

ORIGINAL ARTICLE

Evaluation of staining susceptibility of resin artificial teeth and stain removal efficacy of denture cleansers

SEVCAN KURTULMUS-YILMAZ¹ & SULE TUGBA DENIZ²

¹Department of Prosthodontics, Faculty of Dentistry, Near East University, Mersin 10, Turkey, and ²Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey

Abstract

Objective. To assess the staining susceptibility of four acrylic resin (Ivostar, SR Vivodent PE, Major Dent, Integral) and a nanocomposite resin (Veracia) artificial teeth and to evaluate the stain removal efficacy of denture cleansers. **Materials and methods.** Sixty maxillary incisors of each brand (total = 300) were divided into three groups according to staining solution as coffee, red wine and tea. Baseline color measurements were performed with a spectrophotometer. Specimens were immersed in staining solutions for 14 h (2 h × 7 days) and then second color measurements were performed. Each group was further divided into four sub-groups according to denture cleanser as Corega tabs, Fittydent, NaOCl (0.5%) and distilled water (control) ($n = 5$). Specimens were immersed in denture cleansers for 8 h and third color measurements were made. Thus, the weekly simulation period was completed. This cycle was repeated 12 times to simulate a 3-month time period and measurements were performed at the end of the 4th, 8th and 12th cycles. ΔE values were calculated and data were analyzed with 3-way repeated measures ANOVA and Bonferroni tests. **Results.** Significant color differences were found among the teeth and staining solutions, but all of the color differences were in the clinically acceptable range ($\Delta E < 5.5$). Integral showed the highest ΔE values for all solutions, while Ivostar and Vivodent demonstrated the lowest ΔE values for red wine and tea solutions. There was no significant difference among the denture cleansers in terms of stain removal efficacy. **Conclusions.** Cross-linked acrylic (Integral) and nanocomposite (Veracia) resin teeth were more susceptible to staining. Denture cleansers were efficient on stain removal from artificial teeth.

Key Words: acrylic resin, color stability, denture teeth, discoloration, nanocomposite

Introduction

Recently, esthetic demands and expectations of patients increased in every field of dentistry. For removable dentures, selection of artificial teeth is of great interest since the color stability and staining susceptibility of artificial teeth play a significant role in the overall esthetics of the denture [1,2]. Acrylic resin, porcelain and composite resin artificial teeth are available in the dental market for removable dentures. When the artificial teeth are compared in terms of color properties, porcelain teeth have a good resistance to discoloration [3]. Acrylic resin teeth are more prone to discoloration and wear [1]; however, they outshined with better chemical bonding to the denture base, lighter weight and higher resistance to fracture [3,4]. Therefore, to improve the physical and mechanical

properties of resin teeth, cross-linked acrylic, micro-filled hybrid and nanocomposite resin teeth were developed [5]. Cross-linked acrylic resin teeth may consist of various polymer structures; namely, blend polymer, interpenetrating polymer network (IPN), double cross-linking (DCL) and organic modified polymer network (OMP-N). Another approach to improve the mechanical properties of acrylic resin teeth was addition of inorganic fillers to the polymer matrix [4]. In the literature, there are numerous studies that assessed the effect of cross-linking agents and fillers on the wear resistance, hardness and bond strength of acrylic resin teeth to denture base. However, the data regarding the discoloration of reinforced resin artificial teeth [1–3,6] is limited.

Discoloration of artificial teeth may be caused by composition, wear, hygiene of patient and exposure to

staining solutions [2]. In previous studies [1–3,6] it has been suggested that artificial teeth exposed to coffee, tea, cola, red wine and curry solutions showed slight-to-noticeable color changes.

The extrinsic staining of teeth and denture may be removed by mechanical or chemical denture-cleansing regimens [7]. Numerous denture cleansers are available for chemical cleansing with various constituents, such as alkaline peroxides, alkaline hypochlorites, acids, disinfectants and enzymes [8]. The efficacy of different types of denture cleansers on stain removal from acrylic resin was investigated in a few studies [9,10] by measuring optical density. It has been suggested that all types of denture cleansers had a capacity to remove stain, but the tendency of a cleanser to remove stain is dependent on the formulation of the product itself [10]. In previous studies, only tea [9,10] and chlorhexidine [10] stain removal capacities of denture cleansers were evaluated. Moreover, to the best of the authors' knowledge, the color change of stained artificial teeth after exposure to denture cleansers has not been investigated. The aim of this *in vitro* study was to investigate the color change of five different brands of resin artificial teeth exposed to coffee, red wine and tea solutions and the effectiveness of denture cleansers on the stain removal from resin artificial teeth by evaluating the color difference (ΔE). The first null hypothesis of this study was that there is no difference among the artificial teeth in terms of staining susceptibility after immersion in staining solutions. The second null hypothesis of this study was that there is no difference among the stain removal efficacy of denture cleansers.

