Color Stability of Denture Acrylic Resins and a Soft Lining Material Against Tea, Coffee, and Nicotine

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Abstract

Purpose: The purpose of this study was to investigate the effect of four solutions [saliva (control group), saliva+tea, saliva+coffee, saliva+nicotine] on the color of different denture base acrylic resins (heat-polymerized, injection-molded, autopolymerized) and a soft denture liner.
Materials and Methods: Twenty specimens from each type of test material were prepared (2.5 mm diameter, 2 mm thickness). Five specimens from each test material (heat-polymerized, chemically polymerized, injection-molded acrylic resin, soft denture reliner) were stored in each solution in 37°C in a dark environment. Colorimetric measurements were done on the 1st, 7th, and 30th days. Color differences among specimens immersed in saliva (control group), and staining solutions were evaluated over time. Data were statistically analyzed with one-way analysis of variance (ANOVA) ($\alpha = 0.05$). ANOVA was followed by Tukey test to find which groups differed from each other.
Results: Significant color shifts occurred in heat-polymerized and injection-molded acrylic resins in coffee and in soft liner in nicotine over time ($p < 0.05$) ($\Delta E > 1$). The color shift of soft liner in nicotine was significantly different than that of the remainder of the test materials in nicotine ($p < 0.05$). The color shift magnitudes of each test material in coffee and tea were not significantly different when compared among the test material groups ($p > 0.05$).
Conclusions: The effect of staining solutions on the color of each test material in each session was perceivable by the human eye ($\Delta E > 1$); however, the color shifts of all test materials were clinically acceptable ($\Delta E < 3.7$) except for soft liner in nicotine, which was not clinically acceptable over time. Therefore, minimizing drinking of such beverages and use of tobacco, particularly when soft liner is applied, may be advantageous for denture wearers for long-term color stability.

Poly(methyl methacrylate) (PMMA) resin has been successfully used for various applications in dentistry for many years. It has many advantages, particularly its appearance and ease of manipulation, but it still has certain poor mechanical properties. Fractures may occur during use due to unsatisfactory impact and transverse strength.[1] Dimensional stability is of considerable importance as a clinical problem as well. Therefore, in the clinical practice of dentistry, there are many circumstances in which the need to adjust denture base acrylic resin is necessary. Chemically activated resins are widely used to reduce the processing time and provide rapid delivery. These materials react chemically to initiate the polymerization reaction; however, physical properties of these materials have been found to be unfavorable in previous studies.[2]

To overcome some of these disadvantages of conventional compression molding, an injection-molded technique was attempted for introducing unpolymerized acrylic resin into the mold. A spring mechanism applying continuous hydraulic pressure to a reservoir of unpolymerized resin was used to compensate for the polymerization shrinkage. Recently, a number of dental manufacturing companies have introduced injection-molded systems, and the method is more commonly used.[3-5] Injection-molded denture bases have the advantages of dimensional accuracy, low free-monomer content, and good impact strength, but have the disadvantages of capital equipment costs, low craze resistance, and difficulties associated with attachment of teeth to the denture bases.[6-9]

Patients who suffer from fragile supporting mucosa, excessive residual ridge resorption, substantial undercuts, and traumatic or pathologic tissue loss cannot tolerate a conventional hard denture base.[10] The clinician may recommend soft liners whose clinical use was first reported in 1943.[11] Since then, the use of soft liners has become increasingly popular for providing comfort for denture wearers; however, a number of problems associated with the use of soft denture liners have been reported, such as hardening with time (or loss of softness), colonization by microorganisms, poor tear strength, and color changes.[12-15] The color and appearance of denture teeth is certainly an important property of a denture; however, the denture base material should also match the color and appearance of the underlying tissues.[16] Color stability is one of the most important clinical properties for all dental materials,[1-18] and color changes are indicators of aging or damaging of the materials.[19] Several factors may contribute to the discoloration of dental materials after long-term use. These factors include stain accumulation, water sorption, dissolution of the ingredients, degradation of intrinsic pigments, and surface roughness. It is well known that beverages such as tea, coffee, wine, and some artificial dyes used in food may increase the discoloration of both denture base polymers and soft denture liners. Some authors have investigated the color changes of soft liners accompanied with their aging, and a marked change in their properties, particularly in acrylic liners, was reported to be caused by absorption of water or solubilization in distilled water[19,20] in periods of 4 to 8 months.

