Original Article

Thermal rise during photopolymerization and degree of conversion of bulk fill and conventional resin composites

Sayed Mostafa Mousavinasab[1], Zahra Taromi[2], Elham Zajkani[2]

[1]Dental Materials Research Center, Department of Restorative Dentistry, Dental Research Institute, Isfahan University of Medical Sciences, Isfahan, [2]Department of Restorative Dentistry, School of Dentistry, Zanjan University of Medical Sciences, Zanjan, Iran

Address for correspondence:
Dr. Zahra Taromi,
Department of Restorative Dentistry, School of Dentistry, Zanjan University of Medical Sciences, Mahdavi Blvd, Zanjan, Iran.
E-mail: zahrataromi@gmail.com

ABSTRACT

Background: Light curing of resin composite is associated with a thermal rise that may have harmful effect on the health of the vital pulp. In addition, desirable polymerization is important to achieve mechanical properties and clinical function. The purpose of this *in-vitro* study was to compare the thermal rise under normal dentin during photopolymerization and degree of conversion (DC) of bulk fill and conventional resin composite using continuous high- and soft-start mode.

Materials and Methods: In this *in-vitro* study, Cl I cavities with a dimension of 4 mm × 4 mm × 4 mm and remaining dentin thickness of 1 mm were prepared on 56 extracted human molars. The temperature rise during the light curing of conventional resin composite (Tetric N Ceram, Ivoclar Vivadent) by incremental filling technique and bulk-fill resin composite (Tetric N Ceram Bulk Fill, Ivoclar Vivadent) by bulk-filling technique were measured with a K-type thermocouple wire. DC of both resin composites was measured using Fourier-transform infrared spectroscopy. Data were analyzed using one-way ANOVA, Tamhane and Duncan *post hoc*, two-way ANOVA at the significance level of $\alpha = 0.05$.

Results: Photopolymerization temperature rise due to soft start mode and the first layer of conventional composite was higher than continuous high mode and bulk-filling technique, respectively ($P < 0.001$). DC of conventional resin composite was higher than bulk-fill composite ($P < 0.001$).

Conclusion: Soft-start mode produced higher thermal rise than continuous high mode and conventional resin composite showed higher DC than bulk-fill composite.

Key Words: Composite resins, light curing of dental adhesives, temperature

INTRODUCTION

It is necessary to place several resin composite layers and light cure each layer separately (the incremental technique) to restore deep cavities with the use of conventional resin composites. Therefore, the incremental resin composite technique is a time-consuming procedure. To overcome such a problem, a different type of resin composite has been introduced, which is called bulk-fill resin composite. The unique advantages of this type of resin composite are the feasibility of placing it in 4-mm thick pieces and polymerize these pieces in one step. These resin composites are composed of modified monomers and fillers that have a high capability to conduct light.[1]

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One rationale for limiting the thickness of the layers to 2 mm in conventional resin composites is to allow adequate light to penetrate into the material for initiation and completion of polymerization, convert maximum amount of monomers to polymer, and increase the degree of conversion (DC), which affects the mechanical and clinical properties of resin composites.

Light curing of resin composites might exert thermal stresses on the tooth pulp.[2] An increase in the temperature during photopolymerization depends on various factors, including light intensity, the chemical composition of the resin, thermal conduction properties of resin composite, DC of resin composite, the depth of the cavity, the thickness of the restorative material, and the duration of the exposure to light.[2-4] A study on the amount of increase in temperature within resin composite during polymerization has shown that in bulk-fill resin composites, the increase in temperature is higher.[5] However, several other studies have reported less shrinkage forces in bulk-fill resin composites compared to conventional resin composites.[6-8] Soft-start polymerization is a polymerization technique that decreases the shrinkage stresses and results in a decrease in temperature increase.[9,10]

Given the clear advantage of bulk-fill resin composites in saving time and costs, it appears it is necessary to evaluate thermal changes resulting from photopolymerization and the heat transferred to the pulp and also to determine DC as a parameter affecting the mechanical properties and biocompatibility of these resin composites. Therefore, the aim of the present study was to evaluate thermal changes, due to polymerization, beyond dentin and DC of two types of bulk fill and conventional resin composites using soft start and continuous high light-curing mode.