Materials and methods

Five different brands of artificial teeth (Table I), three staining solutions and three denture-cleansing agents (Table II) were used in the present study. Sixty maxillary central incisors of shade A2 of each brand were used, for a total of 300 specimens. Each brand of teeth was randomly divided into three equal groups according to staining solution as coffee, red wine and tea. Each group was further divided into four subgroups according to denture-cleansing protocol as Corega tabs, Fittydent, sodium hypochlorite and distilled water (control group) ($n = 5$). Before staining,

after staining and after denture cleansing protocols, color measurements were performed and ΔE values were calculated.

Color measurements

Before immersing in staining solutions, CIE $L^*a^*b^*$ color co-ordinates of each specimen were recorded with the use of a clinical spectrophotometer (VITA Easyshade Compact, VITA Zahnfabrik, Bad Säckingen, Germany). The contact probe tip of VITA Easyshade Compact is ~5 mm in diameter and, during the measurement process, the tooth is illuminated by the periphery of the tip, directing the light from white LEDs into the tooth surface. Each specimen was stored in distilled water at $37 \pm 1^\circ\text{C}$ for 24 h before color measurements. A silicon mold and a positioning transparent jig were prepared for each brand of teeth to standardize the repetitive color measurements. Specimens were placed into the silicone mold and measurements were repeated 3-times for each specimen, CIE $L^*a^*b^*$ values were recorded.

Staining and denture cleansing procedures

Filtered coffee (Starbucks Breakfast Blend, Amsterdam, Netherlands), red wine (Melen Merlot, Tekirdag, Turkey) and tea (Lipton Yellow Label Tea, Unilever, Turkey) were used as staining solutions in this study and all solutions were prepared according to manufacturers' instructions. Coffee solution was prepared by adding 100 g of coffee to 1800 ml of cold water into a filter machine and filtered. Tea solution was prepared by immersing 10 teabags into 2000 ml of boiled water for 2 min.

Twenty specimens of each brand were used for each staining solution and each group was randomly subdivided into four groups for evaluating the denture cleansing protocols. Each specimen was stored in a separate plastic container and the containers were coded according to the brand of artificial teeth, staining solution and denture cleanser.

The specimens were immersed in staining solutions for 14 h to simulate the weekly exposure time ($2 \text{ h} \times 7 \text{ days}$) with the beverages [11]. After the storage, the specimens were taken out of the solutions and they were rinsed with distilled water and

Table I. Artificial teeth used in the study.

Artificial teeth	Shade/form	Composition	Manufacturer	Lot No
Ivostar	A2/ 32	PMMA	Ivoclar Vivadent, Schaan, Liechtenstein	MT0552
SR Vivodent PE	A2/ A12	PMMA	Ivoclar Vivadent, Schaan, Liechtenstein	10295
Major Dent	A2V/18A	PMMA	Major Prodotti Dentari Spa, Moncalieri, Italy	9071
Integral	A2/ BM	Cross-linked PMMA (OMP-N)	Merz Dental GmbH, Lütjenburg, Germany	24008
Veracia	A2/06	Nanocomposite	Shofu Inc, Kyoto, Japan	1208

Table II. Denture cleansers used in the study.

Denture cleanser	Manufacturer	Principal ingredients
Corega Tabs	Block Drug Company Inc., Jersey City, NJ	Potassium monopersulfate, sodium bicarbonate, sodium lauryl sulfoacetate, sodium perborate monohydrate, sodium polyphosphate
Fittydent	Fittydent International GmbH, Pinkafeld, Austria	Sodium perborate, sodium bicarbonate, potassium monopersulfate, trisodium phosphate, sulfamic acid
Sodium hypochlorite	Prepared in laboratory	Water, 0.5% sodium hypochlorite

air-dried. Then, the color measurements were repeated as described above. After that, specimens were immersed in denture cleansers which were prepared according to the manufacturers' instructions or distilled water (control group) for 8 h. Then, they were rinsed with distilled water and air-dried and the third color measurements were performed. In this manner, the weekly procedure was completed. Afterwards, the specimens were immersed in fresh staining solutions for 14 h and then into fresh denture cleansers for 8 h, as described. This cycle was repeated 12-times to simulate the 3-month usage of denture. The color measurements were repeated at the end of the 4th, 8th and 12th cycles [11].

The CIE $L^*a^*b^*$ color differences between the baseline–1st week, –1st month, –2nd month and –3rd month were calculated for each specimen with the following formula:

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

where ΔL^* , Δa^* and Δb^* indicate the differences between the baseline and staining solution immersion and baseline and denture cleanser immersion. ΔE value >5.5 was considered clinically unacceptable and ΔE value >2.6 was considered as perceptible to the human eye [12].

