

In vitro spectrophotometric evaluation of Vivera[®] clear thermoplastic retainer discolouration

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Aims: To investigate the in vitro effect of different staining solutions on the colour stability of Vivera[®] retainers.

Methods: Thirty flat specimens fabricated using the Vivera[®] material (Align Technology Inc., CA, USA) were assigned into five Groups (A, B, C, D and E) and immersed at 37°C in solutions of distilled water (control), coffee, tea, red wine, and Coca-Cola[®]. The CIE colour parameters (L*, a*, b*) of each specimen were measured before immersion (T₀) and after 12 hours (T₁), three days (T₂) and seven days (T₃) of solution exposure. Colour differences (ΔE) between the interval groups were calculated.

Results: Significant differences were observed concerning (i) L* between T₃ and T₀, T₁ and T₂ for Group B; (ii) a* between T₀ and T₁, T₂ and T₃ for Groups B, C, D and E, as well as between T₁ and T₂ for Group C; and (iii) b* between T₀ and T₁, T₂ and T₃ for Group B and between T₀ and T₂ and T₃ for Group C. The differences between $\Delta E(T_1-T_0)$, $\Delta E(T_2-T_0)$ and $\Delta E(T_3-T_0)$ were statistically significant for Groups B and C, as well as the difference between $\Delta E(T_1-T_0)$ and $\Delta E(T_2-T_0)$ for Group D.

Conclusions: Coffee, tea and red wine caused visible changes in the retainers' colour.

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Introduction

Several orthodontic retention protocols and devices have been proposed in order to minimise post-treatment change.^{1,2} Although removable retainers are preferable compared with fixed retainers in regard to oral hygiene, they require patient compliance and prolonged use.^{3,4} In order to increase patient acceptance of removable devices, clear thermoplastic retainers have been introduced as an aesthetically acceptable, comfortable and inexpensive alternative to conventional removable retainers.^{5,6} Whereas full-time wear of clear retainers immediately after the removal of fixed appliances is recommended, different

opinions exist concerning the length of time and the wear regimen of these devices.^{7,8,9}

Various materials are currently used for the fabrication of thermoplastic retainers. Most are polypropylene polymers (Essix C+, Raintree Essix, LA, USA) or copolyester polymers (TR, Bay Dental Direct, MI, USA). Align Technology Inc. (San Jose, CA, USA) recently introduced the Vivera[®] retainers using the same fabrication technology of 3D digital imaging as Invisalign[®] aligners. While thermoplastics have the potential to provide important aesthetic advantages and greater patient comfort during orthodontic retention,¹⁰ their chemical and physical properties

