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Effect of Additional Light Curing on Colour Stability of Composite Resins

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ABSTRACT

Aim: The objective of this study was to evaluate the effect of additional light curing on the colour stability of composite resins. *Materials and methods:* Four different composite resins—a nanofill, a nanohybrid, a microhybrid, and a bulk-fill composite resin—were tested. Eighty disc-shaped specimens were prepared from each material using either a quartz tungsten halogen or a light-emitting diode light source and were randomly divided into 2 groups according to the surface treatment: no polishing (nonpolished) or polishing with aluminum oxide discs (polished). Then additional light curing was applied to half of the specimens in each group. All specimens were immersed in coffee solution for 1 week. Colour was measured with a spectrophotometer at baseline and after 1 week of storage in coffee solution. *Results:* Statistically significant differences in colour stability were observed in the restorative materials according to the composition of composite resin, the polishing protocol, and additional light curing, whilst there were no significant differences according to the light source. Additional light curing reduced discolouration in all groups tested. *Conclusions:* Additional light curing may be beneficial after finishing and polishing in order to maintain aesthetics and increase the resistance of composite resins to discolouration.

Introduction

Today, the aesthetic expectations of patients and dentists have increased the necessity of treating dental caries and tooth defects in a way to achieve outstanding functional and aesthetic results. Composite resins are aesthetic restorative materials in common clinical use that are manufactured to meet these expectations.[1]

Although the physical, mechanical, and aesthetic properties of composite resins have greatly improved, the problem of discolouration is still one of the most important causes of clinical failure. The search for an ideal restorative material with high aesthetic and mechanical properties has led to the development of new restorative materials. Several composite resins are available for aesthetic restorations that differ from each other according to the type, size, and amount of filler particles and type of resin matrix. Moreover, composite resin's organic matrix structure, inorganic fillers, and inorganic fillers' features have a direct effect on staining tendency by affecting the surface smoothness of the restoration.[2] In addition to the rapid development of nanotechnology and the increased prevalence of nanocomposites, a new class of composite resin has been introduced, bulk-fill restoratives, and they have gained popularity due to their ease of application. Unlike the conventional resin-based composites, which are placed by layering of maximum 2 mm in thickness, bulk-fill restoratives can be placed with a single 4- to 5-mm layer.[3] These composites are different from conventional nanohybrid composites as they contain polymerisation modulators and plasticisers. In addition, to facilitate deeper light transmission, the filler content has been reduced in bulk-fill composite resins, whilst to improve the mechanical strength, particle sizes have been increased.[4]

Adequate polymerisation of composite resins is essential to achieve optimal mechanical and optical properties. Polymerisation processes and insufficient polymerisation may lead to a decrease in the physical and mechanical properties of composite resins, and they have been reported to be more susceptible to water sorption and dissolution of unreacted monomers, resulting in more discolouration.[5,6] For sufficient

polymerisation, 3 essential conditions are required for the light source: appropriate wavelength range of the light, adequate light output, and curing time.[7] In order to activate the photoinitiator within the resinous dental materials and produce a highly cross-linked structure, sufficient light energy intensity and an adequate wavelength should be provided.[8]

Quartz tungsten halogen (QTH) and light-emitting diode (LED) lights are the most common light sources used in dental clinics. The broad emission spectrum of QTH initiates polymerisation of all known photoactivated resin-based dental materials. However, the halogen bulb generates high heat and demonstrates a weakening of light power over time.[9] LED devices are less energy-consuming than halogen lamps and they have a much longer expected lifetime without significant light intensity degradation over time.[10,11] LEDs also have a broad emission spectrum of absorption to activate the photoinitiators, and their narrow spectral output makes them more efficient for activation of camphoroquinone than the wider wavelength range of halogen lamps.[12] However, the curing performance of these 2 devices remains controversial.[13] It has been shown that LEDs are more successful than QTH with respect to both curing depth[14] and microhardness properties,[15] whilst some studies reported comparable curing efficiency[16] and surface microhardness.[17]

