RESEARCH ARTICLE

The Effects of Mouth Rinses on the Color Stability of Resin-Based Restorative Materials

ABEER EL-SAYED ELEMBABY, BDS, MSD, PhD

ABSTRACT

Objective: The aim of this study was to assess the color stability of three direct resin-based restorative materials: IPS Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein), Nano-filled composite (Filtek Z 350 XT, 3 M ESPE, St. Paul, MN, USA), and Nano-hybrid composite (Tetric Evo Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) upon immersion into the following three mouth rinses: Antiseptol (Kahira Pharmaceuticals and Chemical Industries Co. Cairo-Egypt), Flucal (Alexandria Co. Pharmaceuticals Alexandria, Egypt), and Listerine (Johnson & Johnson, UK).

Materials and Methods: Ninety disc-shaped, 12 mm × 1 mm specimens were divided into three groups according to the type of direct resin-based restorative material used. The specimens were randomly subdivided into three different subgroups ($N = 10$) in terms of immersion medium.

Color change was evaluated prior to and after immersion into the mouth rinses for 24 hours by spectrophotometry (Shimadzu, UV-3101 PC Shimadzu Corporation. Kyoto, Japan).

Results: Data were statistically analyzed using two-way analysis of variance (ANOVA) to assess the color stability of the restorative materials. The post hoc Scheffe's test was applied to clarify pair-wise statistical significance. Results with p-values < 0.05 were considered statistically significant. IPS Empress Direct ($\Delta E = 1.48$) exhibited more favorable stability than the other tested composite resins, Filtek Z 350 X ($\Delta E = 3.05$) and Tetric Evo Ceram ($\Delta E = 10.35$). The immersion media elicited a significant effect on the color stability of the tested, resin-based restorative materials, where Flucal elicited the most significant color change, followed by Listerine and Antiseptol, which elicited the least significant color change.

Conclusions: Within the limitation of this laboratory study, the following conclusions could be drawn: (1) The composite structure, namely the resin formulation, which includes the filler size and type of photo-initiator, has a direct impact on its susceptibility to stain by external agents; (2) Mouth rinses can be considered stainable solutions; (3) The chemical formulation of individual mouth rinses can significantly control their ability to stain.

CLINICAL SIGNIFICANCE

Patient use of mouth rinses should be subject to dental supervision to control their adverse effects on the aesthetic quality of the restoration. Knowing the composition of the restorative material is important, as is its polymerization cycle and the promotion of adequate surface texture in order to select the appropriate material for each clinical application, and to use it in an effective way to promote its best properties.

(J Esthet Restor Dent 26:264–271, 2014)

INTRODUCTION

Patient awareness of their own aesthetics has grown over the past several years. Thus, demand for durable aesthetic restorative material has increased significantly. A successful aesthetic dental restoration requires the achievement of multiple factors, where the reproduction of tooth shape and shade, as well as the maintenance of the selected color throughout the functional lifetime of the restoration in a dynamic oral environment, which plays important roles.[1,2]

Lecturer of Operative Dentistry, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

 DOI 10.1111/jerd.12061

Since their emergence, composite restorative materials have undergone many developmental improvements in terms of their aesthetic qualities, the foremost of which is filler size. Filler size has been progressively reduced to provide smoother surface textures, which in turn are reflected in optimized optical properties.[3]

In addition, alternative photoinitiators have been integrated into commercially available materials within the past few years, predominantly for aesthetic reasons, due to the yellowing effect of camphorquinone/amine systems.[4] Notably, Lucirin-TPO, a mono-acyl-phosphine oxide, is completely colorless after light-curing reactions. Thus, its polymers are less yellow compared with other photoinitiators. Moreover, it presents with an increased molar absorptive and curing efficiency.[5–7]

Currently, caries represents an infectious disease process that is characterized by episodes of de-and re-mineralization.[8] Thus, medical models of treatment initial carious lesions by caries control measures and re-mineralization have been developed.

