



ORIGINAL ARTICLE

# Color and translucency of finished and unfinished esthetic restorative materials after staining and bleaching



Iman Ibrahim ElSayad \*

Conservative Dentistry Department, Faculty of Dentistry, Cairo University, Egypt

Received 15 May 2016; revised 17 January 2018; accepted 20 February 2018

Available online 27 February 2018

## KEYWORDS

Bleaching;  
Color;  
Finishing;  
Staining;  
Translucency

**Abstract** *Purpose:* To evaluate the effect of staining and bleaching on color and translucency of finished and unfinished nano-filled resin composite and giomer. *Materials and methods:* Twenty specimens (ten finished + ten unfinished) were fabricated from each material, then an initial color and translucency measurement was taken. Specimens were stained in coffee for 48 h at 37 °C, rinsed and dried. After which the second color and translucency measurement was taken. After in-office bleaching with 40% H<sub>2</sub>O<sub>2</sub> Opalescence boost, a third color and translucency measurement was taken. CIE L\* a\* b\* system was used for measuring color change and translucency. Two-way ANOVA and paired *t*-test were used for statistical analysis at P ≤ 0.05. *Results:* After staining, all specimens showed clinically acceptable color change ( $\Delta E \leq 3.3$ ) with no significant differences between groups. After bleaching, all specimens showed clinically unacceptable color change ( $\Delta E > 3.3$ ) and significant differences between finished & polished and unfinished groups (P = 0.024). Nano-composites recorded significantly higher translucency than giomer (P = 0.000) except after bleaching. In addition, the translucency of unfinished groups were significantly higher than finished & polished groups (P = 0.001). *Conclusions:* The tested materials responded similarly to staining and bleaching. High concentration bleaching increased color change and reduced translucency. Finishing & polishing restorative materials improves their resistance to color change after bleaching, but it adversely affects translucency.

© 2018 The Author. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

\* Address: 39 Wezarat Al Zeraa, Doki, Giza Postal Code 12311, Egypt.

E-mail address: [iman.sayad@dentistry.cu.edu.eg](mailto:iman.sayad@dentistry.cu.edu.eg).

Peer review under responsibility of King Saud University.



Production and hosting by Elsevier

## 1. Introduction

The esthetic success of a restoration is directly related to its optical appearance (Hosoya et al., 2011). Color and translucency of esthetic restorations are crucial optical properties (Villarroel et al., 2011). To render a restoration imperceptible, restorative materials should reproduce both color and translucency of natural dentition and maintain long-term stability

and resistance to discoloration (Villalta et al., 2006). A number of parameters affect translucency of resinous restorations such as thickness (Arimoto et al., 2010), filler particles, opacifiers (Lee, 2008), and resin matrix composition (Azzopardi et al., 2009). Color stability is related to resin matrix, size of filler particles, degree of polymerization and coloring agents (Nasim et al., 2010). Extrinsic discolorations can be caused by dietary and smoking habits, bad oral hygiene and adsorption or absorption of water-soluble stains within the resin matrix (Bagheri et al., 2005). In addition, resin composites undergo superficial and microstructural changes after finishing and polishing procedures (Nasim et al., 2010).

Proper finishing and polishing of restorations enhance their esthetics and longevity (Jefferies, 2007). Finishing and polishing require the sequential use of gradually smaller grained abrasives to produce a glossy surface (Jones et al., 2004). Finishing and polishing composite restorations aims to adjust occlusion, to create a smooth, uniform, easily cleaned restoration, and to allow an adequate light reflection (Jefferies, 2007). Moreover, to eliminate the superficial resin layer which come in contact with oxygen and does not polymerize (Al-Fawaz and Awilya, 2003). This resin layer has a direct effect on the staining ability of resin composite (Scheie, 2003).

Size and shape of fillers affect surface morphology of composites after finishing procedures (Da Costa et al., 2007). Reducing filler size is expected to improve surface smoothness (Turssi et al., 2005). However, there is a controversy regarding the color stability of nano-filled composites (Lee et al., 2004, Cavalcante et al., 2009).