To determine and quantify the changes in the color of dental materials, an understanding of color space and differential colorimetry is required. Current photometric and colorimetric instruments are capable of reliably quantifying the color of acrylic resin specimens.[21] Photometric and colorimetric instruments measure color and express it in terms of three coordinate values (L^*, a^*, b^*), which locate the object's color within the CIELAB color space.[22] The L^* coordinate represents the brightness of an object, the a^* value represents the red or green chroma, and the b^* value represents the yellow or blue chroma. The color difference (ΔE) of two objects can then be determined by comparing the differences between respective coordinate values for each object. The formula used for calculating color differences in this system is[22]

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

where L^*, a^*, and b^* are differences in color parameters for the two specimens measured for comparison. Numeric description of color permits precise definition of the magnitude of the color difference between objects.

Previous studies reported different acceptability and perceptibility thresholds for color differences in dental materials.[6,23,24] The magnitude of the color difference is based on the human perception of color. It was previously reported that color differences greater than 1 ΔE unit are visually perceivable by 50% of human observers.[6] Besides, under uncontrolled clinical conditions, such small differences in color would be unnoticeable, as average color differences below 3.7 are rated a "match" in clinical conditions.[23]

Although the color stability of denture base resins and soft liners have been evaluated in the literature,[17,25-40] the effect of staining solutions and nicotine on the color of an injection-molded denture resin and a denture soft-reline material has not been assessed to date. The aim of this study was to determine the effect of four solutions on the color of a heat-polymerized resin, a chemically polymerized resin, an injection-molded resin, and a soft denture reline material.

Materials and methods

Three types of denture base resins were used in present study: a heat polymerized resin (H), an injection-molded autopolymerizing resin (I), a conventional autopolymerizing (A) acrylic resin, and a soft relining material (S). The materials and the manufacturers are summarized in Table 1. Twenty specimens from each group were prepared according to their manufacturers' recommendations. The disk-shaped specimens were prepared with a diameter of 2.5 mm and thickness of 2 mm in accordance with ADA specification no. 17. Following polymerization, all specimens were adjusted with no. 600 silicone carbide grinding papers and polished. The specimens were stored in distilled water for 24 hours. The thickness of the specimens was controlled with a micrometer (Praecimeter S. 0.01 mm, Renfert GmbH, Hilzingen, Germany).

Four solutions were used (Table 2). The first solution served as the control group. The specimens ($n = 20$ for each type of material) of acrylic resins and soft liner were divided into four subgroups of five specimens of each material. The color of each specimen was measured with a colorimeter (CR 2000, Minolta Inc., Osaka, Japan) before the specimens were immersed in the solutions (control, tea, coffee, nicotine). Five specimens from each group were stored in each solution at 37°C in a dark environment to simulate intraoral conditions for 30 days. The staining solutions were not changed throughout the test, which enabled the food stain deposit to be determined easily.

Color measurements were performed with a tristumulus colorimeter in the 1st, 7th, and 30th days. The device was calibrated with its white calibration plate before colorimetric measurements. The specimens were washed under water and air-spray dried prior to each color measurement. L^*, a^*, b^* notations were recorded in each measurement session, and color

Table 1 Materials and manufacturer information

Acrylic resin	Symbol	Product name	Manufacturer
Heat-polymerizing	H	Meliodent	Bayer, Strawberry Hill, Newburry, Berks, UK
Injection-molded (autopolymerizing)	I	PalaXpress	Kulzer, Wehrheim, Germany
Autopolymerizing	A	Wertex	Dentimex, Zeist, Holland
Soft liner	S	Ufi Gel	VOCO, Cuxhaven, Germany

Table 2 Content of solutions used

Solutions	Ingredients
Solution 1	Saliva; 990 ml (KCL 1.47 g, $NaHCO_3$ 1.25 g, KSNC 0.52 g, $NaH_2PO_4.H_2O$ 0.19 g, distilled water)
Solution 2	Saliva; 660 ml + tea (330 ml; 4 g/500 ml, Lipton, London, UK)
Solution 3	Saliva; 660 ml + coffee (330 ml;1.5 g/100 ml, Nescafe Classic, Nestle, Noisiel, France)
Solution 4	Saliva; 660 ml + nicotine solution (330 ml; 15 g/250 ml Marlboro, Phillip Morris USA, Richmond, VA)

differences (ΔE) between specimens in different solutions were calculated according to the equation mentioned above. In the present study, a ΔE value over 1 was considered perceivable by the human eye, and values below 3.7 were considered to be clinically acceptable.