MATERIALS AND METHODS

Specimen preparation
A total of 56 sound human third molar teeth were used for the purpose of this *in-vitro* study. The teeth were stored in distilled water up to the day before the study. First, the occlusal surfaces of the teeth were made flat with the use of a disc to achieve better adaptation of the light-curing unit. Then, a Class I cavity, measuring 4 mm in mesiodistal and buccolingual dimensions and in depth, was prepared with the use of a cylindrical diamond bur (tizkavan, Iran). Then, the tooth crowns were removed at a distance of 5 mm from the flattered occlusal surface.

The samples were divided into four study groups (*n* = 14) in terms of the resin composite type and light-curing mode as follows [Figure 1].

Measurement of temperature rise
First, the temperature rise resulting from the light-curing procedure [Table 1] was determined at a distance of 5 mm (equal to the occlusogingival depth of the cavity and the thickness of the remaining dentin) from the thermocouple placed in the Teflon mold in the absence of dentin and the restorative material, using a K-type thermocouple wire with a diameter of 0.1 cm (ST-8891E, Standard Instruments Co., Ltd., Kowloon, Hong Kong) was connected to a data logger (Standard, ST-8891E, Taiwan) and saved on a computer (ΔT_b). To evaluate the thermal protective effect of dentin, the detector of the thermocouple was placed on the pulpal side of the dentin, and the heat resulting from the light-curing unit was determined (ΔT_d). In the next stage, to evaluate the temperature rise resulting from photopolymerization and the temperature rise resulting from the irradiation process of the light-curing unit, the resin composites under the study were placed in the cavities (ΔT_t).

In the conventional resin composite group [Table 2], 2 mm of the prepared cavity was measured with a periodontal probe and filled with resin composite with the use of a spatula. Light curing was applied according to the manufacturer's instructions [Table 1].
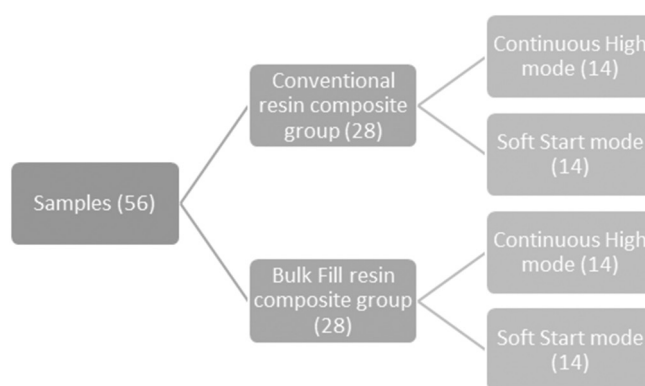

Figure 1: Schematic of study groups in terms of the resin composite type and light-curing mode

Table 1: Specifications of the light-curing modes

Light source	Manufacturer	Type	Curing mode	Power density
Dr's Light	LED	Good Doctors Co., Seoul, Korea	Continuous high	1200 mw/cm²-10 (s)
			Soft start	0-600 mw/cm²-5 (s) 1200 mw/cm²-10 (s)

The resultant temperature rise was measured by the thermocouple and saved on the computer through the data logger. Subsequently, the remaining 2 mm of the cavity was filled with the same resin composite and a piece of Mylar strip matrix was placed on it. The tip of the light-curing device was placed in contract with the Mylar strip matrix on the resin composite, and photopolymerization was carried out. The temperature rise was saved on the computer through the thermocouple [Graph 1].

In the bulk-fill resin composite group [Table 2], a 4-mm thick piece of resin composite was placed in the cavity with the use of a spatula and covered with a piece of Mylar strip matrix. The tip of the light-curing unit was placed in contact with the matrix on the resin composite, and photopolymerization was carried out according to the manufacturer's instructions. The temperature rise was saved on a computer through the thermocouple [Graph 2].

The increases in temperature in all the samples were determined in an environment with identical temperature. The temperature rise was determined every second for 250 s since the initiation of photopolymerization.

