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Color degradation of acrylic resin denture teeth as a function of liquid diet: ultraviolet-visible reflection analysis

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Abstract. The effect of different beverages on acrylic resin denture teeth color degradation is evaluated. Ten acrylic resin denture teeth brands were evaluated: Art Plus (AP), Biolux (BX), Biotone IPN (BI), Magister (MG), Mondial 6 (MD), Premium 6 (PR), SR Vivodent PE (SR), Trilux (TR), Trubyte Biotone (TB), and Vipi Dent Plus (VP). Teeth were immersed in staining solutions (coffee, cola, and orange juice) or artificial saliva (control) ($n = 6$) for 1, 7, 15, or 30 days. Specimen colors were evaluated spectrophotometrically based on the Commission Internationale d'Eclairage $L*a*b*$ system. Color differences (ΔE) were calculated between the baseline and post-staining results. Data were evaluated by analysis of variance and Tukey test ($\alpha = 0.05$). BI (1.82 ± 0.95) and TR (1.78 ± 0.72) teeth exhibited the greatest ΔE values, while BX (0.88 ± 0.43) and MD (1.09 ± 0.44) teeth were the lowest, regardless of solution and measurement period, and were different from BI and TR teeth ($P < 0.05$). Cola and coffee promoted higher denture teeth color alterations than orange juice and saliva ($P < 0.05$). Saliva generated the lowest denture teeth color alterations. Greater immersion times caused higher denture teeth color changes. The lifespan of removable dentures and the aesthetic satisfaction of several edentulous patients may be increased with the use of stain-resistant artificial denture teeth. [DOI: 10.1117/1.JBO.18.10.105005]

Keywords: color stability; denture teeth; acrylic resin.

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1 Introduction

The importance of artificial tooth staining is clear considering that a significant part of the population needs rehabilitation treatment with removable dentures. As aesthetic demand increases and patients' expectations are high, stain resistance plays a significant role in the selection of denture teeth.[1]

Acrylic resin denture teeth are used more frequently because they form a chemical bond with the acrylic resin denture base, are lighter, have a lower propensity to fracture, and have greater ease in occlusal adjustment.[2–4] However, acrylic teeth are inferior to porcelain teeth in regard to maintaining color stability,[5] and they do not remain aesthetic over an adequate long-term period and have less durability.[2]

Denture discoloration can be caused by many factors, which can be divided into intrinsic factors, such as the characteristics of the material composition (e.g., type of photoinitiator and inorganic material), and extrinsic factors relating to wear and exposure to staining substances causing absorption and adsorption of stains.[1,2,4–6]

Several authors have shown the effect of beverages on the color stability of direct and indirect restorative materials[7–22] and acrylic resin denture bases.[23–28] The authors[7–9] observed that both composite and glass ionomer cement are susceptible to staining by the action of various beverages. Gawriołek et al.[14] evaluated the color stability of composites and ceramics after immersion in tea, red wine, coffee, and distilled water. The composites demonstrated lower color stability than the ceramic materials. Leite et al.[24] evaluated the color stability and durability of two soft liners using direct and indirect techniques after thermocycling and immersion in coffee, tea, soda, and red wine. In general, coffee was the solution that most altered the color of these materials. Polished specimens had lower color changes than nonpolished specimens.

There are few *in vitro* studies[1–3,5,29] evaluating the color stability of artificial teeth used in dentures. Studies[1,2,5] on the staining of acrylic resin denture teeth after exposure to beverages such as tea, coffee, cola, juice, or wine are restricted to a few brands. In these studies, the authors observed that all evaluated teeth had good color stability, but that the degree of coloration varied between them.

As the dental market offers a wide variety of denture teeth, a quality evaluation of denture teeth properties that is based on scientific findings is necessary to allow the best choices by clinicians. Thus, the aim of this study was to evaluate the color degradation of 10 different brands of acrylic resin denture teeth when exposed to different beverages (coffee, orange juice, and cola) for four immersion times (1, 7, 15, and 30 days) using spectrophotometry. The null hypothesis being tested was that there would be no significant color change in any of the denture teeth brands irrespective of staining solution and measurement period.

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2 Material and Methods

2.1 *Experimental Design*

In this study, 10 different brands of acrylic resin teeth (maxillary central incisors) for removable dentures [Art Plus (AP), Biolux (BX), Biotone IPN (BI), Magister (MG), Mondial 6 (MD), Premium 6 (PR), SR Vivodent PE (SR), Trilux (TR), Trubyte Biotone (TB), and Vipi Dent Plus (VP)] were evaluated (Table 1). Twenty-four specimens of each brand were used, resulting in a total of 240 specimens.

