Color Stability of Different Denture Teeth Materials against Various Staining Agents

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The purpose of this *in vitro* study was to evaluate the color stability of two brands of porcelain teeth and three brands of acrylic denture teeth. Samples were immersed into three staining drinks as test groups and distilled water as a control. Color measurements of teeth were performed by using a spectrophotometer. Before immersion, the initial color value of each tooth was recorded. Color change values were determined after 1 day, 1 week, 2 weeks, and 4 weeks of immersion. Color differences were characterized using the CIE L*a*b* color space. The color stability of all teeth was significantly affected by the immersion period ($p < 0.0001$). Instant coffee was found to be the most chromogenic agent among the solutions tested ($p < 0.0001$). Among the materials tested, porcelain was found to be more resistant to discoloration. It was concluded that acrylic teeth showed a higher degree of color change and that the amount of color change for each group increased proportionally with time.

Keywords: Color stability, Spectrophotometer, Denture teeth

INTRODUCTION

In removable dentures, artificial teeth are a significant part of the overall esthetical outcome. In the maintenance of esthetical effects, the color stability of artificial tooth materials is one major factor. In this light, denture teeth are made of either methacrylate-based resins or ceramics. In particular, resin teeth are known to have sidelined ceramic teeth from the market recently. This is because resin teeth gain an upper hand over ceramic teeth by virtue of these advantageous properties: better bond to the denture base, lighter weight, and lower fracture proneness¹. On the downside, conventional acrylic teeth are inferior to porcelain teeth in maintaining an adequate esthetic appearance with wear and discoloration, and thus have a shorter durability period and service life. To overcome the wear problems of conventional plastic teeth, high-strength plastic teeth have since been developed and applied clinically².

Since high-strength plastic teeth made of hard resin are still susceptible to staining with pigments, it has been observed that the esthetics of removable partial dentures made from such plastic teeth is gradually impaired in many patients². On the other hand, porcelain teeth are comparatively superior because of their high wear resistance and good esthetical appearance. However, if removable dentures were used for a long period of time without sufficient cleaning, there belies too the staining possibility of porcelain teeth because of the adsorption of colorants on the porcelain surface.

In dental literature, only a few studies have reported on the color stability of both acrylic and porcelain denture tooth materials³⁻⁵. Against this backdrop of information scarcity, this *in vitro* study was undertaken to analyze the color changes of

porcelain and acrylic denture teeth when exposed to common beverages by means of a spectrophotometer.

MATERIALS AND METHODS

In this study, two brands of porcelain teeth and three brands of reinforced acrylic teeth were used. The trade names, manufacturers, types, shades, forms, and codes of the denture teeth used in this study are given in Table 1. From each brand of denture teeth, 40 maxillary right central incisors of shade A1, of the largest size, and with the flattest surface were used.

Denture teeth were immersed into three staining solutions (instant coffee, tea, coke) and distilled water as detailed in Table 2.

Preparation of staining solutions

The tea solution was prepared by immersing five teabags (Lipton Yellow Label Tea, Unilever, Istanbul, Turkey) into 1000 ml of boiled water. To prepare the coffee solution, 20 g of coffee (Nescafe Classic, Nestle, Istanbul, Turkey) was poured into 1000 ml of boiled distilled water. Both solutions were stirred every 30 minutes for 10 seconds until they cooled down to 37°C, and then filtered through a filter paper. The third staining solution was coke (Coca-Cola, Coca-Cola Co., Turkey), whereby 1000 ml of coke at room temperature was poured into a dish. Distilled water, as the fourth solution, was used as a control group.

Before pouring the solutions into dishes, 10 incisors from each brand labeled with a waterproof pen, were fixed vertically on the floor of a container to avoid tooth-to-tooth contact. Fixation was done using a removable adhesive (Tack-It, Faber-Castell, Nürnberg, Germany) at the cervical region of each tooth.

