ORIGINAL ARTICLE

# Effects of staining solutions on the discoloration of orthodontic adhesives: An in-vitro study

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**Introduction:** Our aim was to evaluate the effects of staining solutions on the discoloration of orthodontic adhesives. **Methods:** Six orthodontic adhesives were investigated (Transbond XT [3M Unitek, Monrovia, Calif, USA], Heliosit Orthodontic [Ivoclar Vivadent, Liectenstein], Light Bond [Reliance Orthodontic Products, Itasca, IL, USA], Bisco Ortho [Bisco, Schamburg, IL, USA], Quick Cure [Reliance Orthodontic Products, Itasca, IL, USA], and Filtek Supreme XT [3M ESPE, St Paul, Minn, USA]), and 5 beverages (tea, cola, coffee, red wine, and yogurt). Sixty specimens were prepared. Five specimens from each group were stored in each of the 5 staining solutions. The 5 remaining specimens from each group served as the controls and were stored in distilled water. The specimens were immersed in staining solutions and water at 37°C ± 1°C for 5 days. The test period was 25 days. Before and after the test period, color measurements were carried out with a spectrophotometer, and color changes (ΔE*) were calculated. Statistical differences were evaluated by using analysis of variance (ANOVA) and the Tukey HSD tests. **Results:** Adhesive materials, staining agents, and their interactions were found to play statistically significant roles ($P < 0.001$) in color changes. Among the adhesive materials, the Light Bond water control group consistently showed the lowest ΔE* value for all materials, and the Filtek Supreme XT group showed the highest ΔE* value for all materials. After the in-vitro experimental process for staining solutions and water, unsatisfactory color stability was observed for the conventional adhesive systems except for Light Bond, Transbond XT, and Bisco Ortho water control group (ΔE* >3.7), respectively. **Conclusions:** In esthetically critical areas, discoloration of adhesive materials for fixed orthodontics can cause patient dissatisfaction. Orthodontic composites will discolor from staining beverages during their lifespan. (Am J Orthod Dentofacial Orthop 2010;138:741-6)

For over 60 years, resin-based adhesive composites have been used for direct or indirect bonding of orthodontic attachments to teeth for orthodontic purposes. Most orthodontic adhesives are variations on adhesive and direct-restorative formulations produced for use in restorative dentistry.[1,2]

Direct bonding of orthodontic brackets to teeth has been an important subject in orthodontic research, because of the significance of a stable bond between a tooth etched with phosphoric acid and its bracket.[3] Most studies in the orthodontic literature have focused on evaluation of the physical and mechanical properties of adhesives resins. However, discolorations of resin-based adhesive composites have been investigated in only a few studies.[2,4,5] A study showed that orthodontic bracket bonding and debonding can cause changes in the appearance of tooth enamel.[2] In addition to the formation of structural and surface defects, some variables—eg, enamel loss caused by etching—can affect the enamel color, inducing various alterations on the enamel surface, including white spots.[6] Although there are many findings about enamel white spot formation associated with orthodontic treatment, the incidence of enamel color changes caused by orthodontic bonding and debonding protocols has interested only a few investigators.[2,4,5] There is some evidence that adhesive resin tags could reach a depth of 50 μm in the enamel.[4] As a result of these parameters, debonding and cleaning protocols cannot reverse adhesive resin impregnation into the enamel.[4] Enamel discolorations can occur by direct absorption of food colorants and products from the corrosion of orthodontic appliances.[7] The long-term presence of these resin residues in the enamel tags that extend over the middle third of the buccal surface makes the color stability of these materials critical for tooth color.[5]

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**Table I.** Adhesive resins in this investigation

| *Product* | *Material type* | *Manufacturer* |
|---|---|---|
| Bisco Ortho | Bis-GMA (15%-40%), TEG-DMA (5%-15%), fused silica (30%-60%) | Bisco, Schaumburg, Ill<br>Lot no: 0600004598 |
| Heliosit Orthodontic | UDMA, Bis-GMA and decandiol-DMA (85%), dispersed silicon dioxide (14%), catalysts and stabilizers (1%) | Ivoclar Vivadent, Liechtenstein<br>Lot no: G21064 |
| Light Bond | UDMA, TEG-DMA (22%), fused silica, sodium fluoride (78%) | Reliance Orthodontic Products, Itasca, Ill<br>Lot no: 0609234 |
| Quick Cure | Silica-crystalline, silica-fused (50%-90%), Bis-GMA (1%-10%), TEG-DMA (5%-10%), sodium fluoride (0.1%-2.0%) | Reliance Orthodontic Products, Itasca, Ill<br>Lot no: 0604936 |
| Transbond XT | Bis-GMA (5%-10%), Bis-EMA (10%-20%), TEG-DMA (5%-10%), silane-treated quartz (70%-80%), silane-treated silica (2%) | 3M Unitek, Monrovia, Calif<br>Lot no: 6CX6WM0088 |
| Filtek Supreme | Bis-GMA, TEG-DMA, and Bis-EMA (35%), zirconia-silica (65%) | 3M ESPE, St Paul, Minn<br>Lot no: 6BY3910A1E |