Measurement of the degree of conversion

To determine the DC of the samples, Fourier-transform infrared spectroscopy was carried out at a resolution of 4/cm and 25 scans at a range of 400–4000/cm. After the thermal change tests, the samples were stored at 37°C for 24 h. Then, the light-curing resin composite samples ($n = 6$) were retrieved from the teeth, milled and powdered with a mortar and pestle.[11] Two milligram of the powder were mixed with 58 mg of potassium bromide and pressed to achieve a thin disc, which was placed in a holder and transferred to a spectrophotometer. In relation to uncured resin composite samples, 2 mg of resin composite were mixed with 65 mg of potassium bromide and transferred to the spectrophotometer holder. Finally, DC was determined by calculating the absorption ratios of aliphatic C = C bonds (maximum absorption at 1638 cm^{-1}) versus aromatic C = C bonds (maximum absorption at 1608 cm^{-1}) before and after curing of the samples. Data of each evaluation

process were saved on a computer and calculated using the following formula:

Statistical analysis

ANOVA was used to compare the study groups in terms of thermal changes, due to the heterogeneity of variances, followed by *post-hoc* Tamhane tests. To compare DC after making sure of the normal distribution of data, one-way ANOVA was used for the analysis of data, followed by *post-hoc* Duncan test. Two-way ANOVA was used to evaluate the effect of light-curing mode and resin composite type on DC. Statistical significance was set at $P < 0.05$.

RESULTS

Table 3 presents the means, standard deviations, P value, and 95% confidence intervals of thermal
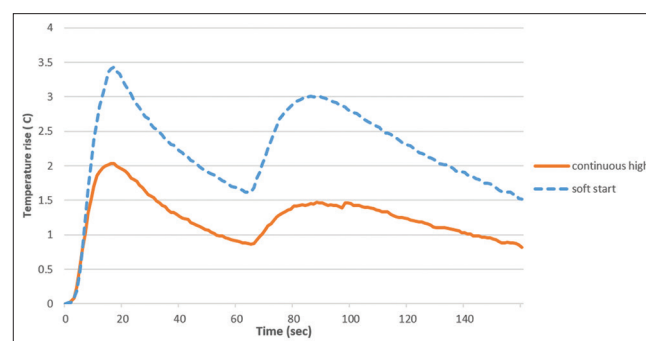
Graph 1: The curve for the temperature rise, resulting from light curing of Tetric N-Ceram resin composite with soft start and continuous high light-curing mode.
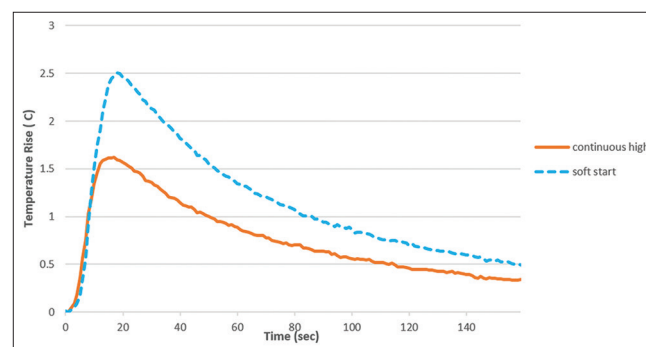
Graph 2: The curve for the temperature rise, resulting from light curing of Tetric N-Ceram bulk-fill resin composite with soft start and continuous high light-curing mode.

Table 2: Characteristics of the resin composites

Resin-based material	Classification	Manufacturer	Resin	Filler type	Filler load	Filler size
Tetric N Ceram - A2 shade	Conventional	Ivoclar Vivadent AG	Dimethacrylates (19-20 weight %)	Barium glass, ytterbium trifluoride	80-81%w 55-57% vol	40-3000 nm (nanohybrid)
Tetric N Ceram Bulk Fill - IVA shade	Bulk Fill	Ivoclar Vivadent AG	Dimethacrylates (19-20 weight %)	Barium glass, ytterbium trifluoride	75-77% w 53-55% vol	40-3000 nm (hybrid)

changes with different resin composite placement and light-curing modes.

There were no significant differences in the DC of the conventional and bulk-fill resin composites between the two light-curing modes. However, DC was significantly different between the two resin composite types [Table 4]. The conventional resin composite exhibited the maximum DC with the use of soft-start light-curing mode (78.37%) and the bulk-fill resin composite exhibited the minimum DC (67.97%) with the use of continuous high light-curing mode [Table 4].

Two-way ANOVA showed that when DC was compared, the cumulative effect of light-curing mode and resin composite type was not significant. The effect of light-curing mode on DC was not statistically significant ($P = 0.144$); however, the effect of the resin composite type was statistically significant ($P < 0.001$).

DISCUSSION

Since the temperature increases after the imitation of photopolymerization of resin composite, resulting in injuries to the dental tissues, the present study was conducted to provide laboratory data on thermal changes within resin composite and the pulp chamber during photopolymerization. In addition, the effect of composite placement technique (the incremental technique vs. bulk-fill technique) on the temperature rise was evaluated with the use of soft start and continuous high light-curing mode.