The denture teeth were immersed in three staining solutions (coffee, cola, and orange juice) and artificial saliva (control) ($n = 6$) for different periods (1, 7, 15, and 30 days).

2.2 *Preparation of Staining Solutions*

The coffee solution consisted of 20 g of coffee (Nescafé Original, Nestle, São Paulo, SP, Brazil) in 1000 mL of warm distilled water, and the solution was stirred until completely homogeneous.[2] The cola (Coke®, Coca-Cola Co., Americana, SP, Brazil) and orange juice (Del Valle, Coca-Cola Co., Americana, SP, Brazil) were obtained commercially. Artificial saliva was used for the control group.

The specimens were divided into individual vials, and six samples of each solution were obtained for each brand (6×4, $n = 24$). The vials were filled with 3 mL of each solution with each specimen being completely immersed and maintained at 37 ± 1°C. The solutions were changed every 3 days, and the solutions were agitated every day to reduce particle precipitation.[2]

2.3 *Spectrophotometric Analysis of Color Degradation*

The color of the specimens was measured using a spectrophotometer that measures ultraviolet-visible reflection (UV-2450, Shimadzu Corp., Kyoto, Japan). The specimens were placed in the center of this measuring device with the aid of a black silicone mold. The silicone mold was prepared from each tooth, such that repeated measurements for the same brand were always in the same position. Furthermore, the reading direction in the spectrophotometer was the same for all brands. This configuration prevented any external light source from entering the system.[2,3]

Before immersion of each set of denture teeth in the appropriate solutions, the specimens were stored in distilled water at 37 ± 1°C for 24 h to keep them hydrated. After 24 h of immersion, a color measurement of each tooth was performed (baseline—T0) using a spectrophotometer. After the first measurement (T0), the teeth were placed in containers, as described above. Subsequent measurements were taken after 1 day (T1), 7 days (T2), 15 days (T3), and 30 days (T4) of immersion in the solutions.[2]

Before each measurement was taken, the teeth were removed from the solution and washed with distilled water. Excess water on the surface of the tooth was removed with soft paper tissue. The spectrophotometer had previously been calibrated according to the manufacturer's standards using the white calibration standard.[2]

Color changes were calculated according to the International Commission on Illumination (Commission Internationale de l'Eclairage—CIE) $L * a * b*$ with the D65 illumination pattern.[3] The color systems are quantitative with rectangular coordinate systems and have a significant relationship with the visual perception of color change. Total color changes are expressed by the formula[30] $\Delta E* = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$, where ΔL, Δa, and Δb are the different values of $L*$, $a*$ and $b*$ before (T0) and after immersion for each time interval (T1, T2, T3, and T4).

2.4 *Statistical Analysis*

A limit of $\Delta E \leq 3.3$ was considered clinically acceptable in this study.[3,5,31] The effect of the type of denture tooth (10 levels), the solution (4 levels), the storage time (4 levels), and the interaction between these factors were analyzed by a three-way repeated measured analysis of variance (ANOVA). The means were

Table 1 Brand of denture teeth used.

Denture tooth	Code	Form/shade	Composition	Manufacturer	Lot number
Art Plus	AP	L46/A3	PMMA, BADMA	Dentsply Ind e Com Ltd., Petrópolis, RJ, Brazil	772524
Biolux	BX	V14/66	PMMA, EDMA	Vipi Ind Com Ltd., Pirassununga, SP, Brazil	7900
Biotone IPN	BI	A25/A3	PMMA	Dentsply Ind e Com Ltd.	788324
Magister	MG	468-11/B2	PMMA	Heraeus Kulzer, Hanau, Germany	66025789
Mondial 6	MD	R455-11/B2	PMMA	Heraeus Kulzer	66024350
Premium 6	PR	04-11/B2	PMMA	Heraeus Kulzer	66027958
SR Vivodent PE	SR	A64/2B	PMMA	Ivoclar Vivadent, Inc., Amherst, New York	F25667
Trilux	TR	E3/2B	PMMA, EDMA	Ruthibras Imp Exp Com de Materiais Odontol Ltd., Pirassununga, SP, Brazil	2800
Trubyte Biotone	TB	2D/66	PMMA, EDMA	Dentsply Ind e Com Ltd.	770721
Vip Dent Plus	VD	A25/66	PMMA, EDMA	Vipi Ind Com Ltd.	2700

Note: PMMA, polymethyl methacrylate; BADMA, butylene glycol dimethacrylate; EDMA, dimethacrylate of polymerized ethylene glycol.

compared using the Tukey honestly significant difference (HSD) test. Statistical software (StatView 5.0, SAS Institute, Inc., Cary, North Carolina) was used for the descriptive analysis and statistics. For all tests, alpha was considered to be 0.05.