Statistical analysis

Normality of the data distribution was checked by the Shapiro–Wilks test and parametric tests were chosen since the data were distributed normally. Three-way

repeated measures ANOVA was used for analysis and post-hoc comparisons were performed by using the Bonferroni test when significance was detected. Values of $p < 0.05$ were accepted as statistically significant.

Results

Color changes (ΔE values) of artificial teeth after immersion in staining solutions are shown in Table III and the results of three-way repeated measures ANOVA are shown in Table IV. All of the ΔE values were under the color mismatch acceptability threshold ($\Delta E < 5.5$). When the staining ability of solutions were evaluated statistically within each artificial teeth group, red wine showed significantly higher ΔE values compared to coffee and tea solutions ($p = 0.001$). Also, color changes caused by red wine solution were perceivable to the eye ($\Delta E > 2.6$). For coffee solution, ΔE values of Integral group and for tea solution ΔE values of Integral and Veracia groups were above the perceptibility threshold ($\Delta E > 2.6$).

Statistical analysis revealed that there were significant differences among artificial teeth for staining susceptibility ($p < 0.01$) (Table III). Integral showed the highest ΔE values for all solutions in comparison to the other artificial teeth ($p = 0.001$). For red wine and tea solutions, Ivostar and SR Vivodent PE were the least staining groups ($p < 0.05$), with no significant difference between them for both red wine ($p = 1.0$) and tea ($p = 0.98$) solutions. However, for the coffee group, there was no significant difference among Major Dent, Veracia, SR Vivodent PE and Ivostar

Table III. Means and standard deviations (SD) of ΔE values between the baseline and after staining.

Artificial teeth	ΔE (Baseline – Staining)					
	Coffee		Red wine		Tea	
	Mean	SD	Mean	SD	Mean	SD
Ivostar	0.8 ^a	0.38	3.7 ^c	0.89	1.3 ^f	0.48
SR Vivodent PE	1.3 ^{a,i}	0.67	3.5 ^c	0.81	1.7 ^{f,i}	0.95
Major Dent	1.6 ^{a,j}	0.68	4.6 ^d	0.93	2.5 ^{g,j}	1.12
Integral	3.3 ^b	1.21	5.1 ^e	1.29	4.3 ^h	1.23
Veracia	1.5 ^a	0.72	4.5 ^d	0.89	3.0 ^g	0.81

Same letters show no statistically significant difference.

Table IV. Results of three-way repeated measures ANOVA.

Source	Type III sum of squares	df	Mean square	F	p
Intercept	5074.539	1	5074.539	1646.8170	0.000
Staining solutions	400.949	2	200.475	65.059	0.000
Artificial teeth	326.939	4	81.735	26.525	0.000
Denture cleansers	1463.184	3	487.728	158.280	0.000
Staining solutions*Artificial teeth	55.204	8	6.900	2.239	0.026
Staining solutions*Denture cleansers	1090.376	6	181.729	58.976	0.000
Artificial teeth*Denture cleansers	142.776	12	11.898	3.861	0.000
Staining solutions*Artificial teeth*Denture cleansers	166.963	24	6.957	2.258	0.001
Error	665.587	216	3.081		

($p > 0.05$), whereas Integral showed the highest ΔE values ($p = 0.001$).

Color change of artificial teeth after staining and immersing in denture cleansers at different time periods are presented in Table V. Statistical analysis showed that there was no significant difference among the stain removal efficacy of denture cleansers (NaOCl, Corega tabs and Fittydent) for all of the artificial teeth groups stained with different solutions ($p = 1.0$). However, for red wine and tea stains, denture cleansers exhibited statistically significant lower ΔE values in comparison to the control group (distilled water) at the end of the 3rd month ($p = 0.001$). Baseline-staining ΔE values of the specimens immersed in red wine were significantly higher than the other time periods for all denture cleanser groups ($p = 0.001$). When the ΔE values were compared according to different time periods, specimens exposed to red wine and tea solutions and cleaned by distilled water (control group) showed significantly increasing ΔE values with time ($p = 0.001$). At the end of the 3rd month, all of the artificial teeth exposed to red wine and immersed in distilled water showed clinically unacceptable color changes ($\Delta E > 5.5$) and all of the teeth stained with tea and immersed in distilled water exhibited perceptible color changes ($\Delta E > 2.6$).