The patient's dietary habits and the quality of the polishing processes were also found to be important in order to maintain the colour stability of an aesthetically successful restoration.[18-21] In response to the apparent absence of literature on additional light curing after polishing and the lack of research on the colour stability of newly developed nanocomposites and bulk-fill materials, the aim of the present study was to evaluate the effect of additional light curing after polishing on the colour change of microhybrid, nanohybrid, nanofill, and bulk-fill composite resins polymerised with QTH or LED light sources. This method should determine whether additional light curing will contribute to the maintenance of colour stability. The hypothesis of our study is that less discolouration will be observed after additional light curing regardless of the composite resin and light source.

Materials and methods

Four different composite resins, all in A2 shade, were used in the present study. The composite resins used are listed in Table 1.

Specimen preparation

Using a Plexiglas mold, 8 × 2-mm disc specimens were prepared with Filtek Ultimate, Filtek Z550, and Filtek Z250, whilst 8 × 4-mm disc specimens were prepared with Filtek Bulk Fill. For each composite resin, 80 discs were produced, making a total of 320 discs. Half of the specimens per composite resin were cured with either LED with a light intensity of 1200 mW/cm^2 or QTH light sources with a light intensity of 600 mW/cm^2.

The composite resins were placed using a plastic instrument and covered with a Mylar strip. To flatten the surfaces, a 1- to 2-mm-thick glass slide was placed over the strip before curing with the light device. Then the samples were cured for 40 seconds with QTH or 20 seconds with LED through the Mylar strip and the glass slide. By means of a radiometer, the output of the light was frequently monitored (Hilux, Benlioglu Dental).

Then the composite discs were divided into 2 main groups in terms of polishing: nonpolished and polished. Forty specimens per composite resin received no finishing or polishing treatment and served as nonpolished controls. For the polished group, discs polished using hard, medium, fine, and superfine grits were used, starting with hard and ending with superfine. The polishing procedures were kept to 10 seconds for each step to avoid microcrack formation.[22] All specimens were thoroughly rinsed with water and air-dried after each step of polishing.

Then the nonpolished and polished groups were randomly divided into 2 subgroups. One half of the specimens were immediately light cured again, whilst the other half were not. Additional light curing was applied to the samples using with the same curing unit and the same curing time (40 seconds with QTH, 20 seconds with LED) as applied at the beginning. The same operator carried out the specimen preparation,

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Table 1 – Composite resins used in this study.

Product (batch No.) Type	Filtek Ultimate (N619696) Nanofill	Filtek Z550 (N636062) Nanohybrid	Filtek Z250 (N709045) Microhybrid	Filtek Bulk-Fill (N708090) Bulk-filling restorative
Organic matrix	Bis-GMA, Bis-EMA, TEGDMA, PEGDMA, UDMA	Bis-GMA, Bis-EMA, TEGDMA, PEGDMA, UDMA	Bis-GMA, Bis-EMA, UDMA	AUDMA, UDMA, DDDMA, AFM
Fillers	Non-agglomerated/non-aggregate 20 nm silica filler, non-agglomerated/non-aggregated 4-11 nm zirconia filler, and aggregated zirconia/silica cluster filler (average cluster particle size−0.6-10 μm)	Surface-modified zirconia/silica fillers 3000 nm (3 μm or less), non-agglomerated/non-aggregated surface-modified silica particles 20 nm	Zirconia, silica 10-3500 nm (0.01-3.5 μm)	Surface modified zirconia/silica, ytterbium trifluoride
Filler amount (W/V)	78.5%/63.3%	81.8%/68.0%	82.0%/60.0%	76.5%/58.4%

3M ESPE is the manufacturer of all materials.

Table 2 – Study groups (n = 320).

