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ORIGINAL RESEARCH ARTICLE

Color Stability Assessment of Three Different Resin Composites After Polymerization with Two Different Light-Curing Units

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Abstract

Purpose: Despite improvements in resin composite structures, color stability remains a challenge, and esthetic problems are the most common factors in renewing restorations. This study aimed to evaluate the effects of two light-curing units on the color stability of three different resin composite materials in different periods.
Materials and Methods: Three different resin composites (Filtek Z550, Filtek Ultimate Flowable, Filtek Bulk Fill Restorative) with an A2 color shade were prepared for each combination of resin composite-curing unit (5x2mm) for a total of 30 specimens. Specimens were cured with either QTH Hilux Ultraplus (700mW/cm2) for 40 seconds or Radii Plus LED Curing Light (1400mW/cm2) for 20 seconds. For standardization of the amount of transmitted energy to the composite, all specimens received 28J/cm2. Color parameters were measured with a colorimeter (Minolta CR-321, Konica Minolta Sensing Pte Ltd, Singapore) after polymerization and at 24 hours, first week, first month, third month, and sixth month. Color changes(ΔE) were calculated for the different storage periods. One-factor repeated three-way analysis of variance (ANOVA) was used to examine the changes in ΔE measurements over time for different fillers and devices.
Results: Significant differences between composites and different periods were observed in the color stability with polymerization either QTH or LED. Independently of the composites, there was no significant difference at the end of six months between QTH and LED curing units with a fixed energy density. The Filtek Z550 material showed the lowest and Filtek Ultimate Flowable material showed the highest ΔE values at the end of the six months among the materials used.
Conclusions: Clinically acceptable color changes were observed for all the materials at the end of six months.

Key words: color stability; light emitting diode; quartz tungsten halogen; resin composites

Introduction

Excellence in esthetic restorations is influenced by correct shade selection.[1] Furthermore, known polymerization-dependent color changes must be considered when selecting a shade for a correct match.[2–4] Such color changes are often observed for certain dental resin-based composite materials sometime after polymerization.[2,4]

The degree of polymerization of a resin composite is represented by the percentage of polymerized monomers after light curing. This is one of the most important parameters for the physical and mechanical properties of a dental material.[5] Inadequate polymerization has a considerable influence on the discoloration of restorations, for example.[6] Other factors that can influence the color stability of light-polymerized resin composites include the type of resin matrix, the filler ratio, photo-initiators, and the light source used for polymerization.[7,8]

Developments in direct resin composites are progressing rapidly. Bulk-fill composites have been designed to reduce the number of clinical steps, enable single-step usage of up to 4mm thickness, speed up the placement of large posterior RBCs, and thereby reduce technique sensitivity.[9]

There are a range of techniques and instruments that can be used to determine the color of a material. Colorimeters are devices that use standard calibration to analyze the color characteristics of an item. These instruments give x, y, and z tristimulus values or CIE L*a*b* values, as described below.[10] One of the most widely used color determination systems was developed by the Commission Internationale de l'Eclairage Lab (CIE), along with its associated

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total color differences CIE L*a*b* system. The advantages of this color system are that it allows small color changes to be detected and these differences to be expressed as a unit. The degree of color change is expressed by ΔE and is calculated using the formula: ΔE*=[(ΔL*)2+(Δa*)2+(Δb*)2]1/2.[11] "Acceptability" refers to the lowest value of color difference noticeable by the naked human eye, although opinions differ as to what this value is. In different studies, researchers have suggested variously that the color change (ΔE*) has to be less than 3[12], 3.3[13,14] , or 3.7[15,16] to be "clinically acceptable". Overall, in the color studies published up to 2023 in the journals indexed in SCI-Expanded, the values for clinically acceptable color change (ΔE) range between 3 and 3.7.

Studies on the color stability of composites often concentrate on investigating the effect of the particle sizes of materials or the effect of various liquids on discoloration. Only a few studies have investigated the effects of light sources on color stability, notably of nanohybrid and bulk-fill composites.[17–19] Hence the scientific literature lacks sufficient information on this topic. In addition, resin composites often undergo significant color changes after curing and being subjected to different conditions. Even though polymerization-dependent color changes have been widely recorded in the past, new restorative materials with smaller particle sizes and different components are continually being introduced. As a result, understanding the importance of their polymerization activity on color stability may be helpful.