The color stability of resin-based adhesive composites might be affected by external and internal factors.[8] External influences are colored mouth rinses and staining foods (such as coffee and red wine),[2,9,10] matrix (hydrophobic or hydrophilic),[8,11] and type of filler particles (organic, inorganic, silica gel, silane coupling agent, and size).[8,12] The material's superficial roughness has an important role in the color changes of adhesive composites influenced by the different materials.[2,8,10] A number of factors influence the extent of discoloration of photo-curing materials, such as the adsorption of dyes or plaques,[13] water sorption,[8,11,13] incomplete polymerization,[14] photo-initiator components (eg, camphorquinone), resin matrix composition, light-curing devices, and irradiation times.[12] The proof for internal color change of adhesive materials can be found in the aging under various physical and chemical conditions, such as humidity, ultraviolet irradiation, and thermal changes.[15] The system of photo-initiators used in adhesive composite as well as on the applied form and the time span of curing have a certain effect on the discoloration of the material.[16] They are induced by chemical changes in the materials' matrices and hence affect all layers of the material; they cause irreversible discolorations in the polymer.[2] There are 2 investigations about the influence of the ultraviolet light exposure on discoloration of orthodontic adhesives and its effect on the change of tooth color.[4,5]

In esthetically critical areas, resin-based adhesive materials must maintain not only the attachment of orthodontic appliance but also an esthetic appearance over the period of service. Discoloration of adhesive materials for fixed orthodontics can cause patient dissatisfaction; this is especially problematic when orthodontic adhesives are subjected to prolonged exposure to staining materials during lengthy treatment. Hence, the color change might be an important criterion in the selection of a particular orthodontic adhesive material for use in an esthetically critical area. Therefore, the aim of the study was to evaluate the combined effect of 5 staining beverages on the discoloration of orthodontic adhesives.

## MATERIAL AND METHODS

The resin-based adhesive composites investigated were Bisco Ortho (Bisco, Schaumburg, Ill), Heliosit Orthodontic (Ivoclar Vivadent, Liechtenstein), Light Bond (Reliance Orthodontic Products, Itasca, Ill), Quick Cure (Reliance Orthodontic Products), Transbond XT (3M Unitek, Monrovia, Calif), and Filtek Supreme (3M ESPE, St Paul, Minn) to test for color changes (Table I). An Elipar FreeLight 2 (3M ESPE) was the light-curing device for preparing the light-polymerizing specimens. The specimens were stored in common colored beverages; for the control group, distilled water was used. The drinks were black tea, black coffee, yogurt, red wine, and a soft drink based on cola (Table II).

Sixty cylindrical specimens (10 for each adhesive group) were manufactured in polytetrafluoroethylene molds at room temperature. Each disk had a diameter of 6 mm and a depth of 1 mm. The manufacturers' instructions were used for preparing, handling, and polymerizing the materials. The mold was filled with material, and the upper and lower surfaces of the mold were covered by 2 glass slides (3 mm). These slides were gently pressed together for removing excess test material. The specimens were cured with the light-emitting diode device having a tip of 8 mm with light intensity of 1200 mW per square centimeter. Standardization of the distance between the light source and the specimen was provided by the thickness of glass slide, which also provided a smooth surface for testing. The specimens were then immersed in distilled water at 37°C ± 1°C for 24 hours for complete polymerization.

Sixty specimens of each adhesive composite resin were divided into 6 groups (n = 10) for staining.