Discussion

Color stability of artificial teeth is an important factor to evaluate the longevity and patient acceptance of a removable denture. Artificial teeth are exposed to several beverages that can cause staining. Especially for removable partial dentures, the color difference between natural teeth and artificial teeth may cause an esthetically unpleasant view. Therefore, color stability of the artificial teeth is a critical selection criterion. In the present study, five different resin artificial teeth were exposed to three different staining solutions and the first null hypothesis was rejected since statistically significant differences were found among the color

changes of the artificial teeth according to the solution ($p < 0.05$). However, all color changes were within the clinically acceptable range ($\Delta E < 5.5$). The second null hypothesis was accepted, as no statistically significant difference was detected among the stain removal efficacy of denture cleansers.

In the present study, the CIE L*a*b* color system was used to measure color differences (ΔE). There are several *in vivo* and *in vitro* studies to determine the color perceptibility [12–16] and acceptability [12,15–19] thresholds for different dental materials. The threshold for perceptible and clinically acceptable color difference values ranged from 1.0 ΔE units [13] to 3.7 ΔE units [15] and 1.7 ΔE units [18] to 6.8 ΔE units [15], respectively. In an *in vivo* study, Douglas et al. [12] determined the thresholds using denture teeth. Therefore, in this study, the thresholds suggested by Douglas et al. [12] were used and $\Delta E < 2.6$ was evaluated as perceptible and $\Delta E > 5.5$ was evaluated as clinically unacceptable.

Staining susceptibility of artificial teeth was found to be material- and staining solution-dependent in this study. Among the artificial teeth evaluated, Integral demonstrated the highest color change for all the solutions tested, statistically. According to the manufacturer, Integral is a tight cross-linked OMP-N material. The staining susceptibility of Integral may be related to the difference in chemical structure of the material. Veracia, a nanocomposite artificial tooth, showed a perceptible discoloration when immersed into red wine and tea (Table III). Veracia consists of a co-monomer of urethane dimethacrylate (UDMA), methylmethacrylate, polymethylmethacrylate (PMMA) and nanosized fillers [5]. UDMA-based matrix resin has been reported to be more prone to discoloration [20]. The higher color change of Veracia may be relevant to the UDMA-based matrix of the nanocomposite resin.

In this study, conventional PMMA artificial teeth SR Vivodent PE and Ivostar exhibit a better color stability in comparison to reinforced acrylic and nanocomposite resin artificial teeth. However, another

Table V. Mean and SD of ΔE values of artificial teeth after staining and immersion into denture cleanser at different time periods.