The sample size of six was determined by preliminary tests in which that number of samples yielded adequate power (large effect size according to Cohen's d effect size statistics). At an alpha level of 0.05, this sample size was able to achieve a power of 0.789 for detecting statistically significant differences.

3 Results

Table 2 shows the mean and standard deviation of ΔE for each type of denture tooth for the different measurement periods and solutions. The obtained ΔE values showed no clinically significant change in color ($\Delta E > 3.3$) (Table 2). The largest color change occurred for the BI denture that was immersed in cola for 30 days, and the lowest color change was observed for the BX denture that was immersed in cola for 1 day.

Factors for dentures, solution, measurement period, tooth $\times$ solution, and time of measurement $\times$ tooth interactions were statistically significant (ANOVA) (Table 3). Considering the different brands of denture teeth, regardless of the measurement period and solution used, BI ($\Delta E = 1.82 \pm 0.95$) and TR ($\Delta E = 1.78 \pm 0.72$) had a higher degree of color change with no significant difference between them ($P = 1$). Meanwhile, BX ($\Delta E = 0.88 \pm 0.43$) and MD ($\Delta E = 1.09 \pm 0.44$) had the lowest values with no significant difference between them ($P = 0.396$); however, they were significantly different from BI and TR ($P < 0.05$) (Fig. 1).

In comparing solutions, regardless of the brand of denture tooth and measurement period, cola was the solution that caused the greatest degree of color change ($\Delta E = 1.51 \pm 0.83$), but there was no significant difference between cola and coffee ($\Delta E = 1.48 \pm 0.74$) ($P = 0.944$). However, cola was significantly different from orange juice ($\Delta E = 1.36 \pm 0.73$) ($P = 0.048$) and artificial saliva ($\Delta E = 1.18 \pm 0.59$) ($P < 0.0001$). Artificial saliva showed the lowest values of color change (Tukey HSD test).

In evaluating the ΔE values across the different measurement periods, regardless of the type of denture tooth and solution, 30 days ($\Delta E = 1.68 \pm 0.84$) of immersion produced statistically higher values of color change in the denture teeth ($P < 0.05$), which was followed by 15 days ($\Delta E = 1.40 \pm 0.72$). However, 1 day ($\Delta E = 1.20 \pm 0.62$) and 7 days ($\Delta E = 1.25 \pm 0.66$) of immersion produced similar color change values to each other ($P = 0.833$).

For all denture teeth, regardless of the measurement period, no significant differences were found between the staining solutions and artificial saliva, except for the BI teeth immersed in cola ($\Delta E = 2.18 \pm 1.13$, $P < 0.0001$) and orange juice ($\Delta E = 2.01 \pm 0.91$, $P = 0.01$) and for the TB teeth immersed in cola ($\Delta E = 1.84 \pm 0.8$, $P = 0.002$). All teeth showed similar color change values when immersed in artificial saliva ($P > 0.05$). For teeth immersed in coffee, the MG teeth showed the highest color change ($\Delta E = 2.06 \pm 0.92$), which was statistically significant in relation to BX ($\Delta E = 1.06 \pm 0.37$, $P < 0.0001$), TB ($\Delta E = 1.08 \pm 0.62$, $P < 0.0001$), SR ($\Delta E = 1.30 \pm 0.48$, $P = 0.021$), MD ($\Delta E = 1.15 \pm 0.46$, $P = 0.0004$), and AP ($\Delta E = 1.25 \pm 0.58$, $P = 0.007$) teeth. For the cola solution, the BI teeth showed the highest color change ($\Delta E = 2.18 \pm 1.13$), but there were similarities among TB ($\Delta E = 1.84 \pm 0.8$, $P = 0.999$), VD ($\Delta E = 1.86 \pm 0.82$, $P = 1$), and TR ($\Delta E = 1.88 \pm 0.77$, $P = 1$) teeth. When immersed in orange juice, the BI teeth showed the highest color change ($\Delta E = 2.01 \pm 0.91$), which was significantly different from BX ($\Delta E = 0.71 \pm 0.30$, $P < 0.0001$), SR ($\Delta E = 1.15 \pm 0.39$, $P = 0.002$), MD ($\Delta E = 1.08 \pm 0.38$, $P = 0.0003$), MG ($\Delta E = 1.24 \pm 0.64$, $P = 0.019$), and AP ($\Delta E = 1.07 \pm 0.44$, $P = 0.0002$) teeth (Fig. 2).