Non-polished				Polished			
QTH		LED		QTH		LED	
Single-light	Additional-light	Single-light	Additional-light	Single-light	Additional-light	Single-light	Additional-light
Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)	Bulk-Fill (n=10)
Z250 (n=10)	Z250 (n=10)	Z250 (n=10)	Z250 (n=10)	Z250 (n=10)	Z250 (n=10)	Z250 (n=10)	Z250 (n=10)
Z550 (n=10)	Z550 (n=10)	Z550 (n=10)	Z550 (n=10)	Z550 (n=10)	Z550 (n=10)	Z550 (n=10)	Z550 (n=10)
Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)	Ultimate (n=10)

finishing, and polishing procedures. New discs were used to finish and polish each specimen. The finishing and polishing procedures and additional light curing were applied to the same side of the specimens.

Thirty-two groups were created (n = 10). The study groups are shown in Table 2. The specimens were incubated in 100% humidity at 37 °C for 24 hours (Nuve Incubator, EN 025).

Colour measurements

A spectrophotometer (VITA Easyshade Compact, VITA Zahnfabrik, Bad Säckingen) has been used to measure baseline colour values (L*, a*, b*) of each specimen with according to the Commission Internationale d'Eclairage (CIELab). Before the measurements of each specimen, the spectrophotometer was calibrated using a standard white background. At baseline and after 7 days of storage in coffee solution, the colour values of specimens were measured. For each specimen, all measurements were repeated three times and the average values were used for evaluation. After baseline colour measurements, all specimens were stored in 100 mL of coffee solution (Nescafe Classic, Nestle) at 37 °C for 7 days. During that period, a freshly prepared coffee solution was used every day. The coffee solution was prepared by dissolving 3.6 g coffee in 300 mL of boiling distilled water and filtered after 10 minutes of stirring.

After 7 days of storage, the specimens were rinsed with distilled water and then blotted with dry tissue paper and the colour was measured. Before and after storage in coffee solution, colour variation, ΔE*, in the L*a*b* colour system was calculated as follows:

$$\Delta E* = \left[(L_1 * - L_0 *)^2 + (a_1 * - a_0 *)^2 + (b_1 * - b_0 *)^2 \right]$$

Statistical analysis

To evaluate the data, a standard statistical software package (IBM SPSS for Windows Version 22.0, SPSS Inc.) at a significance level of $P = .05$ was used. The groups were compared by 4-way variance analysis and dual comparisons were calculated by Bonferroni test ($P < .05$).

Results

Significant differences were identified between the groups when the mean ΔE values were compared. The type of composite resin and additional light curing both had significant effects on discolouration ($P < .05$).

The mean ΔE value and standard deviation comparison of light sources are shown in Table 3. Type of light source had a significant effect on discolouration of only the nonpolished and single light applied bulk-fill composite group and the polished and additional light applied Ultimate composite group ($P < .05$).

All of the groups that were polished showed less discolouration than all the nonpolished groups, and the difference between mean ΔE values was statistically significant. Table 4 shows the mean ΔE values and standard deviations of the nonpolished and polished groups. The effect of additional light curing on discolouration in the different groups is shown in Table 5. Additional light curing caused less discolouration than single light application in all groups tested.

The highest value of discolouration was seen in the nonpolished group of Filtek Ultimate polymerised with LED without additional light curing, whilst the lowest value of discolouration was seen in the polished group of Z550 polymerised with LED with additional light curing.

In the Filtek Z250 and Filtek Z550 groups, there were no significant differences. These composite resins showed less discolouration than nanofill and bulk-fill composites ($P < .05$). The Filtek Bulk Fill groups were the composites most affected.

Discussion

Colour changes depending on the polymerisation process can cause shifts in the resin's optical properties.[23] The residual unconverted methacrylate groups may cause increased water sorption of resin matrix and colour alterations.[24]

The degree of conversion depends on factors such as the radiant intensity of the polymerisation unit and curing time.[25,26] Although in the current study the monomer

Table 3 – Mean ∆E and standard deviation values for comparison of light sources.