After both tea and coffee solutions cooled down

Table 1 Denture teeth used in this study

TYPE OF MATERIALS	TRADE NAME	CODE	MANUFACTURER	SHADE/FORM
Reinforced acrylic	SR-VIVODENT DCL	SRVD	IVOCCLAR-Liechtenstein	010/A17
	VITAPAN	V	VITA Zahnfabrik-Germany	A1/098
	OPTOSTAR	O	HERAEUS KULZER-Germany	A1/520
Porcelain	VIVOPERL PE	VP	IVOCCLAR-Liechtenstein	1A/A17
	VIA LUMIN VACUUM	VLV	VTTA Zahnfabrik-Germany	A1/854

Table 2 Solutions used in this study

TYPE OF SOLUTION	TRADE NAME	MANUFACTURER
Tea	Lipton Yellow Label Tea	Unilever-Turkey
Instant cafe	Nescafe Classic	Nestle-Turkey
Coke	Coca-Cola	Coca-Cola Company-Turkey
Distilled Water	-----	Yeditepe University, Faculty of Dentistry-Turkey

Table 3 National Bureau of Standards (NBS) ratings

NBC unit	Critical remarks of color differences	
0.0–0.5	Trace:	Extremely slight change
0.5–1.5	Slight:	Slight change
1.5–3.0	Noticeable:	Perceivable change
3.0–6.0	Appreciable:	Marked change
6.0–12.0	Much:	Extremely marked change
12.0 or more	Very much:	Change to other color

to 37°C, all solutions were poured into dishes and kept in an incubator. Solutions were freshened once every three days. In addition, to reduce the precipitation of particles in solutions, solutions were stirred once a day.

Color measurements

The specimens were placed in the center of the measuring head of a spectrophotometer with the aid of a silicone putty jig. This silicone mold was prepared so that repetitive measurements for each tooth could be taken from the same tooth region. Furthermore, this mold enabled all teeth from the same brand to sit on the measuring head of the spectrophotometer in the same position. Additionally, this setup prevented any external light source from entering the system. During the processing of the mold, teeth were placed so that their labial surfaces were at the same level as that of the silicone.

Before immersing each set of denture teeth into the solutions, they were stored in distilled water at $37 \pm 1^\circ\text{C}$ for 24 hours. After 24 hours of immersion, the color measurement of each tooth (T_0) was performed using a spectrophotometer (CM-2600d, Konica Minolta Sensing Inc., Japan). After the first measurement (T_0), teeth were placed in containers as mentioned above. Subsequent color measurements were taken after 1 day (T_1), 1 week (T_2), 2 weeks (T_3), and 4 weeks (T_4) of immersion in solutions.

Before each measurement, teeth were removed

from the solutions and rinsed in distilled water. Excess water on the surfaces was removed with tissue papers and teeth were allowed to dry.

Prior to measurement taking, the spectrophotometer was calibrated according to the manufacturer's instructions by using the supplied white calibration standard. Three measurements were taken at a time from one point which corresponded to the central region of the labial surface of each tooth. Average value of these three readings was automatically calculated by the spectrophotometer and recorded. Color changes were characterized using the Commission Internationale d'Eclairage $L^*a^*b^*$ color space (CIE $L^*a^*b^*$).

The color systems are quantitative systems with rectangular coordinates, and they have a meaningful relation to the visual perception of color differences. Total color differences are expressed by the formula⁵⁾, $\Delta E^* = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$, where ΔL , Δa , and Δb are differences in L^* , a^* , and b^* values before (T_0) and after immersion at each time interval (T_1 , T_2 , T_3 , T_4).

To relate the amount of color change (ΔE^*) recorded by the spectrophotometer to a clinical environment, the data were converted to National Bureau of Standards units (NBS units) through the equation, $\text{NBS units} = \Delta E^* \times 0.92$, where critical remarks of color differences as expressed in terms of NBS units. These values are shown in Table 3⁶⁾.

Statistical analysis

Discoloration results were analyzed by repeated measures analysis of variance (ANOVA), with two between-unit factors (five materials and four solutions) and one within-unit factor (four measurement times) to verify the main effects and possible interactions between factors. Two-way ANOVA at each immersion time was used to test the significance of factors involved. Where significant differences were found, one-way ANOVA and Newman–Keulls and Tukey's multiple comparison tests were applied to each between-unit factor.

RESULTS

Table 4 shows the total color difference (ΔE^*) and corresponding NBS values of the denture teeth after 1 day, 1 week, 2 weeks and 4 weeks of immersion in all the test solutions. Statistical analysis results for the comparison of mean ΔE^* values against different variables are shown in Tables 5, 6, and 7.

Results of repeated measures ANOVA indicated that all factors (time, denture teeth, and solution)

and all their possible interactions were statistically significant. Two-way ANOVA revealed that the color stability of all teeth was significantly affected by the immersion period ($p < 0.0001$). Another result of two-way ANOVA revealed that the porcelain material (VL and VLV) was more resistant to discoloration than the resin material (SRVD, V, and O).

When NBS values were evaluated, instant coffee solution was observed to cause "perceivable" color difference at the end of fourth week for only acrylic teeth groups. The staining effects of the other solutions resulted in only slight color changes that could not be noticed by naked eye. Further, it was shown that the color changes of denture teeth intensified with increasing immersion period (Table 4).

In Table 5 where the color changes of denture teeth at the end of each immersion period were compared, there were no significant differences between the ΔE^* values within each teeth group when immersed in tea and coffee solutions.

For the immersion of porcelain teeth in tea and coffee, there were no statistically significant differences between the ΔE^* values for these two solu-

Table 4 Color differences of denture teeth

Teeth	Periods	Distiled water			Tea			Coffee			Coke		
		ΔE^* (mean)	SD	NBS unit	ΔE^* (mean)	SD	NBS unit	ΔE^* (mean)	SD	NBS unit	ΔE^* (mean)	SD	NBS unit
SRVD	1d	0.185	0.12	0.170	0.718	0.33	0.661	0.965	0.40	0.888	0.403	0.27	0.371
	1w	0.248	0.13	0.228	0.976	0.30	0.898	1.829	0.36	1.683	0.648	0.33	0.596
	2w	0.188	0.08	0.173	1.051	0.28	0.967	2.274	0.81	2.092	0.765	0.38	0.704
	4w	0.275	0.15	0.253	1.273	0.40	1.171	2.828	1.03	2.602	0.894	0.41	0.822
V	1d	0.849	0.69	0.781	0.654	0.10	0.602	0.741	0.15	0.682	0.522	0.15	0.480
	1w	0.589	0.21	0.542	0.824	0.17	0.758	1.102	0.25	1.014	0.676	0.34	0.622
	2w	0.469	0.24	0.431	1.081	0.34	0.995	1.334	1.02	1.227	0.708	0.16	0.651
	4w	0.368	0.22	0.339	1.161	0.26	1.068	1.859	1.08	1.710	0.817	0.36	0.752
O	1d	0.546	0.14	0.502	0.529	0.10	0.487	0.706	0.15	0.650	0.409	0.28	0.376
	1w	0.260	0.16	0.239	0.593	0.15	0.546	1.325	0.16	1.219	0.497	0.27	0.457
	2w	0.491	0.30	0.452	0.676	0.24	0.622	1.476	0.24	1.358	0.547	0.18	0.503
	4w	0.538	0.33	0.495	0.960	0.11	0.883	2.150	0.38	1.978	0.681	0.20	0.627
VP	1d	0.240	0.12	0.221	0.380	0.29	0.350	0.365	0.17	0.336	0.261	0.18	0.240
	1w	0.257	0.12	0.236	0.397	0.31	0.365	0.523	0.10	0.481	0.584	0.13	0.537
	2w	0.205	0.11	0.189	0.453	0.36	0.417	0.879	0.75	0.809	0.855	0.42	0.787
	4w	0.233	0.10	0.214	0.579	0.37	0.533	1.009	0.36	0.928	0.829	0.61	0.763
VLV	1d	0.267	0.17	0.246	0.517	0.11	0.476	0.398	0.06	0.366	0.715	0.26	0.658
	1w	0.292	0.14	0.269	0.589	0.20	0.542	0.615	0.12	0.566	0.808	0.31	0.743
	2w	0.299	0.06	0.275	0.699	0.25	0.643	0.736	0.29	0.677	0.795	0.24	0.731
	4w	0.319	0.19	0.293	0.750	0.35	0.690	0.832	0.26	0.765	0.924	0.29	0.850

ΔE^* : Color change value; SD: Stnadard Deviation; NBS unit: National Bureau of Standards unit

Table 5 Comparison of the mean ΔE^* values of denture tooth materials against different solutions for each immersion period

Teeth	Periods	Distiled water	Tea	Coffee	Coke
SRVD	1d	A	BC	B	AC
	1w	D	E	F	E
	2w	G	H	I	H
	4w	J	KM	L	M
V	1d	N	N	N	N
	1w	O	OP	P	O
	2w	P	QR	R	PQ
	4w	S	T	U	VT
O	1d	WX	WX	W	X
	1w	Y	Z	Ω	Z
	2w	α	α	β	α
	4w	γ	ζ	Γ	$\gamma \zeta$
VP	1d	ε	ε	ε	ε
	1w	Δ	$\Delta \eta$	η	η
	2w	θ	$\theta \lambda \mu$	$\lambda \rho$	$\mu \rho$
	4w	ν	$\nu \pi$	$\sigma \tau$	$\pi \tau$
VLV	1d	ϕ	χ	$\phi \chi$	Ψ
	1w	ω	δ	δ	δ
	2w	i	$\acute{o}$	$\acute{o}$	$\acute{o}$
	4w	B	C	C	C

Same letters or symbols in the same row indicate insignificant differences ($p>0.05$).

Table 6 Comparison of the mean ΔE^* values of each denture tooth material with respect to different immersion periods

Teeth	Periods	Distiled water	Tea	Coffee	Coke
SRVD	1d	A	K	γ	H β
	1w	A	L	$\theta \lambda$	K β
	2w	A	M	$\eta \lambda$	y β
	4w	A	N	Δ	U
V	1d	BD	O	$\mu \rho$	D
	1w	B	P	$\nu \pi$	D Π
	2w	BD	QS	$\rho \pi$	ЖИ
	4w	CD	RS	$\nu \sigma$	з И
O	1d	E	U	τ	Φ
	1w	F	UV	ϕ	$\Phi \Psi$
	2w	EF	UY	χ	$\Phi \Pi$
	4w	E	Z	Ψ	B
VP	1d	I	α	$\omega \ddot{E}$	Θ
	1w	I	α	$\ddot{i}$	$\Theta \Theta$
	2w	I	α	$\ddot{i} \acute{o} \ddot{E}$	$\Upsilon \Theta$
	4w	I	α	$\ddot{u} \acute{o}$	$\Upsilon \Theta$
VLV	1d	J	β	B	Θ
	1w	J	β	$\acute{I}$	Θ
	2w	J	β	$\acute{I} \acute{C}$	Θ
	4w	J	β	$\acute{I} \text{J} \text{B}$	Θ

Same letters or symbols in the same column for each teeth group indicate insignificant differences ($p>0.05$).

Table 7 Comparison of the mean ΔE^* values of denture tooth materials in the same immersion period

Periods	Teeth	Distiled water	Tea	Coffee	Coke
1d	SRVD	A	L	X	κ
	V	B	LM	X	$\kappa \mu$
	O	AB	LM	X	κ
	VP	AC	M	Y	κ
	VLV	AD	LM	Y	μ
1w	SRVD	E	N	Z	π
	V	F	NOR	α	π
	O	E	OP	α	π
	VP	E	P	$\beta \gamma$	π
	VLV	E	RP	γ	π
2w	SRVD	G	QS	ζ	Φ
	V	H	Q	ε	Φ
	O	IH	ST	$\zeta \varepsilon$	Φ
	VP	G	T	ε	Φ
	VLV	GH	QT	ε	Φ
4w	SRVD	JK	U	Δ	Ψ
	V	JK	U	$\eta \theta$	Ψ
	O	J	UV	$\Delta \eta$	Ψ
	VP	K	V	$\Theta \lambda$	Ψ
	VLV	J	V	λ	Ψ

Same letters or symbols in the same column indicate insignificant differences ($p>0.05$) for each immersion period

tions after one day and one month of immersion. However; for all acrylic teeth groups, there were statistically significant differences between the mean ΔE^* values after one day and one month of immersion in the three staining solutions (Table 6).

When comparison was made among the staining solutions, the instant coffee solution was found to be more chromogenic than the other solutions ($p<0.0001$). For example, between tea and coke, there were no significant differences between these two solutions in their staining effects.

When comparison was made among the denture tooth materials, porcelain teeth exhibited higher color stability in tea and coffee solutions as compared to the acrylic ones. In the coke solution, no evident differences were observed between the porcelain and acrylic teeth (Table 7).

DISCUSSION

Color changes can be evaluated visually or by instrumental techniques. Since instrumental measurements eliminate the subjective interpretation of visual color comparison, spectrophotometers or colorimeters are used instead of visual evaluation^{7,8}.

Color changes were characterized using the Commission Internationale d'Eclairage L*a*b* color space (CIE L*a*b*). The CIE L*a*b* color

space is currently one of the most popular and widely used color spaces and it is well suited for the determination of small color differences⁹. In this three-dimensional color space, the three axes are namely L*, a*, and b*. The L* value is a measure of the whiteness or brightness of an object. The a* value is a measure of redness (positive a*) or greenness (negative a*). The b* value is a measure of yellowness (positive b*) or blueness (negative b*). The advantage of the CIE L*a*b* system is that color differences can be expressed in units that can be related to visual perception and clinical significance¹⁰.