The purpose of this study, therefore, is to use a colorimeter to determine the color stability over time of three different nanoparticle composite materials polymerized with two different light-curing devices: namely, a Quartz tungsten-halogen (QTH) light source and a Light-emitting diode (LED) device.

The null hypotheses are:

- Color is not influenced by the time elapsed after polymerization, regardless of the resin composite used.
- Over the time, color is not influenced by the composite type, regardless of the type of curing units.
- Polymerization with LED or QTH did not have an influence on the color change, regardless of the resin composite used.

Material and Methods

Ethical Approval and Participants

Three types of resin composite restorative materials with nanoparticle content were used in the study: Filtek Z550 (FZ), a nanohybrid composite; Filtek Ultimate Flowable (FUF), a flowable nanocomposite; and Filtek Bulk Fill Posterior (FBP), a bulk fill composite.

Two criteria were taken into consideration in the experimental group design: the type of resin composite, and the type of polymerization light curing unit. The study was performed following the Modified CONSORT checklist of items for reporting in vitro studies of dental materials.[20] The resin composite materials used in this study are summarized in Table 1.

Specimen Preparation

Five samples (n=5) were prepared for each of the three different composite materials to obtain combinations of "Resin composite–Light Source" for a total of 30 samples. Samples were prepared in transparent silicone molds of 5 mm diameter and 2 mm thickness by applying resin composite in 2 mm single layers; transparent mylar strips were placed between the two glass coverslips to avoid oxygen inhibition and to create a homogenous structure, as well as to prevent air bubble formation.

The polymerization of the samples was carried out by placing the curing tip at 900 with respect to the sample surface on the 1 mm-thick glass coverslip. For standardization of the amount of transmitted energy, half of the samples were cured using an LED Radii Plus light source (SDI Ltd, Victoria, Australia) with a constant energy of 28 J/cm2 (1,400 mW/cm2 x 20s). The other half of the samples were cured by QTH Hilux Ultraplus light source (Benlioglu Dental, Ankara, Türkiye), with the same constant energy output of 28 J/cm2 (700 mW/cm2 x 40s). At the beginning of the polymerization process, the power of both light sources was measured using a radiometer.

All of the experimental groups are shown in Table 2. All specimens were kept for six months in artificial saliva solution: 8.4 mg NaF, 2,560 mg NaCl, 332.97 mg CaCl2, 250.00 mg MgCl2 (.6H2O), 189.48 mg KCl, 3,015.00 mg CH3COOK, 772.00 mg K3PO4 (.3H2O), and 0.1 mL of 85% H3PO4 dissolved in deionized H2O.[21] This artificial saliva solution was changed every month.[22]

Color measurements were carried out immediately after polymerization, and then after 24 hours, seven days, 15 days, one month, three months, and six months, respectively, using a colorimeter (Minolta CR-321, Konica Minolta Sensing Pte Ltd, Singapore).

Before measuring each sample, the colorimeter was calibrated to a white standard color provided by the manufacturer. The color of the samples was measured using a standard white light color temperature of 6,500K and a white background. ΔE values were calculated using an Excel spreadsheet. For each calculation, the difference between the first measurement and the elapsed time was used. At each time point, the measurements were repeated three times for each sample, and the averages were used to determine L*, a*, and b* values for applying the ΔE formula below: ΔE*=[(ΔL*)2+(Δa*)2+(Δb*)2]1/2

Statistical Analysis

Descriptive statistics of the data were calculated and shown as Arithmetic Mean ± Standard Error. Before the statistical analyses, the data were evaluated for parametric test hypotheses: for normality, by using the Shapiro-Wilk test; and for homogeneity of variances, by using the Levene test. One-factor repeated three-way analysis of variance (ANOVA) was used to examine the changes in ΔE measurements over time for different fillers and devices. Time (within subjects), light source, and material (between subjects) were included as variables in the model. In addition, Time*Light, Time*Material, and Time*Light*Material interaction terms were added to the model. For interaction terms found to be significant, Bonferroni correction was used to perform simple effects analysis. The $p<0.05$ criterion was used for all statistical comparisons. Statistical analysis was performed using IBM SPSS Statistics 26 software for Windows (IBM SPSS Inc., Chicago, IL, USA).