To determine the color change in the 1st, 7th and 30th days, mean ΔE values of specimens in each staining solution were evaluated with one-way ANOVA. The significant differences were analyzed with Tukey test to find out which group differed from each other. If normality but not the equation of variances was obtained, Brown–Forsythe F statistics were used for statistical analysis. Statistically significant differences were analyzed with Games–Howell test. When neither normality nor equation of the variances was obtained, Kruskal–Wallis test was used. Mann–Whitney test was used for significant differences.

Results

The effect of duration and different staining solutions on the color shift of three types of acrylic resins and a soft liner was observed in the present study. The ΔE results were calculated between specimens of each test material in the control group (saliva) and the specimens of same materials in different colorants (Table 3).

For H acrylic group, the color differences between control group and coffee were significantly different between the 1st day and 7th day and 7th day and 30th day ($p = 0.001$). The remaining color differences in other colorants were not statistically significant ($p > 0.05$). For I acrylic resin, significant differences were noted only in the coffee group between the 7th day and 30th day ($p = 0.033$). For A acrylic resin, all color differences in all colorants were not statistically significantly different over time ($p > 0.05$). The color differences for S were only significant in nicotine between the 1st day and 7th day and 1st day and 30th day ($p = 0.001$) (Fig 1).

In 1st day color analysis, the color difference magnitudes were not statistically significantly different among acrylic resin groups when evaluated in each colorant. In the 7th day analysis, the color of the soft liner in tea changed significantly differently than the color shift in A and H acrylic resins ($p = 0.004$ for H; $p = 0.002$ for A). The color shift in soft liner in coffee was significantly different from A and I acrylic resins ($p = 0.001$ for I; $p = 0.008$ for A). The color shift of soft liner in nicotine was significantly different from the color change in each type of acrylic resin ($p < 0.05$). In the 30th day analysis, the color shift of soft liner in nicotine was significantly different than the color shift in each type of acrylic resin ($p = 0.003$ for A; $p < 0.05$ for H and I). The color shift in each test group was not significantly different in tea and coffee (Fig 2).

Discussion

Significant color shifts occurred in each test group in each staining solution over time. Moreover, the color shift in different test groups was significantly different when the magnitudes of color differences within the test groups were compared in the 7th day and 30th day ($p < 0.05$).

When the color of heat-polymerized acrylic resin was evaluated, it was observed that the color difference between specimens in the control group and each staining solution was all perceivable by human eye; however, only coffee statistically significantly affected the color of specimens over time ($p < 0.05$). The color difference observed in specimens of injection-molded acrylic resin in the control group and each staining solution was all perceivable by the human eye. The color of specimens in coffee changed significantly over time, particularly after the 7th day ($p < 0.05$). The changes in color of autopolymerizing acrylic resin were all perceivable in each measurement time; however, the color changes over time were not statistically significant in any staining solution. The color shifts in soft liner specimens were all perceivable in each

Table 3 Color differences between test group specimens in control group and specimens in staining solutions occurring over time

		Heat-polymerized (H)		Injection-molded (I)		Autopolymerized (A)		Soft liner (S)	
Solution	Duration	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tea-control group	1st day	2.08	0.84	2.13	1.20	2.25	1.01	2.02	0.90
	7th day	2.33	1.11	2.05	1.13	2.52	0.89	1.69	0.77
	30th day	2.08	0.87	2.21	1.25	2.23	1.06	1.66	0.44
Coffee-control group	1st day	1.76	0.72	2.39	1.45	2.35	1.02	1.74	0.60
	7th day	2.72	0.76	3.03	1.06	2.87	1.00	2.06	0.56
	30th day	1.77	0.98	2.12	1.19	2.41	1.18	1.95	0.44
Nicotine-control group	1st day	2.24	1.01	2.07	1.13	2.27	1.00	2.11	0.62
	7th day	2.47	1.27	2.38	1.12	2.52	1.00	3.73	0.63
	30th day	2.42	1.08	2.49	1.11	2.63	1.19	3.46	0.39