Artificial teeth	Staining solutions	Denture cleansers	Baseline–Staining Mean \pm SD	Baseline–1 week Mean \pm SD	Baseline–1 month Mean \pm SD	Baseline–2 month Mean \pm SD	Baseline–3 month Mean \pm SD
Ivostar	Coffee	NaOCl	0.9 \pm 0.33	2.7 \pm 0.88	1.5 \pm 0.69	1.2 \pm 0.60	1.4 \pm 0.90
		Corega	0.8 \pm 0.39	2.5 \pm 0.77	1.0 \pm 0.47	1.5 \pm 0.47	1.5 \pm 0.24
		Fittydent	0.7 \pm 0.37	1.5 \pm 0.33	1.4 \pm 0.58	1.2 \pm 0.37	1.3 \pm 0.59
		DW	0.8 \pm 0.38	1.3 \pm 1.19	0.8 \pm 0.49	0.9 \pm 0.60	0.9 \pm 0.15
	Red Wine	NaOCl	4.2 \pm 0.82	0.7 \pm 0.56	0.8 \pm 0.56	0.9 \pm 0.36	1.1 \pm 0.70
		Corega	3.5 \pm 0.77	2.0 \pm 1.13	1.7 \pm 0.97	1.9 \pm 1.05	2.1 \pm 1.17
		Fittydent	3.5 \pm 0.68	1.2 \pm 0.21	0.8 \pm 0.43	0.9 \pm 0.39	1.2 \pm 0.50
		DW	3.7 \pm 0.79	1.3 \pm 0.96	3.7 \pm 0.55	8.8 \pm 1.38	13.4 \pm 1.33
	Tea	NaOCl	1.2 \pm 0.47	1.2 \pm 0.57	1.9 \pm 0.82	1.4 \pm 0.53	1.9 \pm 0.78
		Corega	1.2 \pm 0.39	0.7 \pm 0.29	0.8 \pm 0.11	0.7 \pm 0.53	0.6 \pm 0.24
		Fittydent	1.4 \pm 0.62	0.5 \pm 0.22	0.7 \pm 0.32	1.4 \pm 0.89	0.7 \pm 0.40
		DW	1.4 \pm 0.59	0.8 \pm 0.43	0.8 \pm 0.43	2.4 \pm 0.75	4.4 \pm 1.02
SR Vivodent PE	Coffee	NaOCl	1.3 \pm 0.63	1.5 \pm 1.76	1.5 \pm 0.96	1.3 \pm 0.60	0.9 \pm 0.75
		Corega	1.2 \pm 0.52	0.6 \pm 0.37	1.1 \pm 0.39	1.0 \pm 0.38	0.9 \pm 0.32
		Fittydent	1.3 \pm 0.73	1.6 \pm 0.86	0.4 \pm 0.43	0.9 \pm 0.47	1.0 \pm 0.92
		DW	1.5 \pm 0.49	0.7 \pm 0.47	1.2 \pm 0.98	1.4 \pm 0.92	1.5 \pm 0.60
	Red Wine	NaOCl	3.7 \pm 0.87	1.4 \pm 0.55	1.4 \pm 0.55	1.1 \pm 0.82	1.7 \pm 0.80
		Corega	3.6 \pm 0.92	2.7 \pm 0.74	1.5 \pm 0.97	1.6 \pm 0.99	1.9 \pm 1.14
		Fittydent	3.4 \pm 0.81	1.0 \pm 0.68	1.1 \pm 0.98	1.0 \pm 0.89	0.9 \pm 0.42
		DW	3.2 \pm 0.73	1.4 \pm 0.51	2.6 \pm 0.87	8.5 \pm 1.20	14.2 \pm 1.43
	Tea	NaOCl	1.8 \pm 0.99	1.4 \pm 0.72	1.3 \pm 1.08	1.2 \pm 0.24	0.7 \pm 0.40
		Corega	1.5 \pm 0.87	1.3 \pm 0.38	1.4 \pm 0.98	1.6 \pm 0.68	1.5 \pm 1.10
		Fittydent	1.6 \pm 0.92	1.2 \pm 0.75	1.6 \pm 0.33	0.8 \pm 0.93	1.2 \pm 1.03
		DW	2.0 \pm 0.94	2.1 \pm 1.13	1.7 \pm 0.71	1.6 \pm 0.56	3.6 \pm 1.08
Major Dent	Coffee	NaOCl	1.3 \pm 0.72	1.5 \pm 1.08	1.3 \pm 0.68	1.2 \pm 0.42	1.0 \pm 0.60
		Corega	1.8 \pm 0.64	0.6 \pm 0.38	1.3 \pm 0.57	1.6 \pm 0.84	1.1 \pm 0.61
		Fittydent	1.6 \pm 0.66	1.8 \pm 0.77	2.1 \pm 1.12	1.9 \pm 1.21	2.0 \pm 1.23
		DW	1.7 \pm 0.78	1.0 \pm 0.60	1.6 \pm 0.88	1.9 \pm 1.05	1.9 \pm 0.99
	Red Wine	NaOCl	4.4 \pm 0.92	1.4 \pm 0.35	1.6 \pm 1.11	1.0 \pm 0.09	1.0 \pm 0.32
		Corega	5.0 \pm 0.87	1.4 \pm 0.58	1.1 \pm 0.44	1.3 \pm 0.90	1.7 \pm 0.92
		Fittydent	4.6 \pm 0.99	0.9 \pm 0.38	1.6 \pm 0.98	1.5 \pm 0.64	1.4 \pm 0.78
		DW	4.4 \pm 0.93	0.7 \pm 0.35	4.5 \pm 0.73	5.8 \pm 1.07	9.5 \pm 1.23
	Tea	NaOCl	2.3 \pm 1.00	1.4 \pm 0.89	1.7 \pm 0.72	1.3 \pm 0.44	0.8 \pm 0.46
		Corega	2.2 \pm 0.99	1.5 \pm 0.65	2.4 \pm 1.08	1.2 \pm 0.40	1.4 \pm 0.58
		Fittydent	2.5 \pm 1.21	1.5 \pm 0.49	1.7 \pm 1.06	2.1 \pm 0.86	2.0 \pm 1.21
		DW	3.0 \pm 1.11	2.6 \pm 1.11	2.9 \pm 1.14	3.2 \pm 1.19	4.5 \pm 1.22
Integral	Coffee	NaOCl	2.1 \pm 1.21	0.6 \pm 0.56	1.2 \pm 0.64	2.1 \pm 1.09	1.9 \pm 1.19
		Corega	4.1 \pm 1.25	1.4 \pm 0.93	3.0 \pm 1.11	3.1 \pm 0.99	2.9 \pm 1.07
		Fittydent	2.3 \pm 1.18	0.8 \pm 0.20	0.9 \pm 0.50	1.5 \pm 1.01	2.1 \pm 1.22
		DW	4.5 \pm 1.15	2.6 \pm 1.21	3.7 \pm 1.14	3.5 \pm 1.12	2.8 \pm 1.03
	Red Wine	NaOCl	5.5 \pm 1.21	2.2 \pm 0.95	2.4 \pm 1.15	2.1 \pm 1.21	1.7 \pm 1.28
		Corega	5.1 \pm 1.28	2.4 \pm 1.18	1.7 \pm 1.01	2.1 \pm 1.08	1.1 \pm 0.68
		Fittydent	4.7 \pm 1.32	2.2 \pm 1.70	1.5 \pm 1.01	2.5 \pm 0.98	1.3 \pm 0.55
		DW	5.2 \pm 1.30	2.6 \pm 1.02	5.2 \pm 0.55	13.7 \pm 1.20	17.3 \pm 1.31
	Tea	NaOCl	4.0 \pm 1.20	1.8 \pm 1.10	2.6 \pm 0.65	1.2 \pm 0.66	1.3 \pm 0.69
		Corega	4.2 \pm 1.25	1.3 \pm 0.89	3.2 \pm 1.02	0.6 \pm 0.45	1.6 \pm 0.57