Regardless of the staining solution, there were no statistically significant differences between the measurement periods for all denture teeth except for TB ($\Delta E = 1.73 \pm 0.88$), PR ($\Delta E = 1.96 \pm 1.10$), and BI ($\Delta E = 2.52 \pm 0.89$) teeth, where the 30-day period produced the highest values of ΔE ($P < 0.05$). For the 1-day period, the BX tooth ($\Delta E = 0.75 \pm 0.35$) had the lowest amount of color change, and this value differed from BI ($\Delta E = 1.50 \pm 0.67$, $P = 0.026$) and TR ($\Delta E = 1.59 \pm 0.63$, $P = 0.003$) teeth. For the 7-day period, the TR tooth had the greatest color change ($\Delta E = 1.75 \pm 0.66$), and this value was significantly different from MD ($\Delta E = 0.97 \pm 0.52$, $P = 0.015$) and BX ($\Delta E = 0.76 \pm 0.35$, $P < 0.0001$) teeth. For the 15-day period, the TR tooth again had the highest value of ΔE ($\Delta E = 1.81 \pm 0.90$), and this value was significantly different from SR ($\Delta E = 1.09 \pm 0.35$, $P = 0.04$) and BX ($\Delta E = 0.90 \pm 0.36$, $P = 0.0004$) teeth. In the 30-day period, the BI tooth showed the highest color change ($\Delta E = 2.52 \pm 0.89$), but there was no significant difference with the TR ($\Delta E = 1.98 \pm 0.66$, $P = 0.589$), PR ($\Delta E = 1.96 \pm 1.10$, $P = 0.484$), and MG ($\Delta E = 1.85 \pm 0.78$, $P = 0.127$) teeth (Fig. 3).

4 Discussion

The null hypothesis was rejected, as statistically significant differences were found among the color changes of the denture teeth according to the solution and measurement period. However, all color changes were within the clinically acceptable range ($\Delta E \leq 3.3$); thus indicating a satisfactory color stability of the evaluated teeth.

The staining solutions used in this study act as an extrinsic factor for color alteration due to the absorption and adsorption of these stains.[1,2,4–6] Increase in solubility induces greater damage to the surface, affecting the surface roughness and the color of an acrylic resin.[28,32] As previously stated, specimens of soft liners with polished surface exhibited less color alteration than non-polished ones.[24] Therefore, it is possible to infer that the surface profile/topography affects the amount of staining of a material. The pH of the staining solution may be another driving force toward material color change. Acidic solutions promoted greater material's surface degradations. Increased surface area is more prone to be stained than the flattened one.[24]

Color changes can be evaluated clinically or by instrumental techniques by means of a spectrophotometer or calorimeter.[2,16] These devices minimize subjective errors and are more accurate than visual measurement.[10,17] In the present study, a spectrophotometer was used to measure the amount of reflected light, and the color was then evaluated by the CIE $L*a*b*$ color system. The $L*$ value is a measure of the whiteness or brightness of an object. The $a*$ value is a measure of the redness (positive $a*$) or greenness (negative $a*$). The $b*$ value is a measure of the yellowness (positive $b*$) or blueness (negative $b*$). The advantage of the CIE $L*a*b*$ system is that color differences may be expressed in units that can be related to visual perception and have clinical significance.[6.]

Table 2 Mean values (SDs) of color change (ΔE) in denture teeth.