This explorative, experimental, *in-vitro* study was done at room temperature (25°C ± 2°C). Jafarzadeh-Kashi mentioned that the bonding agents might be cured more efficiently at human body temperature than at room temperature, although the Scotchbond MP was not significantly affected by the temperature.[12] However, such an effect might not be

Table 3: Means and standard deviations of thermal changes in the study groups

Temperature rise	Mean	SD	SE	95% CI for mean		Minimum	Maximum	P
				Lower bound	Upper bound			
ΔT_b								
ΔT_High^f	9.28	1.03	0.27	8.68	9.88	7.50	10.90	<0.001
ΔT_Soft^g	12.17	1.29	0.34	11.42	12.92	10.00	13.80	
ΔT_d								
$\Delta T\_con^*\_High^{b,c,d}$	2.73	0.53	0.14	2.42	3.04	1.80	3.50	<0.001
$\Delta T\_con\_Soft^e$	4.87	0.69	0.18	4.46	5.27	3.70	6.10	
$\Delta T\_bulk^{**}\_High^{b,c,d}$	2.81	0.49	0.13	2.52	3.09	2.10	3.80	
ΔT_t								
$\Delta T\_bulk\_Soft^e$	4.53	0.48	0.12	4.25	4.81	3.80	5.40	
$\Delta T\_1st\_High^{a,b}$	2.07	0.61	0.16	1.72	2.43	0.80	3.00	<0.05
$\Delta T\_1st\_Soft^{d,V}$	3.46	0.49	0.13	3.17	3.74	2.60	4.20	
$\Delta T\_2nd\_High^a$	1.66	0.26	0.07	1.51	1.81	1.10	2.00	
$\Delta T\_2nd\_Soft^{c,d}$	3.03	0.50	0.13	2.74	3.32	2.30	4.10	
$\Delta T\_bulky\_High^a$	1.65	0.33	0.09	1.45	1.84	1.10	2.30	
$\Delta T\_bulky\_Soft^{b,c}$	2.50	0.36	0.09	2.29	2.71	2.10	3.20	

ΔT_b: The temperature rise due to light exposure to the thermocouple in the absence of any dentin or composites; ΔT_d: The temperature rise due to light exposure to dentin in the absence of composites; ΔT_t: Total conducted heat; temperature caused by light curing and composite polymerization; *con: Conventional composite; **bulk: Bulk-fill composite. SD: Standard deviation; SE: Standard error; CI: Confidence interval. Same superscript letters indicate nonsignificant differences within the same column

Table 4: The means and standard deviations of the degree of conversion of resin composites with the use of different light-curing modes

Group	Mean	SD	SE	95% CI for mean		Minimum	Maximum	P
				Lower bound	Upper bound			
DC conventional, high	74.00[a]	2.42	0.98	71.45	76.54	71.44	77.36	<0.001
DC conventional, soft	78.37[a]	3.84	1.56	74.34	82.40	72.43	82.84	
DC bulk fill, high	67.97[b]	4.89	1.99	62.84	73.11	60.32	73.89	
DC bulk fill, soft	68.57[b]	4.41	1.80	63.94	73.20	60.69	74.01	

SD: Standard deviation; SE: Standard error; CI: Confidence interval; DC: Degree of conversion. Same superscript letters indicate nonsignificant differences within the same column

applicable for resin composites due to their higher thickness compared to thin layers of bonding agents.

Based on the results of the present study, soft-start light-curing mode resulted in a greater temperature rise, which might be due to the greater energy of this mode compared to the continuous high mode. Based on the results of studies by Looney and Price, the differences in the energy produced by light-cured devices are an important factor for differences in temperature increase with the use of different light-curing modes. Lower energies delivered by light-curing modes will result in less temperature rise.[13] Several studies, consistent with the present study, have shown that when the energy produced by a light source increases, there is an increase in the temperature too.[2,14,15]

In the present study, the mean ΔT_d was significantly higher than the mean ΔT_t with the use of both light-curing modes. In a study by Aguiar *et al.*, too, the mean temperature rise in all the groups without resin composites was higher than that in resin composite groups with all the three thicknesses of dentin, consistent with the results of the present study.[15]

While Lloyd and Hansen and Asmussen reported that the curing process of resin composite creates heat and[16,17] the results of the present study showed that resin composite layers serve as insulators, decreasing the transfer of energy than what is produced. In a study by Kim *et al.*, too, the temperature rise measured in the depth of resin composite decreased with an increase in the thickness of resin composite, which was attributed to the decrease in the penetration of light.[5]

A comparison of ΔT_t values showed that the ΔT_t value of the first layer of conventional resin composite was higher than that of bulk-fill resin composite. Higher ΔT_t value might be attributed to the thickness of conventional resin composite (2 mm) compared to that of bulk-fill resin composite (4 mm).