Pre-reacted glass ionomer filled composites (Giomers) are hybrid esthetic restoratives based on pre-reacted glass ionomer "PRG" technology in which pre-reacted glass ionomer cements are used as fillers (Tian et al., 2012). The surface reaction type (S-PRG) is based on forming a glass-ionomer phase only on the surface of a glass core layer by an acid-base reaction between polycarboxylic acid and special surface-fractured multifunctional fluoroboroaluminosilicate glass filler in presence of water (Hosoya et al., 2011). Staining potential of giomers has not been widely investigated, as well as their reaction to bleaching agents (Hosoya et al., 2011).

Stains can be removed partially or totally by brushing with toothpaste, repolishing, and bleaching (Celik et al., 2009). Bleaching has increased during the last decade with the advent of new in office and at home bleaching agents (Yilmaz et al., 2013). Thus, it is common to bleach restored teeth. Esthetic restorations might show changes due to the softening effect of bleaching which subsequently affect their clinical durability (Villalta et al., 2006). Studies by Rosentritt et al. (2005), Rao et al. (2009) have explained the color changes of resin composite after bleaching by the properties and quality of the polymer; type and quantity of the filler or type and concentration of bleaching agents.

Materials with different monomers may show different resistance to staining and bleaching (Prabhakar et al., 2010). Therefore, this in vitro study evaluated the effect of staining and in-office bleaching on color and translucency of finished and unfinished nano-filled resin composite and giomer. The first null hypothesis was that staining and bleaching have no effect on color of finished and unfinished tested materials. The second null hypothesis was that staining and bleaching have no effect on translucency of finished and unfinished tested materials.

## 2. Materials and methods

### 2.1. Preparation of the specimens

Two esthetic restorative materials, a nano-filled resin composite (Filtek Z350XT) and a giomer (Beautiful II), were tested in this study (Table 1). Twenty specimens, 10 mm in diameter and 2 mm thick, were fabricated from each material using a split Teflon mold. The mold was positioned on a transparent matrix band (Mylar, DuPont, Wilmington, Del.) over a glass slide and it was completely filled with the tested material as one increment. The mold was then covered with another matrix band and a glass slide. A 500 g weight was placed for 1 min on top to let the excess material extrude, compact the material and prevent void and bubble formation. Afterwards, the weight was removed and the tested restorative material was light cured using LED curing unit with an intensity of 1200 mW/cm<sup>2</sup> (Elipar™ S10 LED Curing Light, 3 M Company, St. Paul MN, USA). Curing was done for 40 s according to manufacturer instructions through the glass slide.

### 2.2. Finishing and polishing of specimens

Top surfaces of ten specimens from each material were finished using finishing discs (Sof-Lex™ Contouring and Polishing Discs Kit, 3 M Company, St. Paul MN, USA), while the other ten specimens were left unfinished. Coarse finishing discs were used for 15 s in a hand piece (MK-dent Germany, CE 0123, REF No. AM1014), using a low speed motor (STRONG, model no 204, Seoul South Korea) at 10,000 RPM with moderate pressure according to manufacturer instructions. Spiral finishing wheels (Sof-Lex™ Spiral Finishing and Polishing Wheels, 3 M ESPE Company) were then used for 30 s at 15,000 RPM, followed by spiral polishing wheels for 30 s at same speed. Specimens were then washed with distilled water for 30 s and blot dried with paper towels. An initial color and translucency parameter measurement was taken using a spectrophotometer (UV- Shimadzu 3101 PC, Japan) on a white and a black standard background plates as a baseline measurement before staining procedures. Prior to measuring, the spectrophotometer was calibrated on NPL (national physical laboratory) tiles. Measurements were repeated three times for each specimen; the mean and standard deviation of the readings were calculated. The wavelength scan in the measurements was carried out from 380 to 780 nm.

### 2.3. Staining method

Specimens were stained by preparing a coffee solution after mixing 3.6 g of coffee powder (Nescafe Classic, Nestle, Egypt) in 300 ml of boiling distilled water as per manufacturer's recommendation (Hafez et al., 2010). After 10 min of stirring, the solution was filtered using a filter paper (Hafez et al., 2010). Specimens were incubated in coffee for 48 h at 37 °C, and then they were gently rinsed with distilled water and air dried, after which, a second color and translucency measurement was taken.