Results

The average ΔE values and the standard deviations for different groups at different periods are given in Table 3. When the ΔE values of the QTH-polymerized composites were examined, there was a statistically significant difference between FZ, FUF, and FBP in terms of color change from 24 hours after polymerization to six months later ($p<0.05$).

When the ΔE values of the LED-polymerized composites were examined, although there was not a color change for Group IV in the 24 hours or seven days after the process, a statistically significant difference was found in the sixth month after polymerization ($p<0.05$). However, a statistically significant difference in color change was found ($p<0.05$) in Group V and Group VI, from 24 hours after polymerization to six months afterward (Table 3).

At the end of six months, the highest color change among all groups was ΔE = 2.71, which was observed in Group II. The lowest color change was ΔE = 2.15, which was observed in Group I. When

Table 1. The resin composite materials used in this study

Material	Code	Resin	Filler	Manufacturer	Filler Content (% w/w)
FiltekTM Z550 (Nanohybrid)	FZ	BIS-GMA, UDMA, BIS-EMA, PEGDMA and TEGDMA	Surface-treated zirconia/silica and non-agglomerated surface-modified 20 nm silica	3M ESPE, Germany Shade A2	81.8
FiltekTM Ultimate Flowable (Nanofiller)	FUF	BIS-GMA, TEGDMA and Procrylate resins	Particle sizes between 0.1 and 5.0 micron, non-agglomerated/non-aggregated surface-modified 20 nm and 75 nm silica fillers and one surface-modified aggregated 0.1-10 micron zirconia/clusters (20 nm silica, 4 to 11 nm zirconia, and ytterbium trifluoride)	3M ESPE, Germany, Shade A2	65
FiltekTM Bulk Fill Posterior (Bulk-Fill Composite-Non-Viscous)	FBP	ERGP-DMA, diurethane-DMA and 1,12-dodecane-DMA. In addition, AUDMA (aromatic dimethacrylate), AFM (addition-fragmentation monomers), DDDMA (1,12-dodecanediol dimethacrylate), UDMA	non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, silanated aggregated zirconia/silica cluster filler (comprised of 20 nm silica, 4 to 11 nm zirconia particles), and a ytterbium trifluoride filler consisting of agglomerate 100 nm particles	3M ESPE, St. Paul, MN, USA, Shade A2	76.5

Table 2. Experimental groups of the study

	n	Curing Mode
Group I (FZ+QTH)	5	700mW/cm2 for 40s
Group II (FUF+QTH)	5	700mW/cm2 for 40s
Group III (FBP+QTH)	5	700mW/cm2 for 40s
Group IV (FZ+LED)	5	1400mW/cm2 for 20s
Group V (FUF+LED)	5	1400mW/cm2 for 20s
Group VI (FBP+LED)	5	1400mW/cm2 for 20s

light sources were compared, regardless of composite types, no significant differences were found after the first 24-hour measurements of composites polymerized with either QTH or LED ($p>0.05$). However, there was a statistically significant difference between the light sources in terms of measurements on the seventh day, the 15th day, and after the first month ($p<0.05$). On the other hand, there was no significant difference between QTH and LED light sources when measured after three and six months, respectively ($p>0.05$) (Figure 1).

Statistically significant differences were found among all the composites 24 hours after polymerization, as well as on the seventh day and the 15th day ($p<0.05$), regardless of the light curing unit used. In addition, there was a statistically significant difference between FUF and FZ and between FUF and FBP in the first month of measurements ($p<0.05$); however, there was no statistically significant difference between the FZ and FBP composites after one month ($p>0.05$). Moreover, there were statistically significant differences among all the composites ($p<0.05$) at the three- and six-month intervals (Figure 2).