Garoushi *et al.* showed that an increase in the thickness of bulk-fill resin composite from 1 mm to 4 mm resulted in a significant decrease in the penetration of light.[18] In addition, higher DC of conventional resin composite compared to bulk-fill resin composite, resulting in a greater exothermic reaction, might be another reason for higher ΔT_t of the first layer of conventional resin composite compared to bulk-fill resin composite.

In contrast to the results of the present study, in a study by Kim *et al.*, the temperature rise resulting from a 20-s irradiation of bulk-fill resin composite was higher than that of the first layer of conventional resin composite,[5] which might be attributed to the use of bulk-fill resin composite with high translucency and high resin content.[18,19] It appears this increased translucency and the resultant prevention of light from reaching the depth of the cavity by the composite layer might have a greater role in these changes.

In the present study, in order to simulate the clinical situation, the second layer of conventional resin composite was placed immediately after light curing of the first layer before the temperature returned to normal after light curing the first layer. However, the temperature rise resulting from photopolymerization of the second layer with the use of both light-curing modes was not higher than that of the first layer and the temperature during photopolymerization of the second layer occurred more slowly, and the peak of thermal changes was less than that of the first layer, consistent with the results of a study by Kim *et al.*[5] It appears the reason was the presence of 2 mm of resin composite in the first layer, which served as a thermal insulator for the heat resulting from photopolymerization.

In addition, in the present study, the resin composite placement technique (incremental or layering technique vs. bulkfill) affected DC, but light-curing mode did not show such an effect.

In the incremental technique, resin composite receives higher total energy. Each 2-mm thick layer receives 12 j/cm^2 and 13.5 j/cm^2 energy with the continuous high- and soft-start light-curing modes, respectively, while with the bulk-fill technique, this amount of energy should cure the whole mass of resin composite with 4-mm thickness. Therefore, the amount of light penetrating the 4-mm thickness decreases, resulting in a decrease in DC. The results of the present study were consistent with those of a study by Chang *et al.*[3] Khaksaran posed a higher light intensity is expected to increase the temperature more since more photons are absorbed by the unit of area on a tooth tissue. Besides, it might be capable of inducing more polymerization due to warming material and reducing its viscosity and therefore radical mobility, as well as increasing the collision frequency of unreacted active groups and radicals.[20]

Although DC of bulk-fill resin composite was less than that of conventional resin composite, it was at

the acceptable 55% level,[21] which might be attributed to the increased translucency of bulk-fill resin composites.

The bulk-fill resin composite used in the present study had hybrid particles. In this context, an increase in filler size results in a decrease in the specific surface area between the filler and the organic matrix, decreasing light scattering and increasing the curing depth.[22] In addition, based on the claims of the manufacturer, this bulk-fill resin composite contains Ivocerin, which is a germanium-based initiator, with a higher curing activity compared to camphorquinone. Although Silikas *et al.* reported that the minimum DC necessary to prevent occlusal surface abrasion is 55%,[21] an adequate DC for proper clinical performance is yet to be determined and many studies have reported that DC is directly correlated with mechanical and biocompatibility properties.

CONCLUSION

1. The temperature rise resulting from the irradiation of the remaining dentin was higher than the final heat of polymerization with the use of both Tetric N-Ceram bulk fill and Tetric N-Ceram conventional resin composites
2. The temperature rise with the use of soft-start light-curing mode was higher than that of continuous high light-curing mode
3. The temperature rise resulting from light curing of the first layer of Tetric N-Ceram resin composite was higher than that of Tetric N-Ceramic bulk-fill resin composite
4. The DC of Tetric N-Ceram resin composite was significantly higher than that of Tetric N-Ceram bulk-fill resin composite
5. The temperature rise and DC are directly correlated with the energy density of the light-curing unit.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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