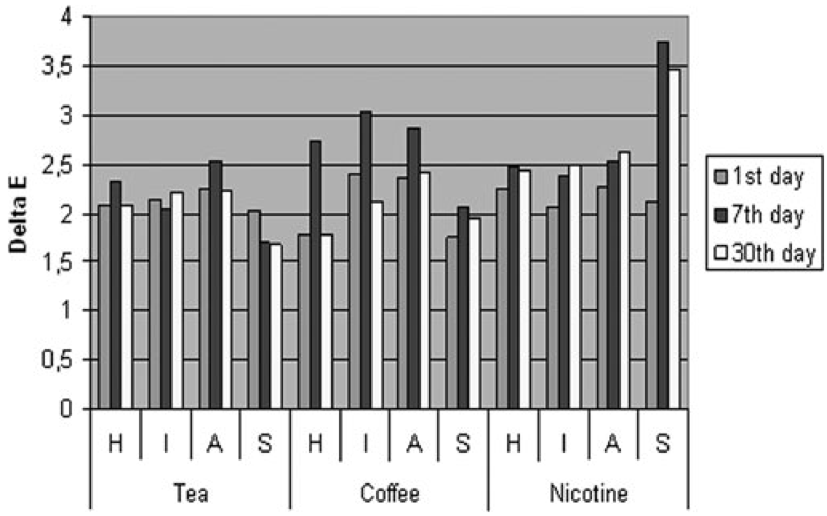

Figure 1 Color shift in each material in different staining solutions over time.

staining solution. Moreover, the color difference in nicotine in the 7th day can be considered as a mismatch even in clinical conditions; however, the color differences were only statistically significant after the 7th day in nicotine ($p < 0.05$).

Keskin[25] investigated the color stability of PMMA denture base polymers after immersion in coffee and tea solutions for 7 days and reported that there was an initial increase, then a decrease, in the discoloration values of the materials. This result was attributed to the removal of accumulated layers. As tea and coffee layers on specimens reach a certain thickness, they tend to break away from the surface of specimens and return to the solution. Similarly, the results obtained from the present study supported this aforementioned phenomenon. Although some color shift magnitudes were not statistically significant, a decrease in color difference values was observed in each type of material in tea and coffee solutions, particularly after the 7th day ($p < 0.05$).

Buyukyilmaz and Ruyter[26] reported that the discoloration values of seven denture base materials were at the same level after 96 hours of immersion in coffee and tea solutions; however, the present study revealed varying discoloration magnitudes for test materials in staining solutions. When the color differences of test specimens were compared in each measurement session, on the 1st day it was observed that the color difference values were not significantly different among test groups ($p < 0.05$); however, on the 7th day, the effect of tea on soft liner was significantly less than that on heat- and autopolymerizing acrylic resins. The color shift of soft liner in coffee was significantly less than that of autopolymerizing and injection-molded acrylic resins ($p < 0.05$). The effect of nicotine was significantly different and more on soft liner than on each type of acrylic resin ($p < 0.05$). Similarly, after 30th day measurements, nicotine solution changed the color of soft liner more than it changed the color of acrylic groups. Consequently, it can be stated that the color of soft liner was affected particularly from nicotine more than the acrylic groups were affected on the 7th and 30th days; however, the effect of tea and coffee was less on soft liner than it was on different acrylic groups. Tea changed the color

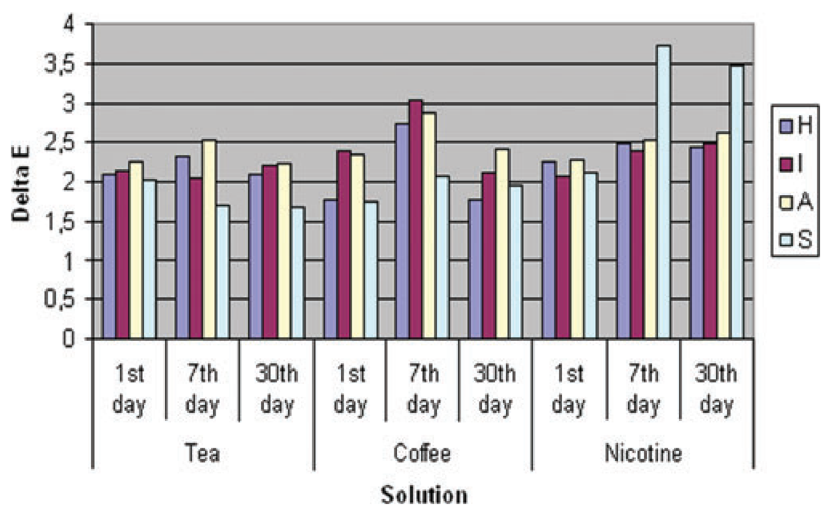

Figure 2 Color differences calculated in different measurement times between specimens in control groups and staining solutions.

of heat- and autopolymerizing resins on the 7th day, whereas the effect of coffee was more on the color of autopolymerizing and injection-molded acrylic resins. The color shifts of test groups were all clinically acceptable ($\Delta E < 3.7$), except for the color change of soft liner in nicotine solution on the 7th day ($\Delta E = 3.73$). The color change of soft liner in nicotine solution on the 30th day was close to the clinical acceptability threshold ($\Delta E = 3.47$).

Many materials used for prosthetic treatment, such as fixed partial denture acrylic resins,[27,28] interim prostheses,[29-31] and soft denture liners,[32] are subject to sorption, a process of absorption and adsorption of liquids dependent upon environmental conditions. The materials absorb liquid slowly over a period of time. The absorption is undoubtedly due primarily to the polar properties of the resin molecules. Because of this property, these materials are known to undergo staining through the use of denture cleansers and from the intake of fluids and foods.[21,28]

There is evidence that beverages like tea and coffee significantly increase the development of stains on dental materials.[32-37] Chan et al[37] compared the staining properties of four foods (coffee, soy sauce, tea, cola). They tested two commercial brands of composite resin and showed that these beverages increased the development of stain. Cooley et al[35] reported that resin restorative materials exhibited staining after immersion in a coffee solution for 7 days. Similarly in the present study, coffee caused a considerable magnitude of color change on some resin-based denture acrylics after 7 days.

Autopolymerizing denture base resins have been found to be less stable than conventional acrylic resins in previous studies.[38] The color stability of autopolymerizing denture base acrylic resins varies with the chemical composition of the monomer. Austin and Basker[41] explained that denture base materials processed by an autopolymerized method have demonstrated up to seven times the level of residual monomer found in conventional heat-polymerized materials. The residual monomer content may be responsible for the color changes observed. Purnaveja et al[39] also showed that autopolymerized resins have color stability inferior to that of heat-polymerized materials. Heat-polymerized acrylic resins are considered more color stable than autopolymerizing acrylic resins due to existence of an amine accelerator.[16] In this study, while the color of heat-polymerizing resin significantly changed in coffee after the 1st day ($p < 0.05$), no statistically significant color shift was observed in autopolymerizing acrylic resin over time in each staining solution; however, when the magnitude of color shifts in all acrylic resins in each solution were considered, it can be stated that the color difference values were limited within a range (1.06 to 3.03) considered perceivable by human eye, but clinically acceptable. Therefore, color shifts in autopolymerizing acrylic resins in coffee may be considered minor. This minor color shift in autopolymerizing resin should not be considered as an indicator that this resin is to be accepted as the option of denture base in terms of color stability.

Before any dental restoration or appliance is placed permanently in the mouth, it should be highly polished. If there is a rough surface on a restoration or denture, it is uncomfortable as food and other debris cling to it. Crispin and Caputo[31] found that color of specimens with rough surfaces significantly changed. According to May et al,[21] color change may be associated with porosity caused by overheating or insufficient pressure during polymerization. The favorable physical properties of injection-molded acrylic resin could be a reason for a prediction of intended color stability. The polishability and lack of porosity of injection-molded acrylic resins has been reported in the literature.[42] Accordingly, low surface roughness of the material, which can affect staining by foods and plaque retention, can be predicted as well;[14] however, the color of injection-molded arcylic resin was significantly affected by coffee solution after 7th day measurements ($p < 0.05$). This may be attributed to the autopolymerizing character of the injection-molded acrylic resin, which is considered to have unfavorable physical properties.[38] The clinically unacceptable color change magnitude of soft liner, which was observed in nicotine after 7th day measurements, may be attributed to the relatively high surface roughness of the material.

Tea leaves contain a considerable amount of flavonoid, which gives tea its functional properties and flavor; however, teaflavins in tea leaves are reported to be the cause of discoloration. Similarly, caffeine and caffeic acid in coffee may lead to discoloration in polymeric materials.[25] Um and Ruyter[36] reported that tea caused more discoloration than coffee after 48 hours' storage of five resin-based materials in coffee and tea solutions. It was reported that discoloration due to tea can be easily removed, depending on the adsorption of the food colorants from tea at the surface of the materials. In contrast, with coffee, the discoloration is probably due to both surface adsorption and absorption of colorants. It was also reported that fewer polar colorants from coffee had penetrated deeper into the materials because the colorants were more compatible with the polymer matrices of the composite resin materials.

Lai et al[43] reported that hydrophobic materials are more prone to staining by hydrophobic solutions. Adversely, in the present study, coffee (hydrophobic solution) had a significant effect on the color of acrylic resins (hydrophilic material),[40] except for autopolymerizing resin over time ($p < 0.05$). Moreover, the effect of coffee was not significant on soft liner, which is a hydrophobic material,[40] while the effect of nicotine was considerable over time ($p < 0.05$).

Tristumulus colorimeters are widely used instruments for the color analysis of dental materials; however, these devices are not error-proof, depending on the small window sizes. The edge-loss effect occurs due to loss of a considerable fraction of the light entering the object as the light emerges on the surface outside the window of measurement.[44] Translucent objects can be a reason for measurement errors as well.[44] Since the materials used in this study were translucent in structure, some errors might have occurred during color measurements. To minimize such errors, an immobilizer for the specimens and colorimeter was used during measurements with a standardized neutral gray background. Besides, one experienced examiner performed the colorimetric measurements.

Other factors that could influence the degree of total color change include thermal cycling or abrasion. The absence of such an environment can be considered as a limitation and an area for future study. Color stability is only one variable to be considered when choosing a denture base material, but it may be of great importance to patients and clinicians when working in the esthetic zone.

Conclusions

Within the limitations of this study, it can be concluded that:

1) The effect of staining solutions on the color of each test material in each session was perceivable by human eye ($\Delta E > 1$).
2) Coffee affected the color of heat-polymerized and injection-molded acrylic resins over time ($p < 0.05$).
3) The effect of tea on the color of test materials did not significantly change over time.
4) The color of autopolymerizing acrylic resin did not significantly change over time in each solution.
5) The color of soft liner was affected by the nicotine solution more than by tea and coffee ($p < 0.05$).
6) The color shifts of all test materials were clinically acceptable, except for soft liner in nicotine, which was not clinically acceptable over time ($\Delta E > 3.7$).

References

1. Jagger DC, Harrison A, Jandt KD: The reinforcement of dentures. J Oral Rehabil 1999;26:185-194
2. Winkler S: Denture base resins. Dent Clin North Am 1984;28:287-297
3. Anderson GC, Schulte JK, Arnold TG: Dimensional stability of injection and conventional processing of denture base acrylic resin. J Prosthet Dent 1988;60:394-398
4. Salim S, Sadamori S, Hamada T: The dimensional accuracy of rectangular acrylic resin specimens cured by three denture base processing methods. J Prosthet Dent 1992;67:879-881
5. Strohaver RA: Comparison of changes in vertical dimension between compression and injection molded complete dentures. J Prosthet Dent 1989;62:716-718
6. O'Brien WJ: Dental Materials and Their Selection (ed 3). Chicago, Quintessence, 2002, pp. 24-36, 210-224, 225-238
7. Smith LSA, Saver JA: Sorbed water and mechanical behaviour of poly(methyl methacrylate). Plast Rubber Process Appl 1986;6:57-65
8. Dixon DL, Ekstrand KG, Bredding LC: The transverse strengths of three denture base resins. J Prosthet Dent 1991;66:510-513
9. Lamb DJ: Problems and Solutions in Complete Denture Prosthodontics (ed 1). London, Quintessence, 1993, pp. 118
10. Wright PS: The success and failure of denture soft-lining materials in clinical use. J Dent 1984;12:319-327
11. Tylman S: The use of elastic and resilient synthetic resins and their copolymer in oral, dental and facial prostheses. Dent Dig 1943;49:167
12. Dootz ER, Koran A, Craig RG: Comparison of the physical properties of 11 soft denture liners. J Prosthet Dent 1992;67:707-712
13. Jin C, Nikawa H, Makihira S, et al: Changes in surface roughness and color stability of soft denture lining materials caused by denture cleansers. J Oral Rehabil 2003;30:125-130
14. Saraç D, Saraç YS, Kurt M, et al: The effectiveness of denture cleansers on soft denture liners colored by food colorant solutions. J Prosthodont 2007;16:185-191
15. Oğuz S, Mutluay MM, Doğan OM, et al: Color change evaluation of denture soft lining materials in coffee and tea. Dent Mater J 2007;26:209-216
16. Paravina RD, Powers JM: Esthetic Color Training in Dentistry. St. Louis, Mosby, 2004, pp. 84, 85, 87
17. Balderamos LP, O'Keefe KL, Powers JM: Color accuracy of resin cements and try-in pastes. Int J Prosthodont 1997; 10:111-115
18. Polyzois GL, Yannikakis SA, Zissis AJ, et al: Color changes of denture base materials after disinfection and sterilization immersion. Int J Prosthodont 1997;10:83-89
19. Makila E, Honka O: Clinical study of a heat-cured silicone soft lining material. J Oral Rehabil 1979;6:199-204
20. Wagner WC, Kawano F, Dootz ER, et al: Dynamic viscoelastic properties of processed soft denture liners: Part II–Effect of aging. J Prosthet Dent 1995;74:299-304
21. May KB, Razzoog ME, Koran III A, et al: Denture base resins: comparison study of color stability. J Prosthet Dent 1992;68:78-82
22. Berns RS, Bilmeyer FW, Saltzman M: Principles of Color Technology (ed 3). New York, Wiley, 2000, pp. 71-74
23. Johnston WM, Kao EC: Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819-822
24. Ruyter IE, Nilner K, Moller B: Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987;3:246-251
25. Keskin S: The treatment of prosthetic dental materials with hypchlorite. MSc thesis, 2002 Middle East Technical University, Ankara, Turkey
26. Buyukyilmaz S, Ruyter IL: Color stability of denture base polymers. Int J Prosthodont 1994;7:372-382
27. Khoklar ZA, Razzoog ME, Yaman P: Color stability of restorative resins. Quintessence Int 1991;22:733-737
28. Ma T, Johnson GH, Gordon GE: Effects of chemical disinfectants on surface characteristics and color of three fixed prosthodontic crown materials. J Prosthet Dent 1999;82:600-607
29. Koumjian JH, Firtell DN, Nimmo A: Color stability of provisional materials in vivo. J Prosthet Dent 1991;65:740-742
30. Scotti R, Mascellani SC, Forniti F: The in vitro color stability of acrylic resins for provisional restorations. Int J Prosthodont 1997;10:164-168
31. Crispin BJ, Caputo AA: Color stability of temporary restorative materials. J Prosthet Dent 1979;42:27-33
32. Shortwell JL, Razzoog ME, Koran A: Color stability of long term soft denture liners. J Prosthet Dent 1992;68:836-838
33. Khan Z, von Fraunhofer JA, Razavi R: The staining characteristics, transverse strength and microhardness of a visible light-cured denture base material. J Prosthet Dent 1987;57: 384-386
34. Wozniak WT, Muller TP, Silverman R, et al: Photographic assessment of color changes in cold and heat-cured resins. J Oral Rehabil 1981;8:333-339
35. Cooley RL, Barkmeier WW, Matis BA, et al: Staining of posterior resin restorative materials. Quintessence Int 1987;18:823-827
36. Um CM, Ruyter IE: Staining of resin-based veneering materials with coffee and tea. Quintessence Int 1991;22:377-386
37. Chan KC, Fuller JL, Hormati AA: The ability of foods to stain two composite resins. J Prosthet Dent 1980;43:542-545
38. Keyf F, Etikan I: Evaluation of gloss changes of two denture acrylic resin materials in four different beverages. Dent Mater 2004;20:244-251
39. Purnaveja S, Fletcher AM, Ritchie GM, et al: Color stability of two self-curing denture base materials. Biomaterials 1982; 3:249-250
40. Canay S, Hersek N, Tulunoğlu I, et al: Evaluation of color and hardness changes of soft lining materials in food colorant solutions. J Oral Rehabil 1999;26:821-829

41. Austin AT, Basker RM: Residual monomer levels in denture bases: the effects of varying short curing cycles. Br Dent J 1982;153:424-426
42. Haug SP, Duke P, Dixon SE, et al: A pilot clinical evaluation of a new injection denture base system. Compend Contin Educ Dent 2001;22:847-852, 854
43. Lai YL, Lui HF, Lee SY: In vitro color stability, stain resistance, and water sorption of four removable gingival flange materials. J Prosthet Dent 2003;90:293-300
44. Bolt RA, Bosch JJ, Coops JC: Influence of window size in small-window color measurement, particularly of teeth. Phys Med Biol 1994;39:1133-1142