Table V. (Continued).

Artificial teeth	Staining solutions	Denture cleansers	Baseline–Staining Mean \pm SD	Baseline–1 week Mean \pm SD	Baseline–1 month Mean \pm SD	Baseline–2 month Mean \pm SD	Baseline–3 month Mean \pm SD
Veracia		Fittydent	4.4 \pm 1.22	2.7 \pm 0.82	3.9 \pm 0.95	1.3 \pm 1.08	1.9 \pm 1.00
		DW	4.7 \pm 1.24	4.1 \pm 1.15	5.9 \pm 0.94	5.2 \pm 1.21	5.3 \pm 1.23
	Coffee	NaOCl	1.3 \pm 0.77	0.9 \pm 0.43	0.7 \pm 0.35	0.8 \pm 0.17	0.9 \pm 0.37
		Corega	1.1 \pm 0.71	0.8 \pm 0.41	1.0 \pm 0.58	1.1 \pm 0.64	0.9 \pm 0.24
		Fittydent	1.4 \pm 0.69	1.2 \pm 0.56	0.9 \pm 0.43	1.5 \pm 1.02	1.1 \pm 0.38
		DW	2.0 \pm 0.73	1.1 \pm 0.61	1.6 \pm 0.73	2.5 \pm 0.93	2.2 \pm 1.00
	Red Wine	NaOCl	4.3 \pm 0.92	1.3 \pm 0.89	0.7 \pm 0.53	1.2 \pm 0.99	1.0 \pm 0.45
		Corega	4.7 \pm 0.88	1.0 \pm 0.46	1.6 \pm 0.95	0.6 \pm 0.19	1.1 \pm 0.56
		Fittydent	4.3 \pm 0.90	0.9 \pm 0.57	1.0 \pm 0.49	0.7 \pm 0.85	0.8 \pm 0.32
		DW	4.6 \pm 0.87	1.9 \pm 0.47	4.8 \pm 1.17	11.4 \pm 1.32	16.0 \pm 1.40
	Tea	NaOCl	3.2 \pm 0.79	0.9 \pm 0.59	1.4 \pm 0.28	1.4 \pm 0.28	1.6 \pm 0.51
		Corega	3.1 \pm 0.86	1.2 \pm 0.34	1.1 \pm 0.60	1.2 \pm 0.93	0.9 \pm 0.30
		Fittydent	2.7 \pm 0.85	0.7 \pm 0.67	1.7 \pm 1.12	0.9 \pm 0.58	0.9 \pm 0.69
		DW	3.1 \pm 0.74	1.5 \pm 0.26	2.6 \pm 0.26	3.6 \pm 0.94	4.9 \pm 1.02

PMMA-based teeth Major Dent showed higher ΔE values. PMMA-based teeth have a high conversion rate and contain low levels of dibenzoyl peroxide, which remain after the conversion reaction and may cause the deterioration of color stability [21]. The differences in staining susceptibility of the PMMA-based teeth may be due to the level of dibenzoyl peroxide existing in the material. The hydrophobic or hydrophilic character of the monomer liquid also affects the color stability of PMMA-based materials. Generally, hydrophilic materials show a greater degree of color change [22]. Higher ΔE values detected on Major Dent may be relevant to the more hydrophilic monomer liquid of the material.

Statistical analysis revealed that there are significant differences in staining ability of solutions. Red wine caused the highest discoloration in comparison to coffee and tea and for red wine solution the color differences of all artificial teeth were perceptible to the human eye ($\Delta E > 2.6$). This finding was consistent with the previous studies [23–25]. It has been reported that alcohol enables staining by softening the resin matrix [26]. Therefore, the alcohol component in red wine (13% alcohol by volume) tested in this study may cause surface roughness that facilitates the staining [26]. For Integral, Ivostar and Veracia, tea solution caused a higher color change than coffee ($p < 0.05$), while there were no significant differences between these solutions for SR Vivodent PE and Major Dent ($p > 0.05$). Consistently with the current study, it has been reported that tea has a greater discoloration effect on the polymeric dental materials than coffee [27,28].