		Measurement period			
Tooth	Solution	1 day	7 days	15 days	30 days
AP	Saliva	0.97 (0.66)	0.85 (0.66)	1.13 (0.62)	0.83 (0.28)
	Coffee	1.11 (1.02)	1.14 (0.22)	1.39 (0.15)	1.36 (0.62)
	Cola drink	0.78 (0.48)	1.13 (0.46)	1.81 (0.45)	1.91 (0.51)
	Orange juice	1.03 (0.42)	1.05 (0.66)	1.09 (0.39)	1.10 (0.37)
BX	Saliva	0.76 (0.12)	0.66 (0.34)	0.94 (0.28)	1.29 (0.45)
	Coffee	0.91 (0.47)	1.04 (0.29)	1.10 (0.41)	1.20 (0.29)
	Cola drink	0.61 (0.42)	0.62 (0.35)	0.91 (0.34)	1.20 (0.85)
	Orange juice	0.72 (0.30)	0.72 (0.32)	0.67 (0.34)	0.72 (0.33)
BI	Saliva	1.35 (0.38)	1.13 (0.86)	0.62 (0.26)	1.75 (0.88)
	Coffee	1.27 (0.50)	1.66 (0.53)	1.93 (0.53)	2.66 (0.40)
	Cola drink	1.69 (0.79)	2.06 (0.63)	2.12 (1.66)	2.87 (1.12)
	Orange juice	1.69 (0.93)	1.71 (0.36)	1.83 (1.16)	2.79 (0.69)
MG	Saliva	1.14 (0.50)	1.18 (0.42)	1.60 (0.71)	1.74 (0.47)
	Coffee	1.66 (0.86)	1.74 (0.94)	2.20 (0.91)	2.64 (0.85)
	Cola drink	1.12 (0.85)	1.21 (0.31)	1.47 (0.90)	1.63 (0.44)
	Orange juice	1.10 (0.85)	1.21 (0.40)	1.24 (0.58)	1.41 (0.79)
MD	Saliva	1.31 (0.39)	0.72 (0.35)	1.26 (0.46)	1.05 (0.36)
	Coffee	1.11 (0.42)	1.12 (0.66)	1.12 (0.52)	1.25 (0.29)
	Cola drink	1.03 (0.39)	0.95 (0.31)	1.02 (0.59)	1.17 (0.65)
	Orange juice	1.04 (0.22)	1.11 (0.68)	1.11 (0.25)	1.08 (0.29)
PR	Saliva	0.85 (0.36)	1.37 (1.14)	0.87 (0.38)	1.37 (0.28)
	Coffee	1.42 (0.59)	1.45 (0.66)	1.55 (0.40)	2.69 (1.39)
	Cola drink	1.33 (1.15)	1.37 (0.92)	1.37 (0.33)	1.83 (1.01)
	Orange juice	1.09 (1.05)	1.37 (0.92)	1.50 (0.23)	1.94 (1.21)
SR	Saliva	1.39 (0.16)	0.93 (0.59)	0.98 (0.36)	1.50 (0.25)
	Coffee	1.23 (0.26)	1.27 (0.43)	0.98 (0.36)	1.73 (0.56)
	Cola drink	1.25 (0.39)	1.26 (0.47)	1.19 (0.41)	1.31 (0.49)
	Orange juice	1.07 (0.42)	1.03 (0.52)	1.22 (0.28)	1.27 (0.35)
TR	Saliva	1.58 (0.43)	1.82 (0.82)	1.28 (0.48)	1.78 (0.71)
	Coffee	1.44 (0.80)	1.81 (0.76)	1.90 (0.59)	2.09 (0.58)
	Cola drink	1.69 (0.72)	1.71 (0.70)	2.11 (1.14)	2.01 (0.48)
	Orange juice	1.67 (0.66)	1.65 (0.53)	1.97 (1.15)	2.04 (0.93)

Table 2 (*Continued*).

Tooth	Solution	Measurement period 1 day	7 days	15 days	30 days
TB	Saliva	0.89 (0.28)	0.67 (0.66)	1.01 (0.44)	1.33 (0.71)
	Coffee	0.80 (0.51)	0.80 (0.34)	1.31 (0.50)	1.42 (0.87)
	Cola drink	1.27 (0.35)	1.66 (0.84)	1.97 (0.68)	2.45 (0.88)
	Orange juice	0.95 (0.40)	1.18 (0.73)	1.49 (0.64)	1.72 (0.74)
VD	Saliva	1.52 (0.48)	1.27 (0.62)	0.99 (0.38)	1.43 (0.52)
	Coffee	1.18 (0.68)	1.35 (0.48)	1.53 (0.47)	1.61 (0.95)
	Cola drink	1.54 (0.64)	1.52 (0.13)	2.14 (0.69)	2.22 (1.31)
	Orange juice	1.61 (0.60)	1.65 (0.16)	1.92 (0.88)	1.73 (0.51)

Table 3 Results of three-way repeated measures analysis of variance (ANOVA).