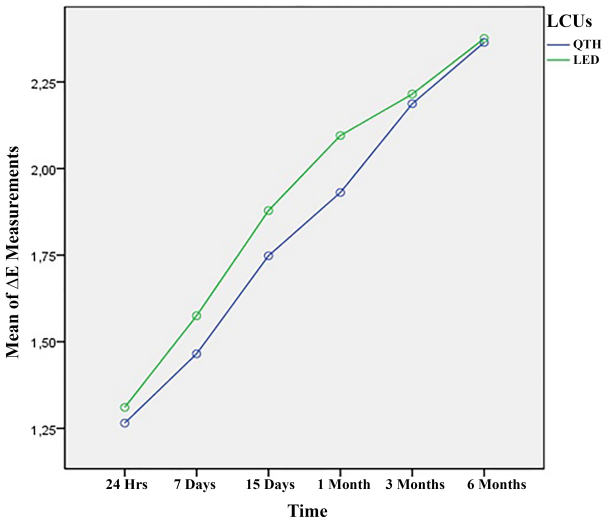

Figure 1. Time*Light Source Comparison

Discussion

In this study, polymerization-dependent color changes of three different methacrylate-based A2 shade resin composite materials were measured with a colorimeter (Minolta CR-321, Konica Minolta Sensing Pte Ltd, Singapore). As part of this investigation, the effects of two types of light sources (QTH and LED) on the color stability of three different resin composites over six months were examined.

In the present study, Group III was examined for color stability, and the largest color change was measured as $\Delta E = 2.23$, six months after polymerization. In addition, Group VI was examined, and the largest color change was measured as $\Delta E = 2.28$, also six months after polymerization. Thus, the null hypothesis(i) was rejected based on these findings. In the literature review, a few studies have been found remarking on the color change of FBP composites.[23,24]

In general, when a composite is polymerized, the same degree of conversion can be achieved with a constant energy density, regardless of light irradiance or exposure time. Anusavice et al.[25] mentioned that a total of 16 J/cm2 of energy density is required for the complete polymerization of a resin composite with a thickness of 2 mm. They also reported that this energy is equivalent to a 40-second polymerization with a light intensity of 400 mW/cm2 (40 s x 400 mW/cm2 = 16 J/cm2) and that the same total energy density can be obtained in 20 s with a power of 800 mW/cm2, indicating that the rate and degree of conversion both increase as the light intensity grows.

It seems that there is no consensus about the adequate light application time required for the resin composites to be fully polymerized. In a similar color stability study, Sabatini polymerized composites using QTH and LED light sources at a constant of 24 J/cm2 energy density.[4] It was seen that the light power applied in clinical conditions is sensitive to several variables and may differ depending on the settings. In our study, a constant energy density of 28 J/cm2 was applied to all the resin composite samples to ensure the amount of energy transmitted was standardized.

In some studies on nanocomposites, the samples were stored in distilled water[26,27], while in others the samples were stored in artificial saliva.[22,28] This latter method was deemed more suitable as it simulates the conditions of the oral cavity. In the present study, samples were stored in an artificial saliva solution for six months which was buffered to neutral pH, and the solution was changed every month.

Commonly, instrumental color measurement methods have been used to eliminate human errors. Instrumental measurements

Table 3. The average ΔE values and the standard deviations for different light sources and restorative materials at different times

Group	24 hours	7 days	15 days	1 month	3 months	6 months
Group I (FZ+QTH)	1.15 ±0.03 A,a	1.27 ±0.02 A,b	1.6 ±0.04 A,c	1.77 ±0.05 A,d	1.9±0.04 A,e	2.15 ±0.04 A,f
Group II (FUF+QTH)	1.45 ±0.02 B,a	1.74 ±0.02 B,b	2.04 ±0.03 B,c	2.25 ±0.02 B,d	2.58 ±0.02 B,e	2.71 ±0.02 B,f
Group III (FBP+QTH)	1.2 ±0.02 C,a	1.39 ±0.02 C,b	1.6 ±0.03 C,c	1.77 ±0.01 A,d	2.08 ±0.03 C,e	2.23 ±0.03 C,f
Group IV (FZ+LED)	1.14 ±0.04 A,a	1.22 ±0.05 D,a	1.59 ±0.04 D,b	1.9 ±0.02 C,c	2.01 ±0.02 A,d	2.2 ±0.03 A,e
Group V (FUF+LED)	1.47 ±0.03 B,a	1.91 ±0.03 E,b	2.18 ±0.03 E,c	2.38 ±0.02 D,d	2.5 ±0.03 B,e	2.64 ±0.02 B,f
Group VI (FBP+LED)	1.32 ±0.03 C,a	1.6 ±0.03 F,b	1.87 ±0.02 F,c	2.01 ±0.03 C,d	2.13 ±0.01 C,e	2.28 ±0.01 C,f