The effectiveness of two peroxide type denture cleansers (Corega tabs, Fittydent) and an alkaline

hypochlorite solution on stain removal from artificial teeth was investigated in this study. Alkaline hypochlorites show efficiency by dissolving or solubilizing organic matter or matrices and they also have a disinfection effect on the dentures [9]. When alkaline peroxide effervescent tablets dissolve in water, the sodium perborate readily decomposes to form an alkaline peroxide solution that releases oxygen. Thereby, alkaline peroxides provide both chemical and mechanical cleaning through oxygen bubbles [29]. According to the results of statistical analysis, all of the denture cleansers were found to be efficient on stain removal compared to the control group. There was no significant difference among the denture cleansers in terms of stain removal efficacy ($p > 0.05$). In a previous study, Al-Huraisi et al. [10] compared different denture cleansers and reported that the efficiency of denture cleanser on stain removal was not related to whether the cleanser contained hypochlorite or peroxide, but it could be dependent on the formulation of the cleanser itself.

Significant differences were found among the artificial teeth in terms of staining susceptibility; however, after denture cleansing protocol there was no significant differences among the ΔE values of artificial teeth and all of the values except for the red wine control group were under the perceptible threshold. Besides the staining susceptibility, it is also important for artificial teeth to be cleansable for esthetics and longevity of the denture.

The texture of the surface resin plays an important role in retaining stain [9]. It has been suggested that 0.5% NaOCl [30] and alkaline peroxides [31] increased the surface roughness of PMMA. The effect of denture cleansers on the surface roughness of

nanocomposite resin is unknown. In the present study, surface roughness of artificial teeth was not investigated. However, the color differences between baseline and 3-month values of artificial teeth were under the color perceptible threshold. On the other hand, the staining of the artificial teeth between the denture cleansing protocols were not detected and the time period simulated in this study might be short. Therefore, it cannot be concluded that the denture cleansers had no effect on the staining susceptibility of resin teeth according to this study. In further investigations, it could be useful to study the effect of denture cleansers on the surface roughness and the correlation between surface roughness and staining susceptibility of the artificial teeth with long time periods.

Artificial teeth were exposed to denture cleansers for 8 h to simulate the overnight soaking as recommended by the manufacturers'. One of the limitations of this study may be the protocol used for simulation of the application frequency of denture cleansers, because the teeth were not cleaned chemically or mechanically during a week, thus the simulation was of a patient with poor maintenance. Another limitation was the types of denture cleansers tested. The ingredients of the peroxides were similar to each other and only one concentration of NaOCl was used. Further studies are needed to evaluate the efficacy of different types and concentrations of denture cleansers on the stain removal from artificial teeth.

Besides the efficacy on stain removal from artificial teeth, active ingredients of denture cleansers may have some side-effects on denture base materials. Peroxides and hypochlorites can cause bleaching of the acrylic resin [7] and hypochlorites can be corrosive to CoCr frameworks of partial removable dentures [7,9]. These effects of denture cleansers were not evaluated in this study and could be subject of further investigations.

Cross-linked acrylic and nanocomposite resin teeth are developed to improve mechanical properties of resin artificial teeth. However, according to the results of the present study, staining susceptibility of artificial teeth should also be taken into consideration. Patients may be warned about the staining effect of red wine and Corega, Fittydent and 0.5% NaOCl can be advised to patients that have staining beverages in their diets.

Within the limitations of this study the following conclusions were drawn:

- (1) Color changes of all artificial teeth after immersion in staining solutions were within a clinically acceptable range ($\Delta E < 5.5$).
- (2) There were significant differences among the artificial teeth in terms of staining susceptibility. Cross-linked acrylic (Integral) and nanocomposite (Veracia) resin teeth were found to be more

susceptible to staining, whereas conventional PMMA artificial teeth were found to be more resistant to staining.