Source	*df*	SS	MS	F	*P* value
Tooth	9	79.696	8.855	15.400	<0.001[a]
Solution	3	16.465	5.488	9.545	<0.001[a]
Tooth × solution	27	32.858	1.217	2.116	0.002
Between subjects	200	115.002	0.575		
Measurement period	3	32.435	10.812	30.877	<0.001[a]
Measurement period × tooth	27	16.086	0.596	1.702	0.015
Measurement period × solution	9	5.802	0.645	1.841	0.058
Measurement period × tooth × solution	81	15.955	0.197	0.563	0.999
Within subjects	600	210.087	0.350		

[a]$P < 0.05$ denotes statistically significant difference.

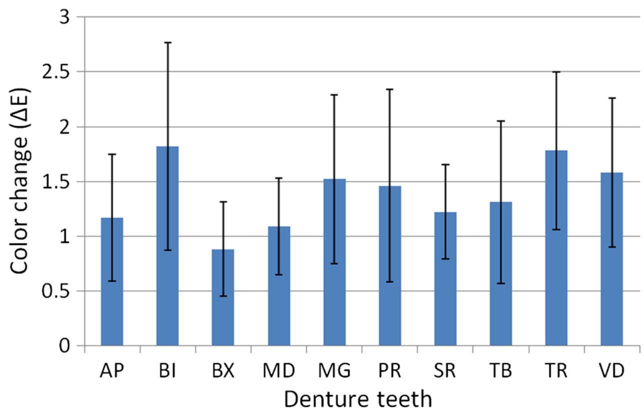

Fig. 1 ΔE mean values of denture teeth regardless of solution and measurement period.

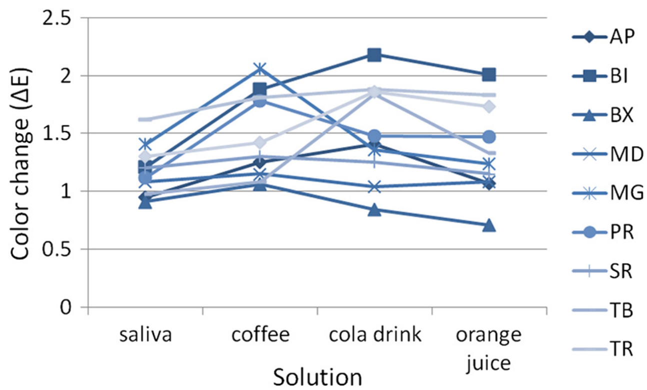

Fig. 2 ΔE mean values of denture teeth as a function of solution type, regardless of measurement period. Uniform standard deviations of ΔE averaged ±0.5 for AP, BX, MD, and SR teeth; ±0.6 for MG, TB, and VD teeth; and ±0.8 for BI, PR, and TR teeth.

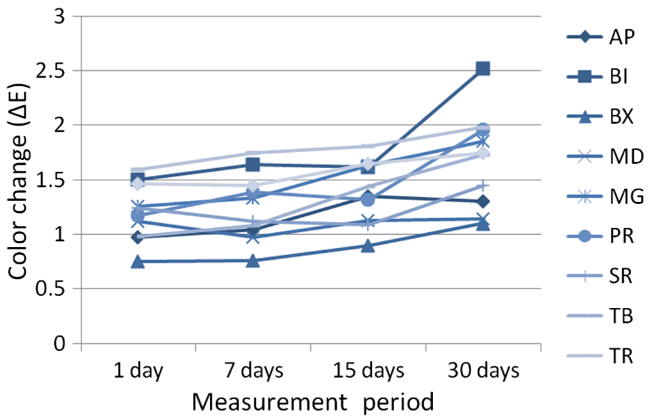

Fig. 3 ΔE mean values of denture teeth as a function of measurement period, regardless of solution. Uniform standard deviations of ΔE averaged ± 0.4 for BX, MD, and SR teeth; ± 0.6 for AP, TB, and VD teeth; and ± 0.7 for BI, MG, PR, and TR teeth.

To avoid factors such as superficial color and clarity of the sample influencing color determination,[16,17] a D65 lighting standard and black background were adopted. Other factors that may influence the evaluation of color are the smoothness and thickness of the sample; however, the sample thickness had no influence in this study, because the color determination was performed in two three-dimensional reference positions in color space $L * a * b *$.[17]

In addition to the light source of the spectrophotometer, the position of the specimen affects the color measurement. A silicone rubber device was manufactured in order to provide the maintenance of each denture tooth in the same position during all measurement periods. After each color measurement of each group, the spectrophotometer was calibrated with a 100% white color device, as an effort to avoid errors during color measurement.