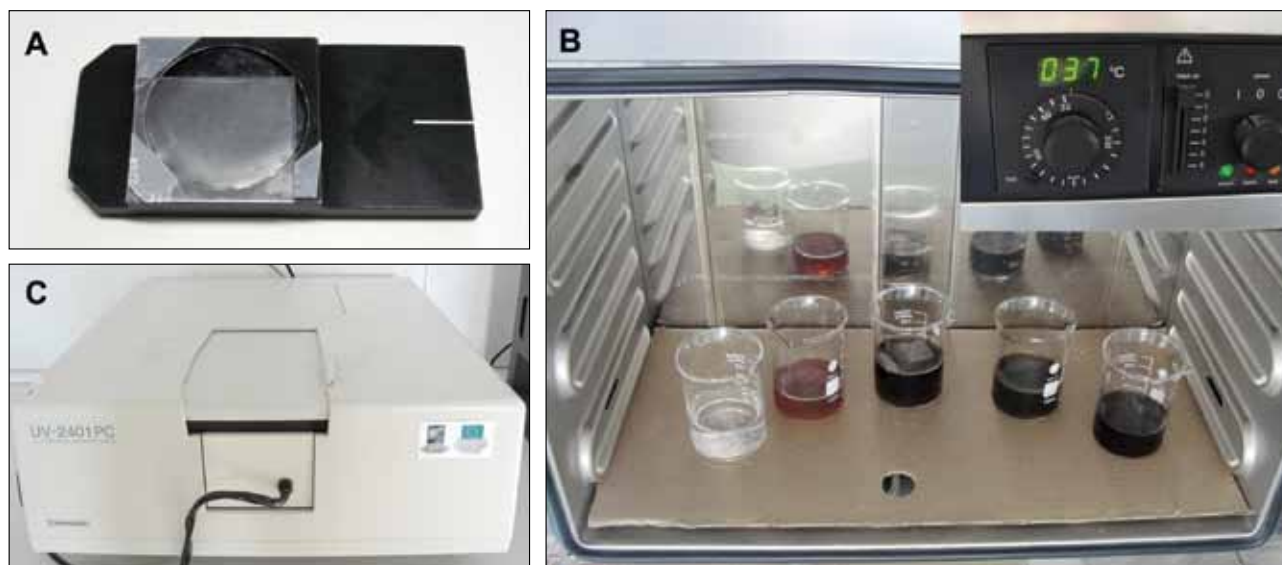


Figure 1. (A) The Vivera® material specimens positioned on the plate dish. (B) Immersion of Group A, B, C, D and E specimens in staining solutions. (C) The UV2401PC UV-VIS recording spectrophotometer.

may be compromised when used in the oral cavity.¹¹ Several studies have demonstrated poor wear resistance and durability along incisal and occlusal surfaces after only a few months of intra-oral use.^{12,13} Additionally, polyurethane, the basic constituent polymeric component of Invisalign® aligners, is not an inert material and is affected by heat, moisture, and prolonged contact with oral enzymes.^{14,15} From an aesthetic point of view, the stability of the colour and transparency of thermoplastic material during the full-time wear of clear retainers remains a critical parameter for clinicians and patients.

The aim of the present investigation was to study in vitro the effect of different staining solutions on the colour stability of Vivera® retainers. The null hypothesis was that there is no statistically significant difference in CIE (International Commission on Illumination) colour parameters L^* , a^* and b^* (lightness, red/green, and blue/yellow) of retainer material before and after solution immersion.

Materials and methods

Thirty flat specimens (23 mm x 23 mm) were fabricated using the Vivera® retainer material produced by Align Technology Inc. Each was subjected to thermal processing, and subsequently shaped with negative pressure similar to the manufacture of Vivera® retainers to ensure that the specimen's material had exactly the same chemical and mechanical properties as the commercially-available retainers (Figure 1A).

The specimens were randomly assigned into five groups ($N = 6$) and were immersed in various solutions at 37°C over several immersion cycles (Figure 1B). Group A, in which specimens were stored in distilled water at room temperature, served as a control group for Groups B, C, D and E. In Group B, specimens were stored in coffee (Nescafe Classic®, Nestle, Switzerland), which was prepared by dissolving 3.6 g of coffee powder in 300 ml of boiling distilled water as per the manufacturer's recommendations. In Group C, specimens were stored in tea (Yellow Label® tea, Lipton, Kenya). The tea solution was prepared by immersing for ten minutes, two prefabricated tea bags (2 x 1.5 g) into 300 ml of boiling distilled water. In Groups D and E, the specimens were stored in red wine (Rapsani®, Tsantali Vineyards & Wineries, Greece) and Coca-Cola® (Coca-Cola®, Coca-Cola Hellenic, Greece), respectively. After each immersion cycle, the specimens were removed, rinsed with tap water, and blot-dried before colour measurement. Fresh solutions were prepared after each staining cycle.

The UV2401PC UV-VIS Recording Spectrophotometer (Shimadzu®, Tokyo, Japan; UVPROBE software version 2.21), equipped with an integrating sphere in the detector system, as established by ISO recommendation, was used in the current study (Figure 1C). The spectrophotometric readings of each object were recorded and the colour of the measured specimen was identified in L^* a^* b^* colour parameters of CIE.¹⁶⁻¹⁸ The coordinate L^* is a measure of lightness similar to 'value' in the Munsell system,¹⁹ and ranges

from 0 (black) to 100 (white); a^* and b^* coordinates represent positions on a red/green and yellow/blue axis, respectively. The readings a^* and b^* combined provide the same information as 'hue' and 'chroma' in the Munsell system. The CIE Lab system arrangement is an approximately uniform three-dimensional colour space whose elements are equally spaced on the basis of visual colour perception, which is quantified based on standard observer curves and standard illuminants.^{16,17}