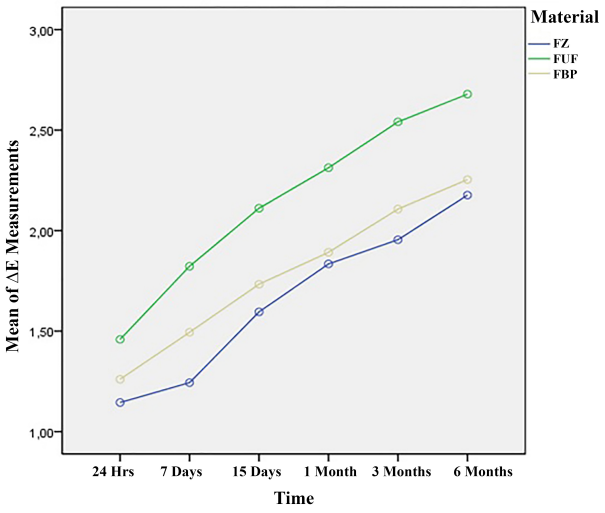

Figure 2. Time*Material Comparison

permit reproducible and reliable results even when color changes are below the eye's level of perception. Colorimeters offer several advantages, including ease of use. Additionally, smaller instruments are effective for both in vivo and in vitro studies and are available at reasonable prices.[10] Measurements with colorimeters can eliminate errors due to subjective decisions while detecting small differences in color shades much better than the naked eye.[29,30] In this study, ΔE values were calculated using a colorimeter and the CIE L*a*b* system for color measurement. The CIE L*a*b* system is widely used as an objective system to assess the colorimetric features of dental resin composites.[14,31]

Gönülol et al.[32] previously studied the 28-day color change of FZ composites polymerized using a LED light source. They reported that FZ exhibited a color change after 28 days with ΔE = 1.9. Our study also showed a color change of ΔE = 1.9 for Group IV after one month, which was in line with these findings. In addition, Group IV had an increased color difference with ΔE = 2.2 after six months. Therefore, the null hypothesis(ii) was rejected.

In a literature review, a few studies have been found that note the color change of FZ composites polymerized with a QTH light source (Group I).[33,34] In this study, Group I exhibited the lowest color change value with ΔE = 2.15 among other composites, after six months. This may be because of the amount of triethylene glycol dimethacrylate (TEGDMA) found in the resin matrix. This resin monomer has also been reported to affect the extent of post-irradiation polymerization. As TEGDMA increases, the amount of post-irradiation polymerization decreases because the monomer generates higher initial conversion, which helps to improve color stability.[35]

Color stability may be improved by increasing filler material and decreasing resin volume. In addition, the increased filler ratio reduces water absorption, resulting in less deterioration on the surface and therefore less color change.[36,37] The nanohybrid composite FZ was used in this study and showed the lowest color change in Group I and IV. This can be explained by the higher filler ratio of FZ (81.8%) compared with the other composite materials used in the study.

Karadaş[38] polymerized FUF composites using a LED light source, with these materials exhibited a color change after 24 hours (ΔE = 2.23). Parallel to his findings, in our study the FUF composite also exhibited a color change after 24 hours. Consistent with these findings, Group V(FUF+LED) exhibited the highest color change(ΔE=2.64) among the composites polymerized with the LED light source, at the sixth month.

Among all the composites used in the current study, Group II(FUF+QTH) exhibited the highest color change, with ΔE = 2.71 after six months. The fact that the FUF composite exhibited the largest color change may be explained by the amount of lower inorganic filler which comprises 65% of the material by weight. Sarac et al.[39] noted a greater decrease in yellow color intensity in samples cured with QTH compared to samples cured with LEDs; they suggested that the light source used for polymerization was a significant factor in the color stabilization of resin composites. Other studies did not find any differences with respect to the light source. For example, Ruttermann et al.[40] polymerized resin-containing restorative materials with LED and QTH for different periods and stored the samples in water and daylight for 180 days. They reported that the duration of polymerization over 60 seconds did not affect the color stability. Similarly, Sabatini[4] reported that different light curing units do not affect color stability, whether the light source is LED or QTH.

In the present study, there were no significant differences between the color changes of Group III and Group VI. When QTH and LED light sources were compared over time, no significant differences were found between the measurements after 24 hours ($p>0.05$). However, there was a statistically significant difference between the two light sources on the seventh day, after 15 days, and after one month ($p<0.05$). There was no significant difference between the QTH and LED light sources at the third and the sixth months ($p>0.05$). Therefore, hypothesis(iii) was partially accepted.