**Table II.** Staining beverages used in the investigation

| *Product* | *Material type* | *Manufacturer* |
|---|---|---|
| Cola Turka | Cola | Ulker Food, İstanbul, Turkey |
| Altınbas | Black tea | Caykur, Rize, Turkey |
| Nescafe Classic | Coffee | Nestle, Vevey, Switzerland |
| Seker Sut | Natural yogurt | Seker Sut, Konya, Turkey |
| Dikmen | Red wine | Kavaklıdere, Ankara Turkey |

Five randomly selected specimens from each group were stored in each of the 5 staining solutions. The 5 remaining specimens from each group were the controls and were stored in distilled water. The specimens were immersed in the staining solutions and water at 37°C ± 1°C for 5 days. The test period was 25 days. The solutions and water were changed daily. The black tea and coffee were prepared with boiled distilled water according to the manufacturer's suggested concentrations. The yogurt, red wine, and cola came from the market ready to drink. The solutions (50 mL for each) and the specimens were placed in small receptacles. After 1 day in the solutions, the specimens were gently rinsed with distilled water for 5 minutes and dried with tissue paper.

The baseline color of all specimens was measured with a colorimeter (Vita Easyshade, Vita Zahnfabrik H. Rauter, Bad Sackingen, Germany) against a white background according to the system of the Commission Internationale de l'Eclairage (CIE) —L*, a*, b*—after 24 hours of storage in distilled water.[17] All measurements were repeated 3 times, and averages for the values of L*, a*, and b* were evaluated. After all discoloration processes, final color measurements was carried out.

The CIE system uses the 3-dimensional colorimetric measurements: L* values correspond to the brightness of a color, a* values to the red-green content, and b* values to the yellow-blue content. The color changes (ΔE*) were calculated from the L*, a*, and b* values for each specimen according to the following formula, which determines the 3-dimensional color space:

$$\Delta E^* = \left[(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)\,2\right]^{1/2}$$

A perceptible color change that is ΔE* >1.0 will be referred to as acceptable up to the value ΔE* = 3.7 in subjective visual determinations made in vitro under optimal lighting conditions.

### Statistical analysis

The descriptive analysis was determined for the control and treatment groups. Statistical differences were evaluated by using 2-way analysis of variance (ANOVA) and the Tukey HSD tests for adhesive materials with statistical software (SPSS for Windows, version 13.0, SPSS, Chicago, Ill). The significance level was set at $\alpha = 0.05$.

**Table III.** ANOVA table for the adhesive resins and staining beverages

| *Variable (source)* | *df* | *SS* | *MS* | *F* | P* |
|---|---|---|---|---|---|
| Treatment | 11 | 12771.47 | 1161.04 | 334.45 | <0.000 |
| Residual | 48 | 166.64 | 3.47 | | |
| Total | 59 | 129.10 | | | |

*SS,* Sum of squares; *MS,* mean square.
*The probability that the results could have occurred by random sampling distribution.

## RESULTS

According to the ANOVA, the adhesive materials, staining beverages, and their interactions were statistically significant ($P = 0.000$) in the color changes (Table III). Mean values and standard deviations of ΔE* values for intervals of baseline and staining, and group differences of orthodontics adhesive materials are listed in Tables IV and V. After day 25 of the staining period, all adhesive materials had perceptibly significant discolorations (ΔE* >3.7) in the treatment (staining solutions) groups. Filtek Supreme was the most affected of the adhesive materials, and Quick Cure was the least affected (Table IV). Overall, the control group (distilled water) had less discoloration than the adhesive materials, but 3 tested composites (Filtek Supreme, Heliosit Orthodontic, Quick Cure) had perceptibly significant discolorations (ΔE* >3.7) (Table V). Light Bond's water control group consistently showed the lowest ΔE* value of all adhesive materials. On the other hand, the Filtek Supreme group showed the highest ΔE* value of all the adhesive materials. After the in-vitro experimental immersion in staining solutions and water, unsatisfactory color stability was observed for the conventional adhesive systems except for Light Bond, Transbond XT, and Bisco Ortho water control groups (ΔE* ≤3.7).

## DISCUSSION

In the literature, there are many studies about discoloration of adhesive resins by staining beverages such as tea, coffee, red wine, yogurt, cherry juice, and cola. But in these studies generally, colorant beverages were investigated one by one; in other words, adhesive resin samples were prepared for discoloration, and the first group was immersed in coffee, and the second group was immersed in tea, and so on. Thus, the effects of

**Table IV.** Difference between ΔE of treatment groups (n = 30) in this investigation and the threshold for clinical detection and Tukey HSD grouping

| Adhesive | ΔE* Mean | ΔE* SD | ΔE threshold for clinical detection | P | Tukey grouping† |
|---|---|---|---|---|---|
| Filtek Supreme | 46.74 | 2.21 | 3.7 | <0.000 | A |
| Light Bond | 34.38 | 2.21 | 3.7 | <0.000 | B |
| Bisco Ortho | 33.42 | 3.02 | 3.7 | <0.000 | B |
| Transbond XT | 27.35 | 2.62 | 3.7 | <0.000 | C |
| Heliosit Orthodontic | 25.87 | 2.36 | 3.7 | <0.000 | C |
| Quick Cure | 24.58 | 2.42 | 3.7 | <0.000 | C |

†Means with same letter are not significantly different at the α = 0.05 level.