For each colour parameter, the unit of change is approximately equal as perceived by the human eye. The corresponding colour differences are therefore expressed in a unit that is related to the human eye's visual perception and this may be found to have clinical significance.²⁰

A standardised protocol for in vitro spectrophotometric colour evaluation was adopted for each specimen. All measurements were performed in the same spectrophotometer. The spectrophotometric data of each specimen was recorded at three consecutive times by positioning, removing and repositioning the specimen in the integration sphere of the spectrophotometer. All measurements were conducted by the first author by employing a repeated-measuring design ($N = 3$) at four time intervals:

(T_0): before specimen immersion into each solution (as received Vivera[®] specimen);

(T_1): after 12 hours of solution exposure;

(T_2): after three days of solution exposure; and

(T_3): after seven days of solution exposure.

The CIE colour parameters (L^* , a^* , b^*) were measured and averaged for each specimen and the resultant ΔE (colour differences) between the interval groups were calculated according to the following equation:

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

where i and ii represent the colour measurements made at two different time points.^{21,22}

A statistical analysis was conducted using the IBM Statistics SPSS 19.0 software and statistical significance was set at $p < 0.05$. A two-way ANOVA with repeated measures model was applied for the analysis of the data. In case of rejection of the sphericity assumption, the Greenhouse-Geisser method for the epsilon correction was used. Pairwise comparisons were done with the Bonferroni method.²³

Method's error

To evaluate intra-examiner agreement (the repeatability of placing the specimen on the plate dish and the positioning of the plate dish in the instrument's integration sphere) the spectrophotometric data (L^* , a^* and b^* chromatic parameters) of 20 specimens were recorded by the first author twice during the same day. The reproducibility of the measurements was estimated with Pearson's r correlation coefficient²⁴ and the magnitude of the method's error was computed by the limits of disagreement²⁴ and the Dahlberg's formula.²⁵

Results

To assess intra-examiner reliability, the L^* , a^* and b^* chromatic parameters of 20 specimens were measured twice in the same day. Pearson's r was found to be greater than 0.99 for the L^* parameter, 0.88 for the a^* parameter, and 0.94 for the b^* parameter. The limits of disagreement were found to be between -0.05 and 0.07 for the L^* parameter, between -0.09 and 0.08 for the a^* parameter and between -0.12 and 0.11 for the b^* parameter. The ΔE values were found to be between 0.01 (minimum) and 0.14 (maximum), which were far lower than the threshold value of 3.7. Dahlberg's magnitude of the method's error formula produced values equal to 0.02 for the L^* parameter, 0.03 for the a^* parameter, and 0.04 for the b^* parameter, respectively. Based on these results, the investigator's reliability was judged to be acceptable and the method's error insignificant.

Descriptive statistics and results are shown in Tables I and II. The main effect of the group and the interaction between time and group were found to be statistically significant (Tables III and IV), hence pairwise comparisons between the levels of the groups at each time level were conducted.

Statistically significant differences were found for the following variables:

The measurements of the L^* parameter at T_3 were significantly different in mean values from T_0 , T_1 and T_2 ($p = 0.001$, $p < 0.001$, and $p < 0.001$, respectively) for Group B (Figure 2).

The T_0 mean value of a^* parameter was significantly different from the mean values of T_1 , T_2 and T_3 ($p < 0.001$, $p = 0.001$, and $p < 0.001$, respectively) for Group B. For Group C, the T_0 mean value was significantly

Table I. Descriptive statistics for the L*, a* and b* parameters.