For effective control of caries, the successful treatment of one or more of the necessary disease components, such as cariogenic bacterial plaque control, must be achieved. Given the difficulty of achieving sufficient levels of cariogenic plaque control using mechanical means, chemo-prophylactic agents might offer an adjunct.[9,10]

The use of mouth rinse to control oral bacteria dates back almost 5,000 years, although it's used has generally been based on anecdotal evidence rather than scientific evidence. This is especially true for over the counter (OTC) products, and there is even less data on herbal remedies.[11,12] This often leads to the use of an inappropriate product and incorrect mode of application, with the end result a failed treatment outcome.[13] Once the carious lesion becomes cavitated, surgical treatment is indicated. Recently introduced tooth-colored restorative materials have been widely used to restore such lesions in order to satisfy patients' esthetic demands.[14]

However, after restoration, the frequent use of mouth rinses could affect the color stability of these resin composite restorations.[15] Although the effect pattern of the mouth rinses on the restorative materials might be different depending on many factors that could not be replicated in vitro, routine in vitro testing of aesthetic restoratives is recommended for any new product.[16]

Based on such thinking, the present in vitro study aims to assess the effect of commercially available mouth rinses on the color stability of three resin-based restorative materials.

MATERIALS AND METHODS

Materials

The details of the materials used in this study are listed in Tables 1 and 2.

Methods

Grouping of the Specimens

Ninety specimens were divided into three main groups ($N = 30$) according to the resin-composite used: IPS Empress Direct, Nano-filled composite, and Nano-hybrid composite. Then each group was subdivided into three subgroups ($N = 10$) according to type of treatment solution used (Antiseptol [AS], Flucal [FL], and Listerine [LI]).

Specimen Preparation

The disc-shaped specimens were fabricated as 12 mm in diameter and 1 mm in thickness, as required by the ISO International Standard #7491:2000.[17] Resin composite materials were applied carefully into a circumferential Teflon mold with the same specimen dimensions positioned onto a 0.05 mm-thick transparent polyester filmstrip (Mylar, DuPont, and Wilmington, DE, USA) over a glass slide. The material was covered with another celluloid strip, and the glass slide weighed of 200 g for 1 minute until the slide touched the mold completely, thus allowing excess composite to flow prior to curing.[18–20] Next, the excess

 DOI 10.1111/jerd.12061

TABLE 1. Different restorative materials used in this study

Commercial brand	Abbreviation	Shade	Manufacturer	Composition			Batch number
				Monomer	Fillers	Photoinitiator	
IPS empress direct	IPS	Universal shadeA3	Ivoclar, Vivadent, Schaan, Liechtenstein	Dimethacrylates20–21.5 wt%	Ytterbium tri-fluoride, barium-aluminum-fluorosilicate glass, mixed oxide, silicon dioxide and prepolymer with a particle size of 0.4 μm-100 nm.	Lucirin TPO	N42827
Filtek Z 350 XT	FZ	Universal shadeA3	3 M ESPE, St. Paul, MN, USA	Bis-GMA, UDMA, Bis-EMA, TEGDMA PEGDMA	Non-aggregated 20 nm silica filler, non-aggregated 4–11 nm zirconia filler Aggregated zirconia/silica cluster filler comprised of 20 nm silica and 4 to 11 nm zirconia particles	Camphorquinone/ amine	N251259
TetricEvo-Ceram	TEC	Universal shadeA3	Ivoclar, Vivadent, Schaan, Liechtenstein	Dimethacrylates 17–18% weight	Barium glass, ytterbium trifluoride, mixedoxide,pre-polymer 82–83% weight the particle size of the inorganic fillers: 40–3,000 nm, mean 550 nm	Camphorquinone/ amine	P80726

TABLE 2. Different mouth rinses used in this study

Commercial brand	Abbreviation	Manufacturer	Composition	Color	pH
Antiseptol	AS	Kahira pharmaceuticals and chemical industries Co. Cairo-Egypt.	Chlorhexidinegluconate 0.1%	Red	6.7
Flucal	FL	Alexandria Co. pharmaceuticals Alexandria, Egypt.	Sodium fluoride 200 mg, quinolyene yellow and methylene blue.	Green	6.7
Listerine	LI	Johnson & Johnson UK	Aqua, ethanol denat (17.88 % w/w), sorbitol, poloxamer 407, benzoic acid, sodium saccharin, eucalyptol, methyl salicylate, aroma, thymol, menthol, sodium benzoate	Green	4.2

restorative material was removed. The tested restorative material was light cured for 20 seconds on each side using a light-curing unit QHL75 (505 mW/cm^2) (Dentsply, York, PA, USA). Irradiance was checked daily using the built-in radiometer.

Immersion of the Specimens in the Treatment Solutions

Immediately after polymerization, the specimens were stored in distilled water in dark container that was maintained in an incubator (JRAD, China) at 37°C for 24 hours, allowing post-polymerization, as well as the elution of unreacted components prior to the initial color measurement.

The specimens were then immersed in 20 mL of the treatment solution in a dark container that was maintained in an incubator at 37°C for 24 hours, which is equivalent to a cumulative time period of 2 years of 2-minute daily use of mouth rinse.[21] All of the specimens were then subjected to a second color measurement.

Color Measurements

Twenty milliliters of distilled water was used to thoroughly rinse each specimen for 120 seconds. Each specimen was then blotted dry using a filter paper, and then subjected to color measurement.

 DOI 10.1111/jerd.12061

The initial color measurements for each specimen prior to immersion in any treatment solution were performed by spectrophotometry and recorded as baseline measurements. After immersion into the treatment solutions, the second color measurements for each specimen were performed again.

The total color difference ΔE* was calculated for each specimen using the following equation:[9]

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})1/2$$

The color differences were measured by spectrophotometry. The measurements were established in mathematical coordinates designated by the international color space CIE-Lab (Commission International de l'EclairageL*a*b*). CIE-Lab is expressed as the L* coordinate, which represents color luminosity that varies from white to black, and as a* and b* coordinates, which represent the chromaticity of the color, with axes varying from green to red and blue to yellow, respectively. This color space is represented by a sphere, where the *Y*-axis represents the L* coordinate, the *X*-axis represents the b* coordinate, and the Z-axis represents the a* coordinate. The matching of these coordinates results in a spatial position that mathematically expresses a color.[22,23]

A scale for ΔE evaluation was used that considers a non-visible difference as when ΔE is less than or equal to 1 unit, a visual perceptible difference to the experienced examiner as when ΔE is between 1 and 2 units, and a clinical acceptable difference as when ΔE is 3.3 units.[24,25]

Statistical Analysis

The recorded data for color assessment were collected and statistically analyzed using two-way analysis of variance (ANOVA) and post hoc Scheffe's test ($p < 0.05$).

RESULTS

The total color difference (ΔE) of each specimen after 24 hours immersion was evaluated relative to baseline (initial measurement). The results of this study showed that the ΔE of Tetric Evo Ceram as higher (10.35) than that of Filtek Z 350 XT (ΔE = 3.05) and IPS Empress Direct (ΔE = 1.48). Perceptible color changes (ΔE = 3.3) were recorded in Tetric Evo Ceram when immersed in Flucal (ΔE = 15.27), Listerine (ΔE = 9.41), and Antiseptol (ΔE = 6.38). In Filtek Z 350 XT, a perceptible color change was observed when immersed in Flucal (ΔE = 4.53), whereas in IPS Empress Direct, a non-perceptible color change occurred with all of the tested mouth rinses. Flucal exhibited a significant capacity for staining the tested restorative materials, followed by Listerine and Antiseptol mouth rinses, respectively.

Two-way ANOVA was applied to determine the effect of three different materials on color change. A post hoc Scheffe's test was applied to assess the pair-wise statistical significance, if any, as shown in Table 3 and Figure 1. Results with *p*-values < 0.05 were considered statistically significant.

TABLE 3. Mean values, standard deviation, and statistical analysis of the color difference (ΔE) values of the different groups

Tested restorative materials	AS	FL	LI	ANOVA *p*-value	Scheffe *p*-value		
					P1	P2	P3
TEC	6.383 ± 0.280	15.279 ± 0.400	9.419 ± 0.373	0.000*	0.000*	0.000*	0.000*
FZ	1.723 ± 0.451	4.531 ± 0.250	2.901 ± 0.237				
IPS	0.613 ± 0.171	2.595 ± 0.290	1.253 ± 0.100				

AS = Antiseptol; FL = Flucal; LI = Listerine; P1 = GI & GII; P2 = GI & GIII; P3 = GII & GIII.
±Indicates the standard deviation value.
*Statistical significant, $p < 0.05$.