In general, it has been mentioned in the literature that composites became darker and less yellow immediately after polymerization. At 24 hours, color changes may still be observed with a shift back to the lighter and yellower side. For some materials, changes observed at 24 hours were sufficient to neutralize the initial changes that occurred after polymerization.[41]

The findings of this study were in line with Sabatini[4] but contrary to those of Sarac[39] and Rütterman et al.[40]; the reason for this may be the high energy density of 28 J/cm2 used in our study. When our results were evaluated considering the light sources, it was thought that both sources have the same or similar efficiency levels for the curing of composite materials. When the composites of this study were evaluated, regardless of the light sources used, the FUF resin composite exhibited the largest color change. While the FBP and FZ composites showed no difference after the first month ($p>0.05$), FBP exhibited a color change at the six-month ($p<0.05$). On the other hand, FZ exhibited the lowest color change.

Ytterbium fluoride (YbF3) fillers are water-soluble components that contribute to fluoride release. These fillers can permeate water after being incubated in a solution, which may affect color stability.[42] It may be considered that, of the materials used in this study, FUF and FBP exhibited more color change than FZ due to their YbF3

component.

A color change occurred between the 24th hour after polymerization and six months later in all of the composites used in this study. It is thought that the reason for the perceived color change in the later periods is related to increased water absorption over time.[13]

The lowest color change that a human eye can notice is still a matter of debate in dentistry research. In color-related studies, a great majority of researchers suggested that the value of ΔE should not be more than "3.3"[13,14] to be "clinically acceptable". Hence, in this study, the acceptable color change limit was considered as ΔE = 3.3. Since the values obtained in this study are below the cutoff value of ΔE = 3.3, any observed color changes are imperceptible to the naked eye and are therefore considered "clinically acceptable". Although the composites used in this study do not exhibit a color change clinically, the patients should be informed about the necessity of careful oral care within the first six months for these resin composites.

Nowadays, new composite systems with improved chemical and physical properties, as well as new light sources with amplified light intensity, are being developed to improve the color stability of resin composites. There is a need, therefore, for more research and future studies on this topic.

Conclusion

With the limitations of this study, it may be concluded that:

- The change in color stability varies depending on the composite type used, regardless of the type of light sources used (QTH or LED) for polymerization, maintaining a constant energy density of 28 J/cm2.
- The least color change occurred in the nanohybrid composite, which has the highest filler ratio.
- The greatest color change occurred in the flowable composite, which has the lowest filler ratio.
- No significant differences were demonstrated between the polymerization effects of the QTH and LED light sources in terms of color change.
- The composites in this study exhibited a "clinically acceptable" color change for up to six months.

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Author Contributions

R.M.A.: Conducting the experiments, data collection, data analysis, design and drafting of manuscript. A.N.: Conceived the idea, interpreting the results, critical revision of the manuscript.

Conflict of Interest

The authors declare no competing interests. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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References