Overall, the BI and TR teeth exhibited the highest values of ΔE with no significant difference between them. These data partially corroborate the results found by Assunçao et al.,[3] in which the greatest color change was found for the BI tooth. Kanie et al.[27] noted that the luminosity of the acrylic resin decreases as the material thickness increases. Therefore, it is believed that the BI and TR teeth are transversely thicker and have a high proportion of dark resin (less light transmission), which could explain the greater color change.

The lowest ΔE values were found for the BX and MD groups, corroborating previous results.[3] Acrylic resin teeth are essentially formed of polymethylmethacrylate and have a high conversion rate and low levels of dibenzoyl peroxide. Dibenzoyl peroxide remains after the conversion reaction and can cause deterioration of the color stability.[30] According to Assunção et al.,[3] BX and MD teeth have small quantities of dibenzoyl peroxide, explaining their reduced color change after staining for up to 30 days. In addition, hydrophilic materials generally exhibit a greater degree of color change than hydrophobic materials.[28] The use of hydrophobic monomers, such as 2-hydroxyethyl methacrylate, for the production of denture teeth can increase the color stability of these teeth. This result could explain why the BX and MD teeth had the lowest color change.

Cola and coffee were the staining solutions that caused the greatest degree of color change with no significant difference between them. This finding was consistent with several studies[1,2,5,16,18] that also concluded that coffee was the most chromogenic solution for different restorative materials. In the study by Mutlu-Sagesen et al.,[5] cola produced a slight color change in conventional acrylic resin, reinforced acrylic resin, and porcelain denture teeth.

In this study, the degree of staining of the denture teeth was time dependent, and a longer immersion in chromogenic solutions caused a greater color change of the denture tooth. These findings are in line with those of previous studies.[1,2,12,23] For the purposes of this study, an immersion period of 30 days was established. The use of this period was based on the fact that most *in vitro* studies[2,4,5,12,19,21,22] have used a time similar to 30 days to obtain a cumulative staining effect.

One limitation of this study may be the protocol used for staining because, clinically, saliva is present, and the teeth do not stay in contact with the staining solutions constantly or for over a long period. Furthermore, teeth are generally cleaned using mechanical means such as brushing, and the use of chemical agents such as mouthwashes and toothpaste that can alter topography and also interfere with staining.

The solutions were stored at 37°C, which simulated the oral cavity. However, coffee is normally ingested when hot, while cola is ingested when cold, and thus these temperature changes could also affect the color change as they can create more porosity, thereby changing the topography.[3]

The present study sought to evaluate the influence of chromogenic beverages on denture tooth staining; however, other factors may also influence color changes. Future studies evaluating the combined effect of brushing and staining solutions are warranted. Additionally, the effect of chemical cleaning agents on the color stability of artificial denture teeth is needed. For more practical information, longitudinal studies monitoring the color change of denture teeth of removable denture users is desired. This is important to evaluate how these different variables interact *in vivo*.

5 Conclusions

Notwithstanding the limitations of this *in vitro* study, the following conclusions were drawn:

1. Regarding the different brands of dentures teeth, BI and TR exhibited the greatest color degradation, and BX and MD showed the least color changes, which were independent of both solution and measurement period. However, all ΔE values were below 3.3, indicating that all the teeth were clinically acceptable.
2. Staining was dependent on time, with the coffee and cola solutions being the most chromogenic and the period with the highest color change being 30 days.

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References

1. W. C. Gregorius et al., "Effects of ageing and staining on color of acrylic resin denture teeth," *J. Dent.* **40**(Suppl 2), e47–e54 (2012).
2. T. Koksal and I. Dikbas, "Color stability of different denture teeth materials against various staining agents," *Dent. Mater. J.* **27**(1), 139–144 (2008).