- (3) Red wine solution caused the highest staining, regardless of the artificial teeth group.
- (4) All of the denture cleansers were found to be efficient on removal of coffee, tea and red wine stains. There was no statistically significant difference among the denture cleansers in terms of stain removal capacity.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

- [1] Koksall T, Dikbas I. Color stability of different denture teeth materials against various staining agents. *Dent Mater J* 2008; 27:139–44.
- [2] Gregorius WC, Kattadiyil MT, Goodacre CJ, Roggenkamp CL, Powers JM, Paravina RD. Effects of ageing and staining on color of acrylic resin denture teeth. *J Dent* 2012;40:e47–54.
- [3] Imamura S, Takahashi H, Hayakawa I, Loyaga-Rendon PG, Minakuchi S. Effect of filler type and polishing on the discoloration of composite resin artificial teeth. *Dent Mater J* 2008;27:802–8.
- [4] Stober T, Lutz T, Gilde H, Rammelsberg P. Wear of resin denture teeth by two-body contact. *Dent Mater* 2006; 22:243–9.
- [5] Suzuki S. In vitro wear of nano-composite denture teeth. *J Prosthodont* 2004;13:238–43.
- [6] Mutlu-Sagesen L, Ergün G, Ozkan Y, Bek B. Color stability of different denture teeth materials: an in vitro study. *J Oral Sci* 2001;43:193–205.
- [7] Alam M, Jagger R, Vowles R, Moran J. Comparative stain removal properties of four commercially available denture cleaning products: an in vitro study. *Int J Dent Hyg* 2011; 9:37–42.
- [8] Jagger D, Harrison A. Complete dentures – problem solving. London: British Dental Association; 1999. p 17–20.
- [9] Jagger DC, Al-Akhazam L, Harrison A, Rees JS. The effectiveness of seven denture cleansers on tea stain removal from PMMA acrylic resin. *Int J Prosthodont* 2002;15:549–52.
- [10] Al-Hurraishi H, Moran J, Jagger R, MacDonald E. Evaluation of stain removal and inhibition properties of eight denture cleansers: an in vitro study. *Gerodontology* 2013;30:10–17.
- [11] Saraç D, Saraç YS, Kurt M, Yüzbaşıoğlu E. The effectiveness of denture cleansers on soft denture liners colored by food colorant solutions. *J Prosthodont* 2007;16:185–91.
- [12] Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. *J Prosthet Dent* 2007;97:200–8.
- [13] Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. *Col Res Appl* 1979;4:83–91.
- [14] Seghi RR, Hewlett ER, Kim J. Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain. *J Dent Res* 1989;68:1760–4.
- [15] Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. *J Dent Res* 1989; 68:819–22.
- [16] Alghazali N, Burnside G, Moallem M, Smith P, Preston A, Jarad FD. Assessment of perceptibility and acceptability of color difference of denture teeth. *J Dent* 2012;40:e10–17.

- [17] Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater* 1987;3:246–51.
- [18] Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. *J Prosthet Dent* 1998;79:254–60.
- [19] Ragain JC Jr, Johnston WM. Color acceptance of direct dental restorative materials by human observers. *Col Res Appl* 2000;25:278–85.
- [20] 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;57:384–6.
- [21] Rosentritt M, Esch J, Behr M, Leibrock A, Handel G. In vivo color stability of resin composite veneers and acrylic resin teeth in removable partial dentures. *Quintessence Int* 1998;29:517–22.
- [22] Hersek N, Canay S, Uzun G, Yildiz F. Color stability of denture base acrylic resins in three food colorants. *J Prosthet Dent* 1999;81:375–9.
- [23] Guler AU, Yilmaz F, Kulunk T, Guler E, Kurt S. Effects of different drinks on stainability of resin composite provisional restorative materials. *J Prosthet Dent* 2005;94:118–24.
- [24] Rutkunas V, Sabaliauskas V, Mizutani H. Effects of different food colorants and polishing techniques on color stability of provisional prosthetic materials. *Dent Mater J* 2010;29:167–76.
- [25] Sepúlveda-Navarro WF, Arana-Correa BE, Borges CP, Jorge JH, Urban VM, Campanha NH. Color stability of resins and nylon as denture base material in beverages. *J Prosthodont* 2011;20:632–8.
- [26] Patel SB, Gordan VV, Barrett AA, Shen C. The effect of surface finishing and storage solutions on the color stability of resin-based composites. *J Am Dent Assoc* 2004;135:587–94.
- [27] Khokhar ZA, Razzoog ME, Yaman P. Color stability of restorative resins. *Quintessence Int* 1991;22:733–7.
- [28] Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. *Quintessence Int* 1991;22:377–86.
- [29] Budtz-Jørgensen E. Materials and methods for cleaning dentures. *J Prosthet Dent* 1979;42:619–23.
- [30] Paranhos Hde F, Peracini A, Pisani MX, Oliveira Vde C, de Souza RF, Silva-Lovato CH. Color stability, surface roughness and flexural strength of an acrylic resin submitted to simulated overnight immersion in denture cleansers. *Braz Dent J* 2013;24:152–6.
- [31] Peracini A, Davi LR, de Queiroz Ribeiro N, de Souza RF, Lovato da Silva CH, de Freitas Oliveira Paranhos H. Effect of denture cleansers on physical properties of heat-polymerized acrylic resin. *J Prosthodont Res* 2010;54:78–83.