**Table V.** Difference between ΔE of control groups (n = 30) in this investigation and the threshold for clinical detection and Tukey HSD grouping

| Adhesive | ΔE* Mean | ΔE* SD | ΔE threshold for clinical detection | P | Tukey grouping† |
|---|---|---|---|---|---|
| Quick Cure | 10.86 | 0.70 | 3.7 | <0.000 | A |
| Heliosit Orthodontic | 5.92 | 0.63 | 3.7 | <0.000 | B C |
| Filtek Supreme | 5.11 | 0.35 | 3.7 | <0.000 | B C |
| Bisco Ortho | 3.57 | 1.21 | 3.7 | NS | C |
| Transbond XT | 3.49 | 0.93 | 3.7 | NS | C |
| Light Bond | 2.12 | 0.94 | 3.7 | NS | C |

*NS*, Not significant.
†Means with same letter are not significantly different at the α = 0.05 level.

the staining solutions were compared separately, and the last word was that the first solution changed the color of the composite more than the second one. One study reported that coffee and tea caused clinically unacceptable color changes, and coffee had more staining capacity than tea.[18] Another study came to the same conclusion.[19] A study about discoloration reported that mouth rinse, tea, coffee, and red wine caused changes in color, and red wine caused the greatest changes.[20] Some authors supported these findings.[21,22] Nicotine, coffee, tea, and colored drinks were reported in other studies for discoloration of adhesive resins.[21,23] Also, a prolonged treatment period of adhesive resins in water might affect their color irreversibly, because of the internal chemical characteristics.[21,24] In spite of this, another study reported clinically acceptable and imperceptible color changes for water treatment of composites.[22]

In this study, 6 dental composites were investigated from the view of color stability. Five were fluid bonding resins for orthodontic bonding, and 1 was resin composite (Filtek Supreme). The unique characteristic of this study was the investigation of the cumulative effect of the colorant solutions on the dental composites. For this purpose, the composites resins were used for 25 days of immersion treatments. The cumulative effects of the staining solutions on the adhesive resins were evaluated after 25 days, since composites are subjected to staining substances not only at different times of the day, but also from many colored beverages and foods in the daily diet. In other words, orthodontic composites remain in the oral cavity for many months, with various staining substances at different times and periods. That process might produce synergetic or counter-effects on the color of the orthodontic composites such as darkening[25] or increased opacity.[5,10] But the cumulative discoloration protocol used this investigation might not dependably simulate the micro-environmental conditions of the oral cavity.

Color changes can be determined with various procedures, including spectrophotometric and visual. Visual investigation is not useful or even possible for the quantitative evaluation of minimal color changes and differences. The results of visual color comparisons are too subjective because of the investigator's personal opinion, and, therefore, the reproducibility of these investigations is low.[26] By using standardized color-quantifying devices such as the spectrophotometer, Vita Easyshade, reproducible, metric, objective, and statistically usable results of color determinations can be obtained. This testing design was based on that of Yannikakis et al[18] and combined with other designs for using artificial treatment to examine color changes of adhesive materials.[2,5]

The parameter ΔE* indicates relative color changes that an investigator could use for the materials before and after treatment or between intervals. In this study, the discoloration was set at 3.7 because Johnston and Kao[26] and other authors[2,5] stated that the average color between compared dental materials was a match in the oral environment at 3.7 (ΔE*). Thus, color changes below or above the value of ΔE* = 3.7 are considered acceptable or unacceptable, respectively.