 DOI 10.1111/jerd.12061

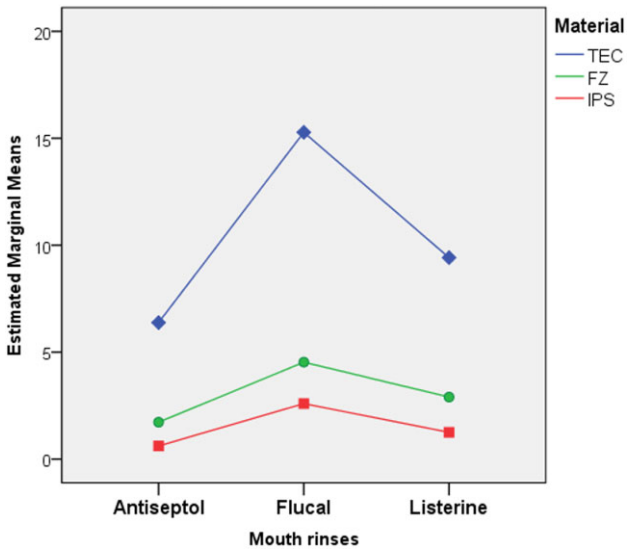

FIGURE 1. Graph representing the mean of (ΔE) values of the different groups.

DISCUSSION

Maintenance of the color throughout the functional lifetime of dental restorations is one of the most important characteristics of aesthetic restorative materials in terms of the durability of the treatment. This characteristic is not consistent among various restorative materials.

The color stability of resin composite restorations is affected by several extrinsic and intrinsic factors. Intrinsic factors include the resin matrix, the size of the filler and the photoinitiator system of the composites. Incomplete polymerization of the resin matrix elicits a considerable influence on color stability. The size of the filler particles of the composite affects surface smoothness and the susceptibility to extrinsic staining.

External discoloration includes variables such as bad oral hygiene, dietary, and smoking habits. The use of mouth rinses is considered one of the extrinsic factors that threaten the color stability of the aesthetic restorations. Recently, the use of mouth rinses has become popular to control caries and periodontal diseases.[15,26–28]

This study evaluated and compared the color stability of three different resin-based restorative materials, TEC, FZ, IPS Empress Direct, after immersion in the following mouth rinse solutions: AS, FL, and LI for 24 hours at 37°C in the dark, which is equivalent to a cumulative time period of 2 years of 2-minute daily use of mouth rinse.[21]

The results revealed that the color change of TEC was clinically unacceptable, where ΔE was higher (9.64) than the maximum acceptable limit ΔE = 3.3. In contrast, IPS Empress Direct and FZ exhibited clinically acceptable color changes of ΔE = 0.95 and ΔE = 3.25, respectively, because their ΔE values remained below the maximum tolerable limit.[29]

The color change in the test specimens might be attributed to their different resin formulations. Although all of the tested composites are dimethacrylate-based resins, they differ in their chemical formulations, proportions, and degrees of cross-linking. These proprietary mixes of matrix-forming resins indeed vary widely in their behavior. Consequently, the polar nature of the resin matrices vary from one to another, as do their susceptibility for water sorption, which allows for the permeation of staining agents such as the mouth rinses, resulting in altered color.[26]

Additionally, water sorption might decrease the durability of the resin composites by expanding and plasticizing their components, hydrolyzing the silane-coupling agents, leading to micro-crack formation. The latter or the interfacial gaps between the fillers and the matrices allow for stain penetration and discoloration.[8,26,27,30] On the other hand, the addition of the co-polymers Bis-GMA, UDMA, Bis-EMA, PEGDMA, and TEGDMA to FZ creates denser polymer networks. Several studies have revealed that the denser the cross-linked network, the more heterogeneous the structure. This heterogeneity within such networks accommodates for larger quantities of water between the polymer clusters.[31–34]

In addition, the increased susceptibility of TEC to stain when compared to FZ and IPS might be attributed to the filler size. FZ contains non-aggregated nano-fillers (4–20 nm) and nano-clusters (aggregated nano-fillers,

 DOI 10.1111/jerd.12061

4–20 nm). The presence of these nano-fillers enhances the smooth surface finish, gloss, and "polish-ability" of the so-called nano-composites, resulting in enhanced performance that resists color changes.[35–40] Although TEC and IPS contain the same types of fillers, the average size of the TEC filler system (550 nm) are larger than the filler contained in IPS (0.4 μm 100 nm) and might be easily eroded by the chemical actions of the mouth rinses, leading to rougher surfaces that are more prone to staining.