			QTH	LED	P
Bulk Fill	Nonpolished	Single light	15.95 ± 3.03	14.09 ± 1.37	.009
		Additional light	13.85 ± 2.02	13.49 ± 2.44	.605
	Polished	Single light	9.30 ± 1.19	10.28 ± 1.16	.167
		Additional light	8.60 ± 1.68	8.50 ± 0.84	.881
Z250	Nonpolished	Single light	13.3 ± 2.40	12.27 ± 1.58	.148
		Additional light	10.25 ± 1.01	11.33 ± 3.19	.126
	Polished	Single light	7.29 ± 1.07	6.95 ± 0.85	.631
		Additional light	6.72 ± 2.22	6.56 ± 1.48	.832
Z550	Nonpolished	Single light	12.79 ± 1.68	12.9 ± 3.64	.877
		Additional light	11.15 ± 1.05	10.98 ± 2.00	.811
	Polished	Single light	7.45 ± 0.45	7.62 ± 0.69	.813
		Additional light	6.58 ± 1.25	6.27 ± 0.57	.666
Ultimate	Nonpolished	Single light	15.55 ± 1.11	16.66 ± 1.09	.117
		Additional light	15.08 ± 2.36	14.67 ± 1.18	.568
	Polished	Single light	8.1 ± 1.06	9.75 ± 2.62	.568
		Additional light	6.70 ± 0.69	6.98 ± 1.14	.020

LED, light-emitting diode; QTH, quartz tungsten halogen.

conversion degrees of composite resins were not evaluated, it is possible that prolonged polymerisation time may have maximised the degree of polymerisation for all tested materials.

Emami and Söderholm[12] reported that light energy per unit area (irradiance value × curing time) should be taken into consideration more than light irradiance (mW/cm^2) in order to achieve efficient polymerisation. It has been suggested that the light energy transferred to the resin should be about 21 to 24 J/cm^2 so that composite specimens prepared in a 2-mm thickness can be polymerised adequately.[5,6,27] The light irradiance of the QTH device (600 mW/cm^2) used in this study was lower than that of the LED device (1200 mW/cm^2), but the exposure time was twice (40 seconds) of that of LED (20 seconds); light energy obtained with both devices was intended to be standardised to 24 J/cm^2. The similar values obtained in the majority of the groups may have been due to the fact that the total light energy transmitted to the resin was similar and therefore the samples were polymerised at an even rate.

In accordance with this information, Sabatini[28] stated that the use of QTH or LED devices would not have an effect on the discolouration of composite resins if a similar light

intensity could be obtained and discolouration is related to the type of composite resin, regardless of the light device. In agreement with the findings of our study, Yazıcı et al.[29] also reported statistically similar discolouration results of a hybrid and a nanofill composite resin polymerised with QTH or LED devices. Contrary to our results, Tak et al.[30] reported more colour change with LED and plasma arc devices than a QTH device after 5 years.

In the current study, all the composite resins tested showed discolouration after immersion in coffee. Colour changes were more intense in the nonpolished groups, as reported in previous studies.[31,32] Finishing and polishing processes are important factors to ensure the functional and aesthetic continuity of restorations in the oral environment. In order to achieve a high level of aesthetics and to maintain that for a long time, it has been shown that polished, smooth, and shiny surface restorations must be obtained. It has been reported that although surface finishing with a Mylar strip gives the lowest values in terms of roughness,[21] it is necessary to remove the resin-rich layer remaining under the Mylar strip in order to obtain a stronger structure in terms of mechanical properties and aesthetic stability.[33]

Table 4 – Mean ∆E and standard deviation values of polished and nonpolished groups.