Time is a major factor for changing the optical properties of adhesive resins. Also, the quality of polymerization type, light activation conditions, curing time, filler particles of the matrix of adhesive resins, actual colors of the surface, type of staining agent, and immersion procedures also affect and alter the optical properties.[8,18] The color changes of polymeric materials might be caused by external or internal influences. External

influences for color changes include staining by superficial adsorption or absorption of pigments from food dyes, tea, nicotine, colored beverages, and so on. Internal factors for color changes are directly related to changes of chemical structures of the adhesive materials; these are irreversible.[5] Oxidation of the polymer matrix or oxidation of the double bonds of the matrix in the adhesive resin are related to chemical discolorations.[27] Problems involved with insufficient polymerization include poor physico-chemical properties, increased solubility in the oral environment, increased microleakage, and consequent color changes.[12] Also, the inorganic filler content of the adhesive resin, including the type and the amount, affects color stability.[28] An adhesive resin with fewer inorganic filler might absorb a staining substance such as coffee or cola more easily than higher filled polymers.[2,22,29] But in our study, although the orthodontic composites Quick Cure, Transbond XT, and Bisco Ortho have the same amount of filler content, their discolorations were different. According to these results, discoloration of orthodontic composites does not depend only on the amount of filler content but also on the type of filler and monomer, the connection capacity of monomer to filler, the degree of conversion, and so on.

Water sorption characteristics of the adhesive resins are affected by hydroxyl, carboxyl, and phosphate groups in monomers and their resultant polymers, and thus they acquire more hydrophilic behavior.[30] The adhesive resins' color could be affected irreversibly from their immersion in water for a long time,[24,27,31] because of high levels of water absorption.[32] The action of water facilitates the penetration of the beverage component into the adhesive resin because of the hydrophilic behavior of the polymeric matrix[33]; this results in discoloration of the adhesive resin.[12]

From our study, 3 brands of adhesive resins from the water control groups showed clinically acceptable and imperceptible color changes after treatment. The other 3 showed greater discolorations. Quick Cure from the water control group had the greatest color change. The $\Delta E^*$ values were 5.11, 5.92, and 10.86 for the discolorated composites Filtek Supreme, Heliosit Orthodontic, and Quick Cure, respectively. For the higher water discolorations of the control groups, there might be several explanations in the literature. Yannikakis et al[18] stated that a composite-based resin demonstrated clinically unacceptable color changes with water for 7 and 30 days of treatments. There might be a number of reasons for the excessive color changes: unreacted double bonds,[27] prolonged periods in water,[21,31] hydrophilic behavior of the polymeric matrix,[33] and the inorganic filler composition of the composites.[28,29]

The color of all adhesives in the stained groups changed dramatically after treatment. Discoloration rates were high. Filtek Supreme had a high rate of discoloration. Although Quick Cure was the most discolored adhesive resin in the water control groups, it was the lowest one in the stained groups after treatment. As mentioned before, discoloration of composite resins with staining solutions depended on the material.[22,34] The resin matrix or filler content of a composite resin might affect its staining capacity. According to the manufacturer's declaration, Filtek Supreme is a nanocomposite with a primary 20-nm silica filler and loosely bonded cluster zirconia-silica particle size ranging from 0.6 to 1.4 mm. For example, Villalta et al[22] investigated Filtek Supreme for discoloration and concluded that, because of its composition, Filtek Supreme demonstrated high discoloration rates, similar to other authors' findings.[29,34] Filtek Supreme is a filling composite material for enamel in conservative dentistry and was used in this study as a control and for comparison with the fluid bonding resins of orthodontics.

## CONCLUSIONS

Within the limitations this study, the following conclusions can be drawn.

1. Orthodontic composites will discolor from staining beverages during their lifespan.
2. Discoloration of orthodontic composites is complex, affected by the inorganic filler content of composite, monomer type, polymerization degree, and many other factors.
3. In esthetically critical areas, discoloration of adhesive materials for fixed orthodontics might cause patient dissatisfaction. The patient's oral hygiene is an important factor for preventing color changes of the orthodontic composite.

In future clinical studies, orthodontic composites should be investigated for the level of discoloration they cause to the esthetics of tooth enamel.

## REFERENCES

1. Ferracane JL. Correlation between hardness and degree of conversion during the setting reaction of unfilled dental restorative resins. Dent Mater 1985;1:11-4.
2. Faltermeier A, Behr M, Mussig D. In vitro colour stability of aesthetic brackets. Eur J Orthod 2007;29:354-8.
3. William A, Brantley TE. Orthodontic materials: scientific and clinical aspects. Stuttgart, Germany: Thieme; 2001.
4. Eliades T, Kakaboura A, Eliades G, Bradley TG. Comparison of enamel colour changes associated with orthodontic bonding using two different adhesives. Eur J Orthod 2001;23:85-90.