1. Nahsan FP, Mondelli RF, Franco EB, Naufel FS, Ueda JK, Schmitt VL, et al. Clinical strategies for esthetic excellence in anterior tooth restorations: understanding color and composite resin selection. J Appl Oral Sci. 2012;20(2):151–6. doi:10.1590/s1678-77572012000200005.
2. Paravina RD, Ontiveros JC, Powers JM. Curing-dependent changes in color and translucency parameter of composite bleach shades. J Esthet Restor Dent. 2002;14(3):158–66. doi:10.1111/j.1708-8240.2002.tb00516.x.
3. Pedrosa MDS, Nogueira FN, Baldo VO, Medeiros IS. Changes in color and contrast ratio of resin composites after curing and storage in water. Saudi Dent J. 2021;33(8):1160–1165. doi:10.1016/j.sdentj.2021.02.002.
4. Sabatini C. Color Stability Behavior of Methacrylate-based Resin Composites Polymerized with Light-emitting Diodes and Quartz-Tungsten-Halogen. Oper Dent. 2015;40(3):271–81. doi:10.2341/14-080-L.
5. Al-Zain AO, Eckert GJ, Platt JA. The Influence of Distance on Radiant Exposure and Degree of Conversion Using Different Light-Emitting-Diode Curing Units. Oper Dent. 2019;44(3):E133–E144. doi:10.2341/18-004-L.
6. Oliveira DC, Souza-Junior EJ, Prieto LT, Coppini EK, Maia RR, Paulillo LA. Color stability and polymerization behavior of direct esthetic restorations. J Esthet Restor Dent. 2014;26(4):288–95. doi:10.1111/jerd.12113.
7. Fidalgo-Pereira R, Carpio D, Torres O, Carvalho O, Silva F, Henriques B, et al. The influence of inorganic fillers on the light transmission through resin-matrix composites during the light-curing procedure: an integrative review. Clin Oral Investig. 2022;26(9):5575–5594. doi:10.1007/s00784-022-04589-5.
8. Ilie N, Hickel R. Resin composite restorative materials. Aust Dent J. 2011;56 Suppl 1:59–66. doi:10.1111/j.1834-7819.2010.01296.x.
9. Chesterman J, Jowett A, Gallacher A, Nixon P. Bulk-fill resin-based composite restorative materials: a review. Br Dent J. 2017;222(5):337–344. doi:10.1038/sj.bdj.2017.214.
10. Paravina RD, Powers JM. Esthetic color training in dentistry. St Louis, Missouri; London: Mosby. 2004:272.
11. Sakaguchi RL, Powers JM. Craig's restorative dental materials-e-book. Elsevier Health Sciences; 2011.
12. Zhang F, Heydecke G, Razzoog ME. Double-layer porcelain veneers: effect of layering on resulting veneer color. J Prosthet Dent. 2000;84(4):425–31. doi:10.1067/mpr.2000.110255.
13. Razavi S, Esmaeili B, Amiri H, Pakdaman M, Bijani A. Color stability of a microhybrid resin composite polymerized with LED and QTH light curing units. J Dentomaxillofacial Radiol Pathol Surg. 2013;2(4):7–14.
14. Shamszadeh S, Sheikh-Al-Eslamian SM, Hasani E, Abrandabadi AN, Panahandeh N. Color Stability of the Bulk-Fill Composite Resins with Different Thickness in Response to Coffee/Water Immersion. Int J Dent. 2016;2016:7186140. doi:10.1155/2016/7186140.
15. Kim BJ, Lee YK. Influence of the shade designation on the color difference between the same shade-designated resin composites by the brand. Dent Mater. 2009;25(9):1148–54. doi:10.1016/j.dental.2009.04.001.
16. Paravina RD, Kimura M, Powers JM. Evaluation of polymerization-dependent changes in color and translucency of resin composites using two formulae. Odontology. 2005;93(1):46–51. doi:10.1007/s10266-005-0048-7.
17. Backes CN, FranCa FMG, Turssi CP, Amaral F, Basting RT. Color stability of a bulk-fill composite resin light-cured at different distances. Braz Oral Res. 2020;34:e119. doi:10.1590/1807-

3107bor-2020.vol34.0119.
18. Barutcigil C, Barutcigil K, Ozarslan MM, Dundar A, Yilmaz B. Color of bulk-fill composite resin restorative materials. J Esthet Restor Dent. 2018;30(2):E3–e8. doi:10.1111/jerd.12340.
19. Bilgili Can D, Ozarslan M. Evaluation of color stability and microhardness of contemporary bulk-fill composite resins with different polymerization properties. J Esthet Restor Dent. 2022;34(6):924–932. doi:10.1111/jerd.12879.
20. Faggion J C M. Guidelines for reporting pre-clinical in vitro studies on dental materials. J Evid Based Dent Pract. 2012;12(4):182–9. doi:10.1016/j.jebdp.2012.10.001.
21. Aykent F, Yondem I, Ozyesil AG, Gunal SK, Avunduk MC, Ozkan S. Effect of different finishing techniques for restorative materials on surface roughness and bacterial adhesion. J Prosthet Dent. 2010;103(4):221–7. doi:10.1016/S0022-3913(10)60034-0.
22. Alshali RZ, Salim NA, Satterthwaite JD, Silikas N. Long-term sorption and solubility of bulk-fill and conventional resin-composites in water and artificial saliva. J Dent. 2015;43(12):1511–8. doi:10.1016/j.jdent.2015.10.001.
23. Freitas F, Pinheiro de Melo T, Delgado AH, Monteiro P, Rua J, Proenca L, et al. Varying the Polishing Protocol Influences the Color Stability and Surface Roughness of Bulk-Fill Resin-Based Composites. J Funct Biomater. 2020;12(1). doi:10.3390/jfb12010001.
24. Karadaş M, Demirbuğa S. Evaluation of color stability and surface roughness of bulk-fill resin composites and nanocomposites. Meandros Medi Dent J. 2017;18(3):199.
25. Anusavice KJ, Shen C, Rawls HR. Phillips' science of dental materials. Elsevier Health Sciences; 2012.
26. de Abreu JLB, Sampaio CS, Benalcazar Jalkh EB, Hirata R. Analysis of the color matching of universal resin composites in anterior restorations. J Esthet Restor Dent. 2021;33(2):269–276. doi:10.1111/jerd.12659.
27. Halacoglu DM, Yamanel K, Basaran S, Tuncer D, Celik C. Effects of staining and bleaching on a nanohybrid composite with or without surface sealant. Eur J Dent. 2016;10(3):361–365. doi:10.4103/1305-7456.184148.
28. Ozera EH, Pascon FM, Correr AB, Puppin-Rontani RM, Castilho AR, Correr-Sobrinho L, et al. Color Stability and Gloss of Esthetic Restorative Materials after Chemical Challenges. Braz Dent J. 2019;30(1):52–57. doi:10.1590/0103-6440201902263.
29. Ertas E, Guler AU, Yucel AC, Koprulu H, Guler E. Color stability of resin composites after immersion in different drinks. Dent Mater J. 2006;25(2):371–6.
30. O'Brien WJ. Dental materials and their selection. vol. 10. Quintessence Chicago; 2002.
31. Bahbishi N, Mzain W, Badeeb B, Nassar HM. Color Stability and Micro-Hardness of Bulk-Fill Composite Materials after Exposure to Common Beverages. Materials (Basel). 2020;13(3). doi:10.3390/ma13030787.
32. Gonulol N, Ozer S, Sen Tunc E. Water Sorption, Solubility, and Color Stability of Giomer Restoratives. J Esthet Restor Dent. 2015;27(5):300–6. doi:10.1111/jerd.12119.
33. Ozan G, Sancakli HS, Tiryaki M, Bayrak I. Effect of light curing modes on the color stability of a nanohybrid composite immersed in different beverages. Odovtos-Int J Dent Sci. 2020;22(2):71–81.
34. Unsal KA, Karaman E. Effect of Additional Light Curing on Colour Stability of Composite Resins. Int Dent J. 2022;72(3):346–352. doi:10.1016/j.identj.2021.06.006.
35. Tarumi H, Imazato S, Ehara A, Kato S, Ebi N, Ebisu S. Post-irradiation polymerization of composites containing bis-GMA and TEGDMA. Dental Materials. 1999;15(4):238–242.
36. Buchalla W, Attin T, Hilgers RD, Hellwig E. The effect of water storage and light exposure on the color and translucency of a hybrid and a microfilled composite. J Prosthet Dent. 2002;87(3):264–70. doi:10.1067/mpr.2002.121743.
37. Kim KH, Ong JL, Okuno O. The effect of filler loading and morphology on the mechanical properties of contemporary composites. J Prosthet Dent. 2002;87(6):642–9. doi:10.1067/mpr.2002.125179.
38. Karadas M. The effect of different beverages on the color and translucency of flowable composites. Scanning. 2016;38(6):701–709. doi:10.1002/sca.21318.
39. Sarac D, Sarac YS, Kulunk S, Ural C, Kulunk T. The effect of polishing techniques on the surface roughness and color change of composite resins. J Prosthet Dent. 2006;96(1):33–40. doi:10.1016/j.prosdent.2006.04.012.
40. Ruttermann S, Suyoun K, Raab WH, Janda R. Effect of exposure time on the color stability of resin-based restorative materials when polymerized with quartz-tungsten halogen and LED light. Clin Oral Investig. 2010;14(5):599–605. doi:10.1007/s00784-009-0316-y.
41. Sabatini C, Campillo M, Aref J. Color stability of ten resin-based restorative materials. J Esthet Restor Dent. 2012;24(3):185–99. doi:10.1111/j.1708-8240.2011.00442.x.
42. Iazzetti G, Burgess JO, Gardiner D, Ripps A. Color stability of fluoride-containing restorative materials. Oper Dent. 2000;25(6):520–5.