			Bulk	Z250	Z550	Ultimate
QTH	Single light	Nonpolished	15.95 ± 3.03^b	13.3 ± 2.40^b	12.79 ± 1.68^b	15.55 ± 1.11^b
		Polished	9.30 ± 1.19^a	7.29 ± 1.07^a	7.45 ± 0.45^a	8.1 ± 1.06^a
		P	<.001	<.001	<.001	<.001
	Additional light	Nonpolished	13.85 ± 2.02^b	10.25 ± 1.01^b	11.15 ± 1.05^b	15.08 ± 2.36^b
		Polished	8.60 ± 1.68^a	6.72 ± 2.22^a	6.58 ± 1.25^a	6.70 ± 0.69^a
		P	<.001	<.001	<.001	<.001
LED	Single light	Nonpolished	14.09 ± 1.37^b	12.27 ± 1.58^b	12.9 ± 3.64^b	16.66 ± 1.09^b
		Polished	10.28 ± 1.16^a	6.95 ± 0.85^a	7.62 ± 0.69^a	9.75 ± 2.62^a
		P	<.001	<.001	<.001	<.001
	Additional light	Nonpolished	13.49 ± 2.44^b	11.33 ± 3.19^b	10.98 ± 2.00^b	14.67 ± 1.18^b
		Polished	8.50 ± 0.84^a	6.56 ± 1.48^a	6.27 ± 0.57^a	6.98 ± 1.14^a
		P	<.001	<.001	<.001	<.001

LED, light-emitting diode; QTH, quartz tungsten halogen.
There is a statistically significant difference between the groups indicated by different letters (P < .05).

Table 5 – Mean ΔE and standard deviation values of composite resins.

		Nonpolished			Polished		
		Single light	Additional light	P	Single light	Additional light	P
QTH	Bulk-fill	15.95 ± 3.03^b	13.85 ± 2.02^b	.003	9.30 ± 1.19^b	8.60 ± 1.68^b	.324
	Z250	13.3 ± 2.40^a	10.25 ± 1.01^a	<.001	7.29 ± 1.07^a	6.72 ± 2.22^a	.421
	Z550	12.79 ± 1.68^a	11.15 ± 1.05^a	.021	7.45 ± 0.45^{ab}	6.58 ± 1.25^a	.217
	Ultimate	15.55 ± 1.11^b	15.08 ± 2.36^b	.506	8.1 ± 1.06^{ab}	6.70 ± 0.69^a	.048
	P	<.001	<.001		.019	.011	
LED	Bulk-fill	14.09 ± 1.37^a	13.49 ± 2.44^b	.393	10.28 ± 1.16^b	8.50 ± 0.84^b	.012
	Z250	12.27 ± 1.58^a	11.33 ± 3.19^a	.185	6.95 ± 0.85^a	6.56 ± 1.48^a	.591
	Z550	12.9 ± 3.64^a	10.98 ± 2.00^a	.007	7.62 ± 0.69^a	6.27 ± 0.57^a	.058
	Ultimate	16.66 ± 1.09^b	14.67 ± 1.18^b	.005	9.75 ± 2.62^b	6.98 ± 1.14^{ab}	<.001
	P	<.001	<.001		<.001	.009	

Different superscript letters indicate statistically significant difference.
LED, light-emitting diode; QTH, quartz tungsten halogen.

Finishing and polishing processes will remove the upper layer and reveal a surface that is farther away from the light source in the deep parts of the restoration. Pilo et al.[34] reported that the physical and chemical properties, such as surface hardness and resistance to abrasion, of composites that are far away from the light source and that are not effectively polymerised are low in conversion degree and have an increased discolouration tendency. It has also been reported that problems such as cytotoxicity due to residual monomers may occur as a result of the inability to complete the polymerisation of the restorative materials in the resin matrix.[35,36] For this reason, what is called "complementary activation" or "postcuring" is carried out after the light polymerisation, in the form of additional light curing, additional heat application, or a combination of these.

Postcuring treatments, employed to indirect composites by using visible light, heat, and/or pressure combining devices, are used to improve the physical and mechanical properties. Indirect composites differ from direct composites by including not only photosensitive initiators but also thermosensitive initiators. Although direct composites do not contain heat-sensitive initiators, some mechanical properties have been reported to improve when postcuring treatments, especially those with heat, when applied to these materials.[37-39] However, the better mechanical properties reported in some studies may have been due to an increase in the degree of conversion,[40] since it is known that residual unreacted monomers due to insufficient polymerisation compromise the polymer's mechanical properties,[14] resulting in wear, degradation, and discolouration[41] as well as compromised colour stability.[42] These postcuring treatment devices are extra-oral devices and it is not possible to apply this method in the oral cavity.[37] In the current study, additional light curing on direct composites has been used to imitate postcuring treatment effects on indirect composites.

Additional light curing can be applied after removal of the matrix band by longer application of light to the front or back side of the samples[43] or to both sides.[18,44] Furthermore, additional light can also be applied postpolishing in order to improve the physico-mechanical properties of the surface resulting from the finishing and polishing processes.[45] There are also studies in which light exposure for a longer period is reported to have positive effects on the mechanical properties of materials.[5] In the present study, additional light curing contributed positively to less discolouration in all groups. The physico-mechanical properties of the materials may be improved and less discolouration may be achieved by applying additional light.

Previous studies compared the colour stability of nanofill and microhybrid composites after different finishing and polishing processes, and the highest discolouration values were in the nanofill groups, which is consistent with the results of our study.[43,46,47] BisGMA and TEGDMA, hydrophilic monomers, in the resin matrix of the nanofill composite may have been responsible for this result.

In the dental literature, there are limited studies on the discolouration of bulk-fill composite resins.[3,48] Fillers and other components play an important role in the optical properties of composite resins[49] and, basically, the main difference amongst bulk-fill composites is the increased depth of polymerisation.[50] In earlier studies, the increase in the depth of polymerisation of bulk-fill materials was explained by the presence of more initiator systems and higher translucency,[51-53] and it was reported that bulk-fill composites have higher translucency than conventional ones and the higher polymerisation depths were due to the translucency of these composites.[3]

Kim et al.[3] reported that translucency and microhardness values decreased as the thickness increased in bulk-fill composite resins and stated that the hardness ratio between the upper and lower surfaces of the bulk-fill composite prepared in a 4-mm thickness is 80%. This may cause the bulk-fill composite resin to demonstrate high discolouration.

Regarding the contents of the materials, it is seen that the Filtek Bulk Fill composites have less filler both in weight (76.5%) and in volume (58.4%) than the other composites used in the study. The Filtek Bulk Fill has significantly higher discolouration values when compared to the other composites used and is consistent with the higher discolouration of composites with low filler content in previous studies.[54,55] In addition, in the current study it was found that the bulk-fill composite resin has a higher tendency for discolouration than conventional composites, which may have been influenced by the presence of different components such as fillers, light-sensitive components, and polymerisation stress-reducing agents in the content of the Filtek Bulk Fill.[56] However, the interaction between bulk-fill composites and colourant solutions is not fully understood and more studies are needed in this regard.

The results of our study show that the effects of composite resin types and polishing system and additional light on discolouration were statistically significant. The hypothesis has been accepted that less discolouration will be observed with additional light curing regardless of the composite resin and light source type.

It should be noted that there are some limitations to the present study. The effect of different curing times and polymerisation units on degree of conversion of composite resins was not evaluated in the current study. In future studies, it is planned to evaluate the degree of conversion to verify the results of this study. Because this was an in vitro study that cannot simulate the oral cavity, future in vivo studies are also required.

Conclusions

In the light of the findings of this study, QTH and LED light devices generally affected the discolouration levels of composite resins in a similar way, composite resin type and polish method played a role in the colouring values of composite resins, more colour change was observed in composite resins not subjected to polishing treatment, and the additional light application caused less colouration.

Finishing and polishing should be performed in order to maintain aesthetic properties by providing less discolouration in composite resins, and additional light application after these operations may make a positive contribution to less discolouration of composites depending on the filler content of the materials. Further research is needed to determine the effect of additional light curing on the physical and mechanical properties of direct composite resins and its clinical relevance.

Acknowledgements

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