3. W. G. Assuncao et al., "Effect of polymerization methods and thermal cycling on color stability of acrylic resin denture teeth," *J. Prosthet. Dent.* **102**(6), 385–392 (2009).
4. Y. Satoh et al., "Study on high-strength plastic teeth. Tooth discoloration," *J. Nihon Univ. Sch. Dent.* **35**(3), 192–199 (1993).
5. L. Mutlu-Sagesen et al., "Color stability of different denture teeth materials: an in vitro study," *J. Oral Sci.* **43**(3), 193–205 (2001).
6. A. Joiner, "Tooth colour: a review of the literature," *J. Dent.* **32**(Suppl 1), 3–12 (2004).
7. D. Dietschi et al., "Comparison of the color stability of ten new-generation composites: an in vitro study," *Dent. Mater.* **10**(6), 353–362 (1994).
8. R. M. Fay, C. S. Walker, and J. M. Powers, "Discoloration of a compomer by stains," *J. Gt. Houst. Dent. Soc.* **69**(8), 12–13 (1998).
9. N. Abu-Bakr et al., "Color stability of compomer after immersion in various media," *J. Esthet. Dent.* **12**(5), 258–263 (2000).
10. R. Bagheri, M. F. Burrow, and M. Tyas, "Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials," *J. Dent.* **33**(5), 389–398 (2005).
11. P. Villalta et al., "Effects of staining and bleaching on color change of dental composite resins," *J. Prosthet. Dent.* **95**(2), 137–142 (2006).
12. Y. Omata et al., "Staining of hybrid composites with coffee, oolong tea, or red wine," *Dent. Mater. J.* **25**(1), 125–131 (2006).
13. J. K. Subramanya and S. Muttagi, "In vitro color change of three dental veneering resins in tea, coffee and tamarind extracts," *J. Dent. (Tehran)* **8**(3), 138–145 (2011).
14. M. Gawriolek et al., "Color and luminescence stability of selected dental materials in vitro," *J. Prosthodont.* **21**(2), 112–122 (2012).
15. Y. F. Ren et al., "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–e56 (2012).
16. E. Ertas et al., "Color stability of resin composites after immersion in different drinks," *Dent. Mater. J.* **25**(2), 371–376 (2006).
17. A. U. Guler et al., "Effects of different drinks on stainability of resin composite provisional restorative materials," *J. Prosthet. Dent.* **94**(2), 118–124 (2005).
18. R. Scotti, S. C. Mascellani, and F. Forniti, "The in vitro color stability of acrylic resins for provisional restorations," *Int. J. Prosthodont.* **10**(2), 164–168 (1997).
19. C. M. Um and I. E. Ruyter, "Staining of resin-based veneering materials with coffee and tea," *Quintessence Int.* **22**(5), 377–386 (1991).
20. A. A. Kheraif et al., "Effect of different beverages on the color stability and degree of conversion of nano and microhybrid composites," *Dent. Mater. J.* **32**(2), 326–331 (2013).
21. S. A. Yannikakis et al., "Color stability of provisional resin restorative materials," *J. Prosthet. Dent.* **80**(5), 533–539 (1998).
22. M. Fujita et al., "Color change of newly developed esthetic restorative material immersed in food-simulating solutions," *Dent. Mater. J.* **25**(2), 352–359 (2006).
23. P. Imirzalioglu et al., "Color stability of denture acrylic resins and a soft lining material against tea, coffee, and nicotine," *J. Prosthodont.* **19**(2), 118–124 (2010).
24. V. M. Leite et al., "Effect of ageing and immersion in different beverages on properties of denture lining materials," *J. Appl. Oral Sci.* **18**(4), 372–378 (2010).
25. J. L. Shotwell, M. E. Razzoog, and A. Koran, "Color stability of long-term soft denture liners," *J. Prosthet. Dent.* **68**(5), 836–838 (1992).
26. F. Keyf and I. Etikan, "Evaluation of gloss changes of two denture acrylic resin materials in four different beverages," *Dent. Mater.* **20**(3), 244–251 (2004).
27. T. Kanie et al., "Color change in acrylic denture base resin reinforced with wire mesh and glass cloth," *Dent. Mater. J.* **22**(4), 425–435 (2003).
28. N. Hersek et al., "Color stability of denture base acrylic resins in three food colorants," *J. Prosthet. Dent.* **81**(4), 375–379 (1999).
29. P. M. Silva et al., "Effect of repeated immersion solution cycles on the color stability of denture tooth acrylic resins," *J. Appl. Oral Sci.* **19**(6), 623–627 (2011).
30. M. Rosentritt et al., "In vivo color stability of resin composite veneers and acrylic resin teeth in removable partial dentures," *Quintessence Int.* **29**(8), 517–522 (1998).
31. I. E. Ruyter, K. Nilner, and B. Moller, "Color stability of dental composite resin materials for crown and bridge veneers," *Dent. Mater.* **3**(5), 246–251 (1987).
32. C. Machado et al., "Influence of mechanical and chemical polishing in the solubility of acrylic resins polymerized by microwave irradiation and conventional water bath," *Dent. Mater.* **20**(6), 565–569 (2004).