Group	T	L*			a*			b*		
		Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
A (water)	T ₀	33.128	0.54	0.244	0.182	0.04	0.012	-2.339	0.17	0.058
	T ₁	33.222	0.59	0.214	0.171	0.03	0.013	-2.312	0.12	0.075
	T ₂	33.412	0.69	0.263	0.172	0.03	0.017	-2.296	0.12	0.113
	T ₃	33.260	0.58	0.283	0.136	0.03	0.025	-2.227	0.15	0.119
B (coffee)	T ₀	33.526	0.50	0.244	0.151	0.02	0.012	-2.361	0.18	0.058
	T ₁	33.249	0.52	0.214	0.081	0.03	0.013	-1.966	0.16	0.075
	T ₂	33.142	0.60	0.263	0.070	0.03	0.017	-1.447	0.24	0.113
	T ₃	32.127	0.53	0.283	0.019	0.06	0.025	-.543	0.34	0.119
C (tea)	T ₀	33.007	0.84	0.244	0.203	0.01	0.012	-2.243	0.13	0.058
	T ₁	32.863	0.74	0.214	0.257	0.03	0.013	-1.901	0.24	0.075
	T ₂	32.613	0.95	0.263	0.352	0.08	0.017	-1.352	0.48	0.113
	T ₃	32.673	1.18	0.283	0.311	0.10	0.025	-.765	0.50	0.119
D (red wine)	T ₀	31.844	0.62	0.244	0.181	0.04	0.012	-2.293	0.10	0.058
	T ₁	31.834	0.37	0.214	0.279	0.04	0.013	-2.395	0.18	0.075
	T ₂	32.038	0.47	0.263	0.270	0.03	0.017	-2.376	0.18	0.113
	T ₃	32.165	0.55	0.283	0.254	0.03	0.025	-2.379	0.17	0.119
E (Coca-Cola)	T ₀	32.792	0.39	0.244	0.192	0.02	0.012	-2.221	0.11	0.058
	T ₁	32.922	0.29	0.214	0.158	0.02	0.013	-2.141	0.20	0.075
	T ₂	32.980	0.33	0.263	0.122	0.02	0.017	-1.992	0.21	0.113
	T ₃	33.128	0.31	0.283	0.100	0.05	0.025	-2.002	0.09	0.119

Table II. Descriptive statistics for ΔE parameter.

Group	Time	Mean	SD	SE
A (water)	$\Delta E(T_1-T_0)$	0.160	0.08	0.058
	$\Delta E(T_2-T_0)$	0.305	0.21	0.126
	$\Delta E(T_3-T_0)$	0.201	0.10	0.134
B (coffee)	$\Delta E(T_1-T_0)$	0.502	0.06	0.058
	$\Delta E(T_2-T_0)$	0.999	0.17	0.126
	$\Delta E(T_3-T_0)$	2.301	0.35	0.134
C (tea)	$\Delta E(T_1-T_0)$	0.552	0.10	0.058
	$\Delta E(T_2-T_0)$	1.164	0.45	0.126
	$\Delta E(T_3-T_0)$	1.975	0.25	0.134
D (red wine)	$\Delta E(T_1-T_0)$	0.501	0.25	0.058
	$\Delta E(T_2-T_0)$	0.749	0.45	0.126
	$\Delta E(T_3-T_0)$	0.838	0.56	0.134
E (Coca-Cola)	$\Delta E(T_1-T_0)$	0.199	0.13	0.058
	$\Delta E(T_2-T_0)$	0.349	0.09	0.126
	$\Delta E(T_3-T_0)$	0.431	0.16	0.134

different from the mean values at T₁, T₂ and T₃ ($p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively) and the T₁ mean value was significantly different from the T₂ mean. The T₀ mean was significantly different from the mean values at T₁, T₂ and T₃ ($p < 0.001$, $p < 0.001$, and $p = 0.039$, respectively) for Group D. Lastly, for Group E, the T₀ mean was significantly different from the mean values at T₁, T₂ and T₃ ($p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively) (Figure 3).

Statistically significant differences were found in the b* parameter between T₀ and T₁, T₂ and T₃ for Group B ($p < 0.001$) and between T₀ and T₁, T₂ and T₃ for Group C ($p = 0.001$, $p < 0.001$, and $p < 0.001$, respectively) (Figure 4).