Color difference (ΔE^*) was calculated from a formula previously mentioned. In dental literature, many authors^{4,7,11-13} used ΔE^* values to evaluate the "perceptibility" of color differences. However, it is noteworthy that the criteria of perceptibility adopted by each author were different. To counter such differences and disagreements in the criteria used, the NBS rating system is a frequently used method to determine the degree of color difference since it offers absolute criteria by which ΔE^* values can be converted to remarks with clinical significance⁹. In the present study, therefore, corresponding NBS units were calculated to assess the color differences caused by immersion time and/or solution type. It was found that the NBS values of all acrylic teeth groups when immersed in instant coffee were greater than 1.5, meaning that color change was "noticeable (perceivable)" (Table 4).

Apart from color change in instant coffee, the L*, a*, and b* values of all teeth groups changed in relation to immersion period. In the assessment of L* values, it was determined that the teeth became darker with time. The a* values signified a shift toward green while the b* values a shift toward yellow.

It was pointed out that there is a correlation between color and discoloration in provisional restorative materials and dental composites, and was confirmed that lighter materials discolor more markedly than darker ones^{14,15,16}. On this ground, teeth of shade A1 were selected for this study because they supposedly exhibit the staining effect more distinctly. Nonetheless, the effect of staining solutions on darker teeth should be a subject to be further investigated in future studies.

For drinks, coffee, tea, and coke are identified to be staining substances^{3,7,9,17-20}. For this reason, these solutions were used in this study for staining effect evaluation. Among these three solutions, coffee was the most chromogenic agent. This finding was consistent with a study performed by Mutlu-Sagesen *et al.*³, which investigated the color stability of denture teeth. Besides, numerous studies^{18,19,21,22,23,24} also concluded that coffee was more staining than tea.

In the present study, when acrylic denture teeth were compared against porcelain, it was found that the former group exhibited less color stability than the latter in all the three staining solutions (Table 4). This result was consistent with the studies of Satoh *et al.*², Mutlu-Sagesen *et al.*³, and Belli *et al.*²⁵. This could be explained by the water sorption property of acrylic materials. Staining agents in tea, coffee, and cola penetrated into the acrylic materials because of this absorption property.

When NBS values at the fourth week immersion period were evaluated, "perceivable" changes were observed only in acrylic teeth groups immersed in instant coffee solution. Color changes in tea and coke solutions were only "slight changes" according to the NBS rating system. However, in another study²³ performed with a similar methodology which investigated the color changes of acrylic denture base materials, "perceivable" color changes were noted not only in coffee but also in tea solution at the end of fourth week. Differences on these two studies' results could be due to differences between the structures of denture base acrylic and reinforced acrylic of denture teeth.

A period of four weeks' immersion might be considered by some as too long an experimental period. However; in most *in vitro* studies^{2,3,7,13,26,27,28}, the final period is typically four weeks or more in order to achieve a cumulative staining effect and obtain distinct results. One of the drawbacks in the present investigation might be related with the methodology utilized for the staining procedure. Between the different immersion intervals, the experimental tooth specimens were not subjected to any cleaning procedure, which might not accurately reflect clinical conditions. Thus, the results obtained herein might serve to reveal the consequences of a low quality denture care.

Color differences with corresponding ΔE^* values lower than 3.3 are acceptable in clinical dentistry^{7,15}. In the current study, the ΔE^* values of all groups did not exceed 3.3. Therefore, it was concluded that the staining of all teeth groups by the solutions used in this study remained in clinically acceptable ranges. A similar study²³ performed to investigate the color stability of three denture base materials showed that color changes for these materials in (the most staining) instant coffee solution for four weeks remained within clinically acceptable limits — with ΔE^* values being less than 3.3. This result was consistent with the present study and could be considered as complementary findings because denture base materials are the other component of removable dentures.

CONCLUSIONS

Within the limitations of this *in vitro* study, the fol-

lowing conclusions were drawn:

- (1) Porcelain denture teeth were more color-stable than reinforced acrylic denture teeth.
- (2) Discoloration of teeth increased proportionally with immersion period.
- (3) The most chromogenic staining solution was found to be the instant coffee solution.

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