### 2.4. Bleaching procedures

All specimens were subjected to bleaching using 40% H<sub>2</sub>O<sub>2</sub> Opalescence boost (Ultradent Products, Inc., South Jordan,

**Table 1** Tested materials used in the study.

Material	Category	Manufacturer	Composition	Batch no
Filtek Z350XT	Nanofilled resin composite	3 M ESPE, dental product, St. Paul, MN, USA	<b>Matrix:</b> Bis-GMA, UDMA, Bis-EMA 6, TEGDMA, and PEGDMA <b>Filler:</b> Non-agglomerated nano-particles of silica 20 nm in size, and nano-agglomerates formed of zirconia/silica particles ranging from 0.6 to 1.4 $\mu\text{m}$ (78.5% w/w, 63.3% v/v)	N500218
Beautiful II	Giomer nanohybrid restorative S-PRG technology	Shofu Dental Corporation, San Marcos, CA, USA	<b>Matrix:</b> Bis-GMA, TEGDMA, UDA <b>Filler:</b> Aluminofluoroboro-silicate glass, $\text{Al}_2\text{O}_3$ , size from 0.01 to 4.0 average 0.8 ( $\mu\text{m}$ ) DL- camphorquinone (70% w, 68.6% v)	020852
Opalescence boost	Bleaching system	Ultradent Products, Inc., South Jordan, Utah, USA	40% $\text{H}_2\text{O}_2$ -potassium nitrate-fluoride	84

Utah, USA.), which was applied on one surface of the specimens 3 times, each time for 15 min. The specimens were washed with distilled water for 1 min and blotted dry between applications. At the end of the bleaching procedures, specimens were washed under running water for 1 min and a third color and translucency measurement was taken.

### 2.5. Color and translucency measurements

An integrating sphere of 60 mm diameter was attached and installed in the sample compartment of the spectrophotometer to measure diffuse transmittance & diffuse reflectance of the sample with the use of beam switching software. The integrating sphere opening was 18 mm diameter on reflection side. The sample beam was at incident angle of  $0^\circ$  and the reference beam was at  $8^\circ$ . The CIE  $L^* a^* b^*$  parameters for each specimen were calculated in several steps via special software (MatLab) for the determination of color changes and translucency (Lee et al., 2007). Color is measured in three coordinate dimensions:  $L^*$  value refers to “lightness”; the higher the  $L$  value, the higher the lightness (a value of 100 corresponds to perfect white and that of zero to black); “ $a^*$ ” shows red color on positive values and green color on negative values ( $+a^* = \text{red}$ ;  $-a^* = \text{green}$ ); “ $b^*$ ” shows yellow color on positive values and blue color on negative values ( $+b^* = \text{yellow}$ ;  $-b^* = \text{blue}$ ) (Johnson and Kao, 1989). CIE  $L^* a^* b^*$  values were recorded and color changes ( $\Delta E$ ) were computed according to following formula (Villalta et al., 2006).

$(\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2})$  for each specimen. While the translucency parameter (TP) was calculated according to the equation (Johnston et al., 1995).

$\text{TP} = [(L_W^* - L_B^*)^2 + (a_W^* - a_B^*)^2 + (b_W^* - b_B^*)^2]^{1/2}$  where W refers to color for each specimen against the white background and B refers to color of the specimen against the black background. Higher TP values represent greater translucency.

### 2.6. Statistical analysis

Data were statistically analyzed using Minitab 17 statistical package for windows (Minitab Inc. Pennsylvania, USA). Normality of the data distribution was checked and parametric tests were chosen since the data were distributed normally. Two-way ANOVA was used to test the significance of staining

and bleaching at  $P < 0.05$ . Paired  $t$ -test was used for comparison between groups when significance was detected.

### 3. Results

According to color changes in esthetic restorations, three different intervals were used:  $\Delta E < 1$ , imperceptible by the human eye;  $1.0 < \Delta E < 3.3$ , appreciated only by a skilled person, clinically acceptable; and  $\Delta E \geq 3.3$ , easily observed, clinically unacceptable (Vichi et al., 2004). Mean and SD for color change results are shown in Table 2. After staining, all specimens showed clinically acceptable color change ( $\Delta E < 3.3$ ) and no significant differences were recorded between groups ( $p = 0.083$ ). However, after bleaching all specimens showed clinically unacceptable color change ( $\Delta E \geq 3.3$ ). The color change was significantly higher in unfinished groups than finished & polished groups ( $p = 0.024$ ). No significant difference was evident between restorative materials ( $p = 0.995$ ).

Mean and SD for translucency results are shown in Table 3. Statistical significant difference was exhibited between nano-composite and giomer ( $P = 0.000$ ) except after bleaching ( $p = 0.459$ ). In addition, significant difference between finished and unfinished groups was recorded ( $P = 0.001$ ). The highest TP values were recorded with unfinished nano-composite at baseline and after staining groups (10.24, 9.6) respectively. While the finished and polished nano-composite and giomer groups after bleaching recorded the lowest TP values (5.64, 5.73) respectively. Giomer groups showed significant differences in TP after staining and after bleaching compared to baseline TP values. The highest TP value among giomer groups was recorded with unfinished group after staining (7.6); the lowest was finished and polished group after bleaching (5.73). While nano-composite groups showed significant differences in TP after bleaching only compared to baseline. The highest TP value among nano-composite groups was exhibited with unfinished group after staining (9.6); the lowest was finished and polished group after bleaching (5.64). Baseline TP values of the tested materials were always higher than their corresponding stained and bleached groups. The highest TP values recorded at baseline was ranked as follows: unfinished nano-composite (10.24) > finished and polished nano-composite (9.14) > unfinished giomer (8.34) > finished and polished giomer (7.56).

**Table 2** Descriptive statistics (mean (SD)) and test of significance for color change ( $\Delta E$ ) values after staining and after bleaching of the tested materials.

Material	Finishing & polishing		P-value	After bleaching		P-value
	After staining			After bleaching		
	Finished & polished	Unfinished		Finished & polished	Unfinished	
Nano-composite	1.09(0.09)	1.15(0.11)	0.769	4.26(0.46)	4.75(0.22)	0.629
Giomer	1.03(0.17)	1.18(0.06)		4.34(0.30)	4.84(0.51)	
P-value	0.083		0.408	0.024*		0.995

\* Significant at  $P < 0.05$ .

**Table 3** Descriptive statistics (mean (SD)) and test of significance for TP values at baseline, after staining and after bleaching of the tested materials.

Variable	Baseline	After staining	After bleaching
Nano-composite finished & polished	9.14(0.33) <sup>ab</sup>	8.84(0.41) <sup>bc</sup>	5.64(0.26) <sup>f</sup>
Nano-composite unfinished	10.24(0.40) <sup>a</sup>	9.60(0.29) <sup>a</sup>	6.83(0.23) <sup>c</sup>
Giomer finished & polished	7.56(0.16) <sup>d</sup>	6.84(0.27) <sup>c</sup>	5.73(0.28) <sup>f</sup>
Giomer unfinished	8.34(0.30) <sup>c</sup>	7.60(0.31) <sup>d</sup>	6.55(0.21) <sup>e</sup>
P-value for material	0.000*	0.000*	0.459
P-value for finishing & polishing	0.001*	0.001*	0.000*

\* Significant at  $P < 0.05$ . Different letters indicate statistical significant difference.

#### 4. Discussion

Spectrophotometers and colorimeters have been widely used in measuring discoloration as they eliminate subjective errors (Joiner, 2004). Most of the color measurement devices utilized in dentistry use  $\Delta E$  from the *Commission Internationale de l'Eclairage CIE* ( $L^*a^*b^*$ ) color system to determine color changes because it is suitable for determination of small color differences (Khokhar et al., 1991). Its greatest advantage as a tool for representing and characterizing color is its uniformity and color values on the three axes are distributed closely with respect to the human perception of color (Pruthi et al., 2010). In this study, color and translucency are measured with a spectrophotometer and color change is expressed in  $\Delta E$  units which is the sum of change for each of  $L$ ,  $a$ , and  $b$  parameters as calculated mathematically between successive color measurements. There is a controversy in the clinically acceptable level of color change. Ideally, the stain removal process would be considered perfect if  $\Delta E$  is equal to zero (Nahedh and Awlyia, 2013). This means that the restorative material has returned to its baseline color before staining.

For achieving the desirable esthetics, the esthetic restoratives should be able to maintain intrinsic color stability and resistance to surface staining. However, with aging, restorations acquire external stains and develop internal discoloration. This may be explained by the biphasic nature of the material (composed of matrix and filler particles) which facilitates inclusion of external stains in its structure (Pruthi et al., 2010). Coffee which was used in this study is a commonly used beverage that has a strong potential to stain teeth and restoratives and have been used in many studies (Villalta et al., 2006; Celik et al., 2009; Hafez et al., 2010; Tian et al., 2012). According to coffee manufacturers, it takes an average of 15 min to drink a cup of coffee; coffee drinkers consume an average of 3.2 cups of coffee per day (Hafez et al., 2010). Thus, storage

for 48 h in coffee simulates an average of two months of coffee intake (Hafez et al., 2010).

The findings of this study showed that coffee induced clinically acceptable color change in all samples as  $\Delta E < 3.3$  (Table 2), this was in agreement with the studies of Fontes et al. (2009), Topcu et al. (2009), and Al-Samadani (2013). However, other studies (Villalta et al., 2006; Hafez et al., 2010; Tian et al., 2012) found that coffee had induced severe clinically unacceptable staining of resin composites and giomers. This discrepancy can be explained by the different staining methodologies followed in these studies. Some studies immersed the specimens in coffee for several weeks and others changed coffee daily with a freshly prepared one. Coffee may stain by adsorption and by absorption of its colorants onto/into the organic phase of composites (Hosoya et al., 2011). The increase in fluid uptake was found to be due to incorporation of hydrophilic monomers in the resin matrix. Bis-GMA and TEGDMA are hydrophilic monomers, but fluid uptake in Bis-GMA resins increased from 3 to 6%, while in TEGDMA it increased from 0 to 1% (Bagheri et al., 2005). Although Bis-GMA and TEGDMA are present in both tested materials in this study, their color change after staining was clinically acceptable. This low staining susceptibility can be attributed to low water absorption rate or low resin content and satisfactory gloss. Another possible cause is the presence of UDMA which is more stain resistant than Bis-GMA or TEGDMA because of its low water sorption and solubility (Khokhar et al., 1991). This can also indicate that freshly prepared nano-composites and giomers are color stable. This could be attributed to the uniform surface texture retained by nano-filled resinous materials even after finishing and polishing. Thus, coffee may have not caused intense staining which is expected with rough surfaces.

The interaction between bleaching agents and restorative materials is of clinical significance and should be focused on

Canay and Cehreli (2003). The bleaching procedure followed in this study simulated in-office bleaching using Opalescence boost, which is a chemically activated system with high hydrogen peroxide (40%) concentration. The first null hypothesis tested has to be rejected as staining and bleaching affected the color of nano-filled composite and giomer. The second null hypothesis was partially validated, as staining and bleaching affected the translucency of finished & polished and unfinished giomer compared to baseline translucency. However, the translucency of finished & polished and unfinished nano-filled composite was affected by bleaching only compared to baseline values.

On the other hand, after bleaching clinically unacceptable  $\Delta E$  values was gained. This increase in  $\Delta E$  values was mostly due to the marked increase in brightness ( $\Delta L$  values), which is a measure of illuminated reflectance (Mohammadi et al., 2012). A possible explanation for this color change after bleaching could be the low stain ability of the tested materials, indicated by low  $\Delta E$  values after staining. Thus, bleaching with a high  $H_2O_2$  % agent caused this marked lightening to the low stained specimens. This is consistent with reports that Bis-GMA based restoratives have shown color change in response to bleaching agents (Canay and Cehreli, 2003; Villalta et al., 2006). Other studies (Pruthi et al., 2010; Poggio et al., 2012) found that bleaching agents have returned  $\Delta E$  values of some of the tested materials to a clinically acceptable level even after severe color change due to staining. They attributed this to the superficial cleansing by bleaching agents. However, the findings by Rao et al. (2009), came in accordance with the current study, who found high  $\Delta E$  values for all tested materials after bleaching. They attributed this to the high concentration  $H_2O_2$  bleaching agent which may cause chemical softening of restorative materials (Yap and Wattanapayungkul, 2002). This also came in agreement with Nahedh and Awlyia (2013), who found that Opalescence Xtra Boost (38%  $H_2O_2$ ) did not return the tested restoratives to clinically acceptable  $\Delta E$  values. They suggested that a short and intense attack from a strong oxidizing agent would be less effective than a longer treatment with a lower  $H_2O_2$  % agent.

Finished groups showed significantly less color change compared to unfinished groups after bleaching ( $P = 0.001$ ). It is known that resinous restoratives exhibit an oxygen inhibited surface layer when cured in air. The surface obtained by using a Mylar matrix is rich in resin organic binder. The use of matrices eliminates the presence of an uncured surface layer. On the other hand, the surface beneath the matrix may not have the same degree of curing as the resin composite bulk that has not been exposed to oxygen during placement (Ergucu et al., 2007). Thus a possible explanation for this finding is that using a Mylar matrix had resulted in surfaces with lower degree of polymerization (Gordan et al., 2003). Monaghan et al. (1992) stated that breakdown of poorly polymerized resin matrix was one of the causes of color change in bleached composites. They also found that the oxidation of surface pigments and amine compounds has a role in color change. A second explanation may be that the organic matrix-rich surface layer of unfinished surfaces, cured with a matrix, stain by adsorption and absorption. This would cause swelling and separation between matrix and inorganic fillers (Nahedh and Awlyia, 2013), which makes them more vulnerable to bleaching.

Translucency is the ability of a material to allow light to pass through and thus allow the appearance of the underlying

background (Yu et al., 2009). It can be described as partial opacity or a state between complete opacity and complete transparency (Yu and Lee, 2008). A higher value for the translucency parameter (TP) represents greater translucency; if the material is completely opaque, TP value is zero (Yu and Lee, 2008). TP has been used in several researches to evaluate resin composites translucency (Arimoto et al., 2010; Li et al., 2010). Giomer groups showed a significant decrease in TP after staining ( $P = 6.84, 7.60$ ) when compared to corresponding baseline measurement ( $P = 7.56, 8.34$ ). While the nano-composite showed no significant difference when compared to baseline ( $p > 0.05$ ). This can be explained by the higher fillers content (78.5% w) and lower size (0.6–1.4  $\mu m$ ) in nano-composite compared to nano-hybrid giomer fillers content (70% w) and size (0.01–4.0  $\mu m$ ). Studies showed that the smaller the fillers size and the lower the organic matrix percentage, the lower the opacity level and the less staining potential (Fontes et al., 2009; Mitra et al., 2003).

In the present study, bleaching caused significant reduction in TP values in all groups compared to baseline and after staining values ( $P < 0.05$ ). This reduction may be due to increased reflectance indicated by the high  $\Delta L$  values. Yilmaz et al. (2013), found that bleaching did not affect translucency of resin composites. They attributed this to low concentrations of bleaching agents used. In the current study, it was interesting to observe that the TP of unfinished groups was significantly higher than their corresponding finished and polished groups at baseline, after staining and after bleaching. This could be explained by that Mylar matrix produced smoother surfaces with higher gloss than sof-Lex discs finished surfaces (Ergucu et al., 2007).

Using one staining solution was a limitation in the study. Immersion of esthetic restoratives in a single type of staining beverage does not reflect the actual staining potential of human dietary behavior. In addition, food and beverages ingestion is a dynamic process that does not allow sustained static retention of stain in the oral cavity (Ren et al., 2012). However, selecting an immersion period of 48 h in this study was to prevent precipitation of sediments with long standing in stagnation. Staining by long immersion has no resemblance to clinical realities, as clinically the exposure to stain is intermittent and the action of saliva or other fluids can dilute the stain.

## 5. Conclusions

Considering the limitations of this in vitro study, the following could be concluded:

1. The tested restorative materials reacted similarly to staining and bleaching.
2. The high concentration in office bleaching agent produced an increased color change and reduced translucency of the tested restorative materials.
3. Finishing and polishing restorative materials improves their ability to resist color change after bleaching, but it adversely affects their translucency.

## Conflict of interest

We have no conflict of interest to declare.

## References

- Al-Fawaz, A.A., Awilya, Y., 2003. The effect of three finishing systems on three esthetic restorative materials. *Saudi Dent J.* 15, 104–107.
- AL-Samadani, K.H., 2013. Color stability of restorative materials in response to Arabic coffee, Turkish coffee and nescafe. *J. Contemp. Dent. Pract.* 14, 681–890.
- Arimoto, A., Nakajima, M., Hosaka, K., Nishimura, K., Ikeda, M., Foxton, R.M., Tagami, J., 2010. Translucency, opalescence and light transmission characteristics of light cured resin composites. *Dent. Mater.* 26, 1090–1097.
- Azzopardi, N., Moharamzadeh, K., Wood, D.J., Martin, N., van Noort, R., 2009. Effect of resin matrix composition on the translucency of experimental dental composite resins. *Dent. Mater.* 25, 1564–1568.
- Bagheri, R., Burrow, M.F., Tyas, M., 2005. Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials. *J. Dent.* 33, 389–398.
- Canay, S., Cehreli, M.C., 2003. The effect of current bleaching agents on the color of light polymerized composites *in vitro*. *J. Prosthet. Dent.* 89, 474–478.
- Cavalcante, L.M., Masouras, K., Watt, D.C., Pimenta, L.A., Silicas, N., 2009. Effect of nanofillers' size on surface properties after tooth brush abrasion. *Am. J. Dent.* 22, 60–64.
- Celik, C., Yüzügüllü, B., Erkut, S., Yazici, A.R., 2009. Effect of bleaching on staining susceptibility of resin composite restorative materials. *J. Esthet. Restor. Dent.* 21, 407–414.
- Da Costa, J.D., Ferracane, J., Paravina, R.D., Mazur, R.F., Roeder, L., 2007. The effect of different polishing systems on surface roughness and gloss of various resin composites. *J. Esthet. Restor. Dent.* 19, 214–224.
- Ergucu, Z., Turkun, L.S., Aladag, A., 2007. Color stability of nanocomposites polished with one-step systems. *Oper. Dent.* 33, 413–420.
- Fontes, S.T., Fernández, M.R., Moura, C.M., Meireles, S.S., 2009. Color stability of a nanofill composite: effect of different immersion media. *J. Appl. Oral. Sci.* 17, 388–391.
- Gordan, V.V., Patel, S.B., Barrett, A.A., Shen, C., 2003. Effect of surface finishing and storage medium on bi-axial flexure strength and microhardness of resin-based composite. *Oper. Dent.* 28, 560–567.
- Hafez, R., Ahmed, D., Yousry, M., El-Badrawy, W., El-Mowafy, O., 2010. Effect of in-office bleaching on color and surface roughness of composite restoratives. *Europ. J. Dent.* 4, 118–127.
- Hosoya, Y., Shiraishi, T., Odatsu, T., Nagafuji, J., Kotaku, M., Miyazaki, M., Powers, J.M., 2011. Effects of polishing on surface roughness, gloss, and color of resin composites. *J. Oral. Sci.* 53, 283–291.
- Jefferies, S.R., 2007. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. *Dent. Clin. North Am.* 51, 379–397.
- Johnson, W.M., Kao, E.C., 1989. Assessments of appearance match by visual observation and clinical colorimetry. *J. Dent. Res.* 68, 819–822.
- Johnston, W.M., Ma, T., Kienle, B.H., 1995. Translucency parameter of colorants for maxillofacial prostheses. *Int. J. Prosthodont.* 8, 79–86.
- Joiner, A., 2004. Tooth color: review of literature. *J. Dent.* 32, 3–12.
- Jones, C.S., Billington, R.W., Pearson, G.J., 2004. The *in vivo* perception of roughness of restorations. *Br. Dent. J.* 196, 42–45.
- Khokhar, Z.A., Razzoog, M.E., Yaman, P., 1991. Color stability of restorative resins. *Quintessence. Int.* 22, 733–737.
- Lee, Y.K., 2008. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. *Dent. Mater.* 24, 1243–1247.
- Lee, W.K., Lu, H., Oguri, M., Powers, J.M., 2007. Changes in color and staining of dental composite resins after wear simulation. *J. Biomed. Mater. Res. B Appl. Biomater.* 82, 313–319.
- Lee, Y.K., Lim, B.S., Rhee, S.H., Yang, H.C., Powers, J.M., 2004. Changes of optical properties of dental nano-filled resin composites after curing and thermocycling. *J. Biomed. Mater. Res. B Appl. Biomater.* 71, 16–21.
- Li, Q., Xu, B.T., Li, R., Wang, Y.N., 2010. Spectrophotometric comparison of translucent composites and natural enamel. *J. Dent.* 38, e117–122.