The mean differences between $\Delta E(T_1-T_0)$, $\Delta E(T_2-T_0)$ and $\Delta E(T_3-T_0)$ were statistically significant for Groups B and C ($p < 0.001$) as well as the mean difference between $\Delta E(T_1-T_0)$ and $\Delta E(T_2-T_0)$ for Group D ($p = 0.031$) (Figure 5, Table V). Total ΔE observed differences ranged from 0.03 to 2.86 units.

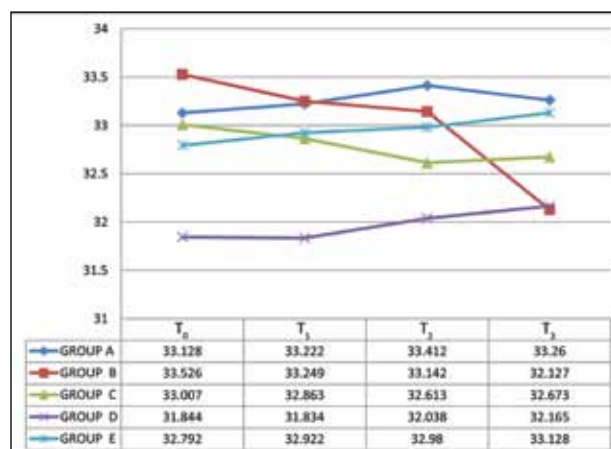


Figure 2. Estimated mean L^* values with 95% confidence intervals (CIs) produced from the ANOVA model.

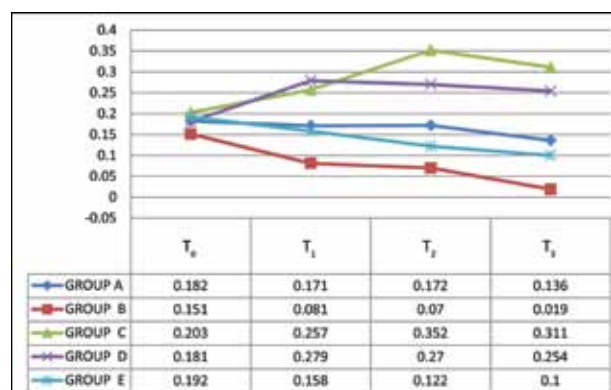


Figure 3. Estimated mean a^* values with 95% CIs produced from the ANOVA model.

Discussion

The results of the present study suggest that staining effects were more prominent in Group B (coffee), followed by Group C (tea) and Group D (red wine). Coffee seemed to cause a significant decrease in mean L^* and a^* values and an increase in the mean b^* value of the Vivera® material. This finding implied that the average retainer colour became darker and shifted more into the green and yellow ranges. Tea caused a significant increase in the mean a^* and b^* values of the Vivera® material, which indicated a colour shift more into the red and yellow ranges. Red wine increased, while Coca-Cola decreased the mean a^* value of the retainer colour, implying that the colour shifted more into the red and green ranges, respectively. Storage in water did not seem to affect the colour of the retainers during the immersion period used in this study. Statistically significant differences were also found in the ΔE parameter. Mean ΔE changes induced by coffee [mean $\Delta E(T_3-T_0) = 2.301$ units] and tea [mean $\Delta E(T_3-T_0) = 1.975$ units] were found to be visible

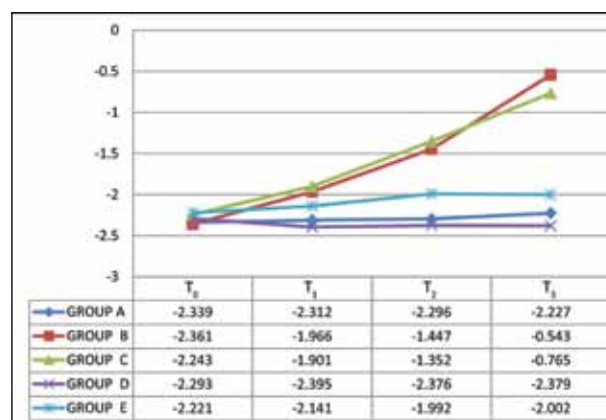


Figure 4. Estimated mean b^* values with 95% CIs produced from the ANOVA model.

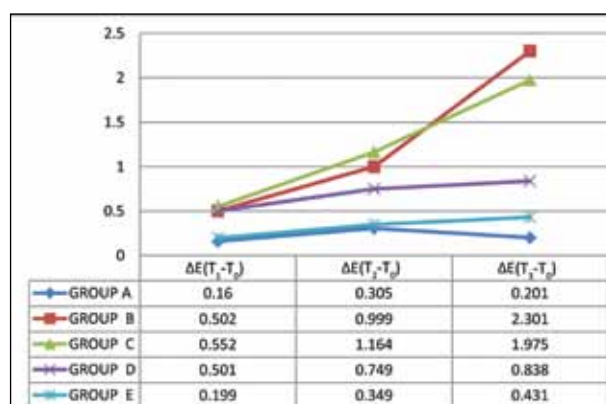


Figure 5. Estimated mean ΔE (colour difference) values with 95% CIs produced from the ANOVA model.

($\Delta E > 1$ unit) while changes induced from red wine were considered as invisible ($\Delta E < 1$).^{21,22} The total observed differences ranged from 0.03 to 2.86 units and were considered clinically acceptable ($1 < \Delta E < 3.7$),²⁶ although prolonged immersion in the staining solutions could possibly cause clinically significant changes in the specimen's colour.

Coffee, tea, red wine and Coca-Cola, among other drinks, are identified as staining solutions²⁷⁻³⁴ and for this reason they were used in the present study for staining effect evaluation. Coffee was found to be the most chromogenic agent among the solutions used. This finding was consistent with previous studies investigating the colour stability of different dental materials, such as denture teeth.^{32,35} Several studies have also concluded that coffee caused more staining than tea.^{27,29,31,35-37} Additionally, rinsing experiments have shown that tannic acid, included in tea, promoted the formation of a brown stained pellicle on teeth,³⁸ whereas black tea and red wine components have been shown to induce in vitro pellicle maturation.³⁹

Table III. Results of 2-way ANOVA for L*, a* and b* parameters.

Source	Type III sum of squares	Degrees of freedom	Mean square	F statistic	Significance (p-value)
L* Time	0.657	1.525	0.431	1.799	0.185
Time * Group	7.719	6.101	1.265	5.281	<0.001
Error (Time)	9.134	38.134	0.240		
Intercept	129070.844	1	129070.844	110939.301	0.000
Group	23.151	4	5.788	4.975	0.004
Error	29.086	25	1.163		
a* Time	0.018	2.085	0.009	4.071	0.021
Time * Group	0.183	8.341	0.022	10.435	<0.001
Error (Time)	0.110	52.130	0.002		
Intercept	4.020	1	4.020	1404.623	<0.001
Group	0.623	4	0.156	54.389	<0.001
Error	0.072	25	0.003		
b* Time	8.656	1.532	5.648	119.324	<0.001
Time * Group	10.306	6.130	1.681	35.518	<0.001
Error (Time)	1.814	38.312	0.047		
Intercept	469.300	1	469.300	3277.621	<0.001
Group	14.102	4	3.525	24.622	<0.001
Error	3.580	25	0.143		

Table IV. Results of 2-way ANOVA for ΔE parameter.

Source	Type III sum of squares	Degrees of freedom	Mean square	F statistic	Significance (p-value)
Time	8.866	2	4.433	116.502	<0.001
Time * Group	8.197	8	1.025	26.925	<0.001
Error (Time)	1.903	50	0.038		
Intercept	50.417	1	50.417	344.273	<0.001
Group	17.271	4	4.318	29.484	<0.001
Error	3.661	25	0.146		

The discolouration of polymeric materials may be caused by a wide array of sources including:

- extrinsic discolouration arising from the superficial absorption or adsorption of colour pigmentation of food dyes, coloured mouth rinses, plaque or the coloured components produced in plaque by chromogenic bacteria or from the chemical transformation of pellicle components;⁴⁰⁻⁴²
- discolouