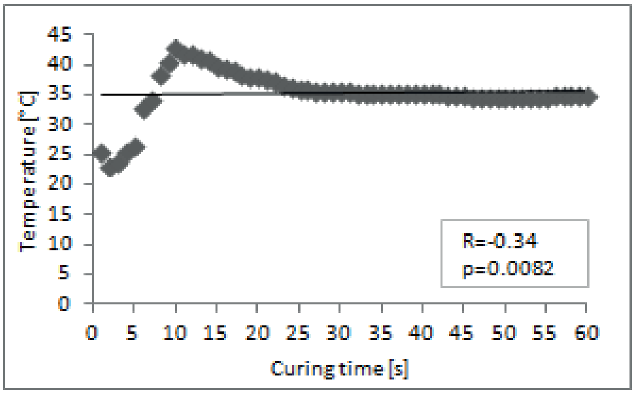

Fig. 5. Correlation of curing time and temperature for Filtek Silorane cured with LED 55 LCU

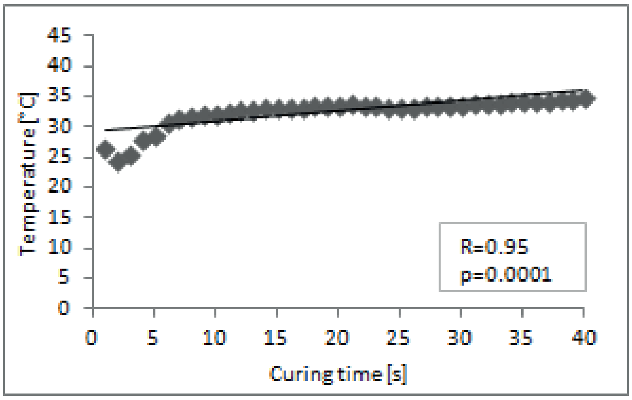

Fig. 6. Correlation of curing time and temperature for Filtek P60 cured with LED 55 LCU

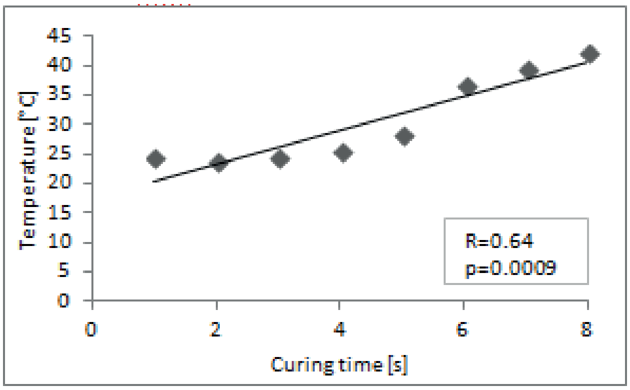

Fig. 7. Correlation of curing time and temperature for Filtek Silorane cured with LED 10W LCU

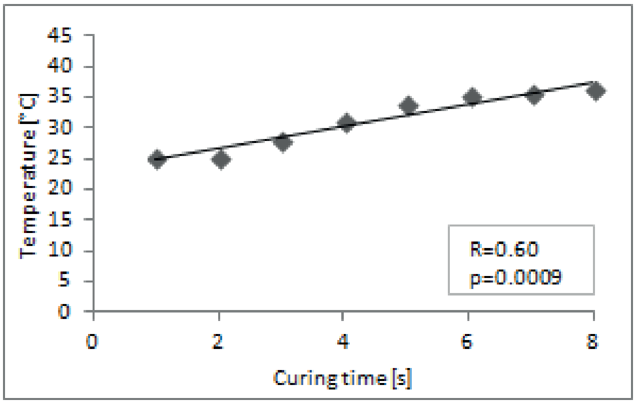

Fig. 8. Correlation of curing time and temperature for Filtek P60 cured with LED 10W LCU

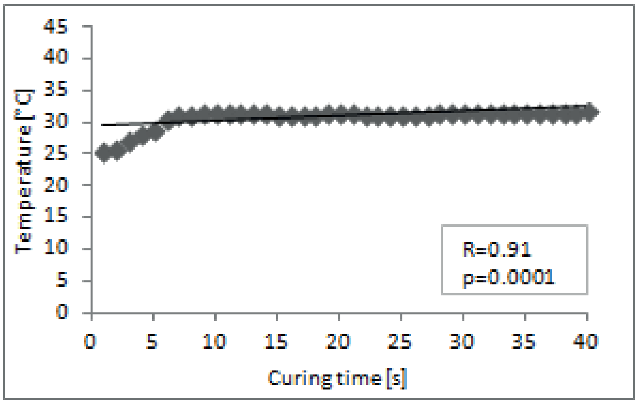

Fig. 9. Correlation of curing time and temperature for Filtek P60 cured with Radii Plus LCU

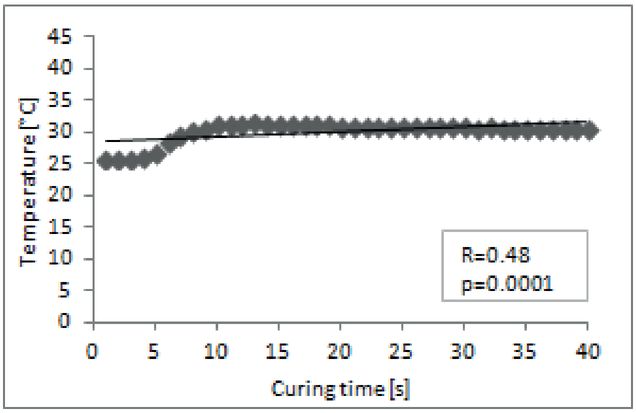

Fig. 10. Correlation of curing time and temperature for Filtek P60 cured with Elipar Highlight LCU

4. Discussion

In the studies by Santini et al. [16] Shorthall and Harrington [17] there was a significantly higher temperature rise with both LEDs compared to the conventional halogen control LCU. They concluded that it was influenced by the type of LCU. On the other hand, Hanning and Bott found that light intensity rather than the type of light source was important [18].

In this study, the temperature values varied for each RBC, according to LCU type. There were some statistically significant correlations of curing distance and temperature according to LCU type and RBC type. Moreover, almost every correlation of curing time and temperature according to LCU type and RBC type was statistically significant.

The study by Uhl et al. showed that the effect of RBC polymerization using different LCUs was dependent on the chemical composition of RBCs rather than on the LCU type [19].

In this paper, regardless the type of RBC, every time the highest temperature was reached with LED 55 LCU. For both RBCs, Filtek Silorane and Filtek P60, the temperature during polymerization with LED 55 LCU was significantly higher than temperature of LED 10W, Radii Plus and Elipar Highlight LCUs.

Uhl et al. concluded that LED LCUs represent a real alternative to halogen LCUs for the light polymerization of dental composites by a considerable lower-temperature increase within the composite [20].

This study showed that there were no statistically significant differences between the temperature measured during the curing with QTH Elipar Highlight LCU and LED 10W and Radii Plus LCUs. The temperature during the polymerization with LED 55 was significantly higher compared with other LCUs.

5. Conclusions

1. The temperature values varied for each resin-based material, according to light-curing-unit type.
2. The highest temperatures were reached with LED 55 LCU.
3. The distance of curing seemed to have least influence on temperature changes during polymerization.
4. The correlation of curing time and temperature according to light-curing-unit type and resin-based composite type was statistically significant.

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