However, IPS exhibited the least extent of color change among the tested restorative materials. Its resistance to changes in color might be also attributed to the type of photoinitiator. Traditionally, resin composite systems, such as TEC and FZ, contain camphoroquinone, a visible light-sensitive diketone photoinitiator that is responsible for initiating free radical polymerization. Camphoroquinone absorbs energy within the visible light range (400–500 nm) with a peak at 468 nm. Photons associated with this frequency range are absorbed by camphoroquinone, raising it from ground state to an excited triplet state. When the excited triplet collides with an amine co-initiator, an amino-alkyl free radical forms that can initiate polymerization. Camphoroquinone is yellow, which changes when photoactivated, becoming "transparent." However, when the activating irradiation is insufficient, a small amount of camphoroquinone remains inactive, exhibiting a residual yellow in the final color of the composite resin, which might produce a darker color in the restorative material.[41–43]

In recent products such as IPS, new photoinitiators have been introduced either to reduce the intensity of the yellow color of the composite resin restorative material that is typically produced by the addition of camphoroquinone or to prevent the inactivation of the amine co-initiator by acidic monomers contained in some enamel and dentin adhesives. These new photoinitiators, such as Lucirin TPO in IPS, absorb light energy in the lower ranges of the visible light spectrum.[44,45]

In regards to the results of this study, the immersion of the tested specimens in the Flucal mouth rinse produced more significant staining of the resin-based restorative materials than the Listerine and Antiseptol mouth rinses. This finding might be attributed to that the percentage of sodium fluoride in Flucal (0.2%). Although the Flucal mouth rinse is alcohol free, it yielded perceptible color changes in the tested restorative materials.

Alcohol is not the only factor that elicits a softening effect on restorative materials. In addition to alcohol, mouth rinses can contain other substances, such as detergents, emulsifiers, and organic acids, which can lead to the degradation of the composite resin surface.[46,47]

Listerine has a low pH (4.2), and low-pH mouth rinses with higher alcohol content might affect some physical-mechanical properties of resin composites, softening the aesthetic restorative materials and significantly increasing the biodegradation of the resin composites over time. This phenomenon is a complex process that might result in composite polymer matrix collapse, causing several problems such as filler-polymer matrix debonding, release of residual monomers, and wear and erosion that causes staining.[48]

The staining of teeth and oral mucous membranes is a well-known side effect of chlorhexidine mouth rinses,[49] and non-perceptible color changes $\Delta E^* = 2.75$ were observed after immersion in Antiseptol mouth rinse. This result might be due to the absence of food additives in the chlorhexidine immersion solution that might modify the resulting effects, which plays an important role in decreasing the extent of color change of the resin-based restorative materials exposed to chlorhexidine-containing mouth rinses.[12]

When discussing the clinical relevance of these results, the oral environment must be considered, as it differs in several ways from in vitro conditions. Factors such as the variety of food, saliva, and their interactions might intensify discoloration. The success of restoration is dependent on the selection and effective usage of the appropriate material for each clinical application.

 DOI 10.1111/jerd.12061

CONCLUSIONS

Based on the employed methodology and the obtained results, it can be concluded that:

1 The composite structure, namely the resin formulation, which includes the filler size and type of photoinitiator, has a direct impact on its susceptibility to stain by external agents.
2 Mouth rinses can be considered stainable solutions.
3 The chemical formulation of individual mouth rinses can significantly control their ability to stain.

DISCLOSURE

The author does not have any financial interest in the companies whose materials are included in this article.

REFERENCES

1. Ishikawa-Nagai S, Yoshida A, Da Silva JD, Miller L. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns: part 1: analysis and interpretation of tooth color. J Esthet Restor Dent 2010;22(1):42–52.
2. Burke FJT, Qualtrough AJE. Aesthetic inlays: composite or ceramic? Br Dent J 1994;176(2):53–60.
3. Ten Bosch JJ, Coops JC. Tooth color and reflectance as related to light scattering and enamel hardness. J Dent Res 1995;74:374–80.
4. Price RB, Felix CA. Effect of delivering light in specific narrow bandwidths from 394 to 515 nm on the micro-hardness of resin composites. Dent Mater 2009;25:899–908.
5. Neumann MG, Miranda WG Jr, Schmitt CC, et al. Molar extinction coefficients and the photon absorption efficiency of dental photoinitiators and light curing units. J Dent 2005;33:525–32.
6. Neumann MG, Schmitt CC, Ferreira GC, Correa IC. The initiating radical yields and the efficiency of polymerization for various dental photoinitiators excited by different light curing units. Dent Mater 2006;22:576–84.
7. Emami N, Sderholm KJ. Influence of light-curing procedures and photo-initiator/co-initiator composition on the degree of conversion of light curing resins. J Mater Sci Mater Med 2005;16(1):47–52.
8. Peutzfeldt A, Assmussen E. The effect of post curing on quantity of remaining double bonds, mechanical properties and in vitro wear of two resin composites. J Dent 2003;31:341–51.
9. Diab M, Zaazou MH, Mubarak EH, Fahmy OMI. Effect of five commercial mouth rinses on the microhardness and color stability of two resin composite restorative materials. Aust J Basic Appl Sci 2007;1(4):667–74.
10. Devore LR. Antimicrobial mouth rinses: impact on dental hygiene. J Am Dent Assoc 1990;125:235–85.
11. Scully C, Field EA, Randall C. Over-the-counter remedies for oral soreness. Periodontol 2000 2008;48:76–84.
12. Moran JM. Home-use oral hygiene products: mouth rinses. Periodontol 2000 2008;48:42–53.
13. Lang NP, Tan WC, Krahenmann MA, Zwahlen M. A systematic review product of the effects of full-mouth debridement with and without antiseptics in patients with chronic periodontitis. J Clin Periodontol 2008;35: 8–21.
14. Fischman SL. A clinician's perspective on antimicrobial mouth rinses. J Am Dent Assoc 1994;125:20–2.
15. Yazici AR, Celik C, Dayangac B, Ozgunaltay G. The effect of curing units and staining solutions on the color stability of resin composites. Oper Dent 2007;32:616–22.
16. Celik C, Yuzugullu B, Erkut S, Yamanel K. Effects of mouth rinses on color stability of resin composites. Eur J Dent 2008;2:247–53.
17. Gürdal P, Akdeniz BG, Hakan Sen B. The effects of mouth rinses on microhardness and color. J Oral Rehabil 2002;29:895–901.
18. Miyagawa Y, Powers JM, O'Brien WJ. Optical properties of direct restorative materials. J Dent Res 1981;60:890–4.
19. Alpoz A, Ertuğrul F, Cogulu D, Topaloğlu-Ak A. Effects of light curing method and exposure time on mechanical properties of resin based dental materials. Eur J Dent 2008;2:37–42.
20. Ciccone-Nogueira JC, Borsatto MC, de Souza-Zaron WC, et al. Microhardness of composite resins at different depths varying the post-irradiation time. J Appl Oral Sci 2007;15(4):305–9.
21. El-Badrawy WA, McComb D, Wood RE. Effect of home-use fluoride gels on glass ionomer and composite resin restorations. Dent Mater 1993;9:63–7.
22. Hunter R, Harold R. The measurement of appearance. Reston (VA): Wiley-Interscience Publication; 1987, pp. 28–59. Ch. 2.
23. Schanda J. Colorimetry-Understanding the CIE System, 1st ed. University of Pannonia, Hungary: John Wiley & Sons, Inc publication; 2007, pp. 25–49. Ch. 3.
24. Um CM, Ruyters IE. Staining of resin-based veneering materials with coffee and tea. Quintessence Int (Berl) 1991;22:377–86.

 DOI 10.1111/jerd.12061

25. Stoddard JW, Johnson GH. An evaluation of polishing agents for composite resin. J Prosthet Dent 1999;65:491–5.
26. Bagheri R, Burrow MF, Tyas M. Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials. J Dent 2005;33:389–98.
27. Calheiros FC, Sadek FT, Braga RR, Cardoso PE. Polymerization contraction stress of low-shrinkage composites and its correlation with micro leakage in class V restorations. J Dent 2004;32:407–12.
28. Lee YK, Powers JM. Combined effects of staining substances on resin composites before and after surface sealant application. J Mater Sci Mater Med 2007;18:685–91.
29. Dietschi D, Campanile G, Holz J, Meyer J. Comparison of color stability of ten new generation composites: an in-vitro study. Dent Mater 1994;10:353–62.
30. Sarafianou A, Iosifidou S, Papadopoulos T, Eliades G. Color stability and degree of cure of direct composite restoratives after accelerated aging. Oper Dent 2007;32:406–11.
31. Elliott JE, Lovell LG, Bowman CN. Primary cyclization in the polymerization of bis-GMA and TEGDMA: a modeling approach to understanding the cure of dental resins. Dent Mater 2001;17:221–9.
32. Kalachandra S. Dimethacrylate monomers and polymers as biomaterials. Polym Sci 1997;2:95–106.
33. Kalachandra S, Turner DT. Water sorption of polymethacrylate networks: bis-GMA/TEGDMA copolymers. J Biomed Mater Res 1987;21:329–38.
34. Prakki A, Cilli R, Vieira IM, et al. Water sorption of CH3- and CF3-Bis-GMA based resins with additives. J Appl Oral Sci 2012;20(4):472–7.
35. Yap S, Yap A. Polish retention of new aesthetic restorative materials over time. Singapore Dent J 2004;26(1):39–43.
36. Ergücü Z, Türkün LS, Aladag A. Color stability of nano composites polished with one-step systems. Oper Dent 2008;33(4):413–20.
37. Mundim FM, Garcia LFR, Pires de Souza FP. Effect of staining solutions and repolishing on color stability of direct composites. J Appl Oral Sci 2010;18(3):249–54.
38. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc 2003;134(10):1382–90.
39. Vichi A, Ferrari M, Davidson CL. Color and opacity variations in three different resin-based composite products after water aging. Dent Mater 2004;20(6):530–4.
40. Puetzfeldt A. Resin composite in dentistry: the monomer systems. Eur J Oral Sci 1997;105:97–116.
41. Kalachandra STD, McGrath JE, Sankarapandian M, Shobha HK. Structure-property relationship in dental composites based on polydimethacrylates. Polym Pap 1997;38:94–5.
42. Sideridou ITV, Papanastasiou G. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resin. Biomaterials 2002;23:1819–29.
43. Rueggeberg FA, Ergle JW, Lockwood PE. Effect of photoinitiator level on properties of a light-cured and post-cure heated model resin system. Dent Mater 1997;13:360–4.
44. Tanoue N, Matsumura H, Atsuta M. The influence of ultraviolet radiation intensity on curing depth of photoactivated composite veneering materials. J Oral Rehabil 1998;25:770–5.
45. Teshima W, Nomura Y, Tanaka N, et al. ESR study camphorquinone/amine photoinitiator system using blue light-emitting diodes. Biomaterials 2003;24:2097–103.
46. Gürgan S, Onen A, Koprülü H. In-vitro effect of alcohol-containing and alcohol-free mouth rinses of some restorative materials. J Oral Rehabil 1997;24:244–6.
47. Trauth KG, Terosside Godoi AP, Colucci V, et al. The influence of mouth rinses and simulated tooth brushing on the surface roughness of a nano-filled composite resin. Braz Oral Res. 2012;26(3):209–14.
48. Villalta P, Lu H, Okte Z, et al. Effects of staining and bleaching on color change of dental composite resins. J Prosthet Dent 2006;95:137–42.
49. Addy M, Moran J, Newcombe R, Warren P. The comparative tea staining potential of phenolic, chlorhexidine and anti-adhesive mouth rinses. J Clin Periodontol 1995;22:923–8.
50. Studer K, Koniger R. Initial photoyellowing of photocrosslinked coatings. Eur Coat J 2001;1:26–37.
51. Park YJ, Chae KH, Rawls HR. Development of a new photoinitiation system for dental light-cure composite resin. Dent Mater 1999;15:120–7.

Reprint requests: Abeer El-Sayed ElEmbaby, BDS, MSD, PhD, Restorative Dental Science Department, Faculty of Dentistry, Dammam University, PO Box 1982, El Dammam 31441, Kingdom of Saudi Arabia; email: ab_elembaby@yahoo.com

 DOI 10.1111/jerd.12061