- Mitra, S.B., Wu, D., Holmes, B.N., 2003. An application of nanotechnology in advanced dental materials. *J. Am. Dent. Assoc.* 134, 1382–1390.
- Mohammadi, N., Kimyai, S., Abed-Kahnamoii, M., Ebrahimi-Chaharom, M.E., Sadr, A., Daneshi, M., 2012. Effect of 15% carbamide peroxide bleaching gel on color stability of giomer and microfilled composite resin: An *in vitro* comparison. *Med. Oral. Patol. Oral. Cir. Bucal.* 17, e1082–1088.
- Monaghan, P., Trowbridge, T., Lautenschlager, E., 1992. Composite resin color change after vital tooth bleaching. *J. Prosthet. Dent.* 67, 778–781.
- Nahed, H.N., Awlyia, W.Y., 2013. The effectiveness of four methods for stain removal from direct resin-based composite restorative materials. *Saudi. Dent. J.* 25, 61–67.
- Nasim, I., Neelakantan, P., Sujeer, R., Subbarao, C.V., 2010. Color stability of microfilled, microhybrid and nanocomposite resins, an *in vitro* study. *J. Dent.* 38 (Suppl 2), e137–142.
- Poggio, C., Beltrami, R., Scribante, A., Colombo, M., Chiesa, M., 2012. Surface discoloration of composite resins: Effects of staining and bleaching. *Dent. Res. J. (Isfahan)* 9, 567–573.
- Prabhakar, S.R., Sahana, S., Mahantesh, T., Vishwas, T.D., 2010. Effects of different concentrations of bleaching agent on the micro hardness and shear bond strength of restorative materials – An *in vitro* study. *J. Dent. Oral. Hyg.* 2, 7–14.
- Pruthi, G., Jain, V., Kandpal, H.C., Mathur, V.P., Shah, N., 2010. Effect of bleaching on color change and surface topography of composite restorations. *Int. J. Dent.* Article ID: 695748.
- Rao, Y.M., Srilakshmi, V., Vinayagan, K.K., Narayanan, L., 2009. An evaluation of the color stability of tooth colored restorative materials after bleaching using CIELAB color technique. *Indian J. Dent. Res.* 20, 60–64.
- Ren, Y.F., Feng, L., Serban, D., Malmstrom, H.S., 2012. Effects of common beverage colorants on color stability of dental composite resins: The utility of a thermocycling stain challenge model *in vitro*. *J. Dent.* 40 (Suppl 1), e48–56.
- Rosentritt, M., Lang, R., Plein, T., Behr, M., Handel, G., 2005. Discoloration of restorative materials after bleaching application. *Quintessence. Int.* 36, 33–39.
- Scheie, A.A., 2003. The role of antimicrobials. In: Kidd, E., Fejerskov, O. (Eds.), *Dental Caries: The Disease and its Clinical Management*. Iowa, Blackwell Munksgaard, pp. 179–188.
- Tian, F., Yap, A.U.J., Wang, X., Gao, X., 2012. Effect of staining solutions on color of pre-reacted glass ionomer containing composites. *Dent. Mater.* J. 31, 384–388.
- Topcu, F.T., Sahinkesen, G., Yamanel, K., Erdemir, U., Oktay, E.A., Ersahan, S., 2009. Influence of different drinks on the colour stability of dental resin composites. *Eur. J. Dent.* 3, 50–56.
- Turssi, C.P., Ferracane, J.L., Serra, M.C., 2005. Abrasive wear of resin composites as related to finishing and polishing procedures. *Dent. Mater.* 21, 641–648.
- Vichi, A., Ferrari, M., Davidson, C.L., 2004. Color and opacity variations in three different resin-based composite products after water aging. *Dent. Mater.* 20, 530–534.
- Villalta, P., Lu, H., Okte, Z., Garcia-Godoy, F., Powers, J.M., 2006. Effects of staining and bleaching on color change of dental composite resins. *J. Prosthet. Dent.* 95, 137–142.

- Villarroel, M., Fahl, N., De Sousa, A.M., De Oliveira Jr, O.B., 2011. Direct esthetic restorations based on translucency and opacity of composite resins. *J. Esthet. Restor. Dent.* 23, 73–77.
- Yap, A.U., Wattanapayungkul, P., 2002. Effects of in-office tooth whiteners on Hardness of tooth colored restorations. *Oper. Dent.* 27, 137–141.
- Yilmaz, S.K., Cengiz, E., Ulusoy, N., Ozak, S.T., Yuksel, E., 2013. The effect of home-bleaching application on the color and translucency of five resin composites. *J. Dent.* 41, e 70–75.
- Yu, B., Lee, Y.K., 2008. Translucency of varied brand and shade of resin composites. *Am. J. Dent.* 21, 229–232.
- Yu, B., Ahn, J.S., Lee, Y.K., 2009. Measurement of translucency of tooth enamel and dentin. *Acta Odontol. Scand.* 67, 57–64.