5. Eliades T, Gioka C, Heim M, Eliades G, Makou M. Color stability of orthodontic adhesive resins. Angle Orthod 2004;74:391-3.
6. Ogaard B. Prevalence of white spot lesions in 19-year-olds: a study on untreated and orthodontically treated persons 5 years after treatment. Am J Orthod Dentofacial Orthop 1989;96:423-7.
7. Maijer R, Smith DC. Corrosion of orthodontic bracket bases. Am J Orthod 1982;81:43-8.
8. Dietschi D, Campanile G, Holz J, Meyer JM. Comparison of the color stability of ten new-generation composites: an in vitro study. Dent Mater 1994;10:353-62.
9. Khokhar ZA, Razzoog ME, Yaman P. Color stability of restorative resins. Quintessence Int 1991;22:733-7.
10. Leibrock A, Rosentritt M, Lang R, Behr M, Handel G. Colour stability of visible light-curing hybrid composites. Eur J Prosthodont Restor Dent 1997;5:125-30.
11. Ameye C, Lambrechts P, Vanherle G. Conventional and microfilled composite resins. Part I: color stability and marginal adaptation. J Prosthet Dent 1981;46:623-30.
12. Betsy KM, Luiz RDMCA, Luiz Henrique M. Prates, Jose Roberto Bertolino, Alfredo T.N. Pires. Influence of drinks on resin composite: evaluation of degree of cure and color change parameters. Polymer Testing 2007;26:438-444.
13. 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;87:264-70.
14. Ferracane JL. Current trends in dental composites. Crit Rev Oral Biol Med 1995;6:302-18.
15. Iazzetti G, Burgess JO, Gardiner D, Ripps A. Color stability of fluoride-containing restorative materials. Oper Dent 2000;25:520-5.
16. Janda R, Roulet JF, Kaminsky M, Steffin G, Latta M. Color stability of resin matrix restorative materials as a function of the method of light activation. Eur J Oral Sci 2004;112:280-5.
17. Colourimetry. Official recommendations of the Commission Internationale de l'Eclairage. Supplement 21. Paris, France: Commission Internationale de l'Eclairage; 1978. p. 15-30.
18. Yannikakis SA, Zissis AJ, Polyzois GL, Caroni C. Color stability of provisional resin restorative materials. J Prosthet Dent 1998;80:533-9.
19. Scotti R, Mascellani SC, Forniti F. The in vitro color stability of acrylic resins for provisional restorations. Int J Prosthodont 1997;10:164-8.
20. Stober T, Gilde H, Lenz P. Color stability of highly filled composite resin materials for facings. Dent Mater 2001;17:87-94.
21. Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. Quintessence Int 1991;22:377-86.
22. Villalta P, Lu H, Okte Z, Garcia-Godoy F, Powers JM. Effects of staining and bleaching on color change of dental composite resins. J Prosthet Dent 2006;95:137-42.
23. Prayitno S, Addy M. An in vitro study of factors affecting the development of staining associated with the use of chlorhexidine. J Periodontal Res 1979;14:397-402.
24. Asmussen E, Peutzfeldt A. Influence of UEDMA BisGMA and TEGDMA on selected mechanical properties of experimental resin composites. Dent Mater 1998;14:51-6.
25. Kolbeck C, Rosentritt M, Lang R, Handel G. Discoloration of facing and restorative composites by UV-irradiation and staining food. Dent Mater 2006;22:63-8.
26. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819-22.
27. Ruyter IE. Composites—characterization of composite filling materials: reactor response. Adv Dent Res 1988;2:122-9.
28. Eldiwany M, Friedl KH, Powers JM. Color stability of light-cured and post-cured composites. Am J Dent 1995;8:179-81.
29. Lee YK, Lu H, Powers JM. Effect of surface sealant and staining on the fluorescence of resin composites. J Prosthet Dent 2005;93:260-6.
30. Santerre JP, Shajii L, Leung BW. Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products. Crit Rev Oral Biol Med 2001;12:136-51.
31. Asmussen E. An accelerated test for color stablity of restorative resins. Acta Odontol Scand 1981;39:329-32.
32. Khan Z, Razavi R, von Fraunhofer JA. The physical properties of a visible light-cured temporary fixed partial denture material. J Prosthet Dent 1988;60:543-5.
33. Luiz BKM, Amboni RDMC, Prates LHM, Bertolino JR, Pires ATN. Influence of drinks on resin composite: evaluation of degree of cure and color change parameters. Polymer Testing 2007;26:438-44.
34. Abu-Bakr N, Han L, Okamoto A, Iwaku M. Color stability of compomer after immersion in various media. J Esthet Dent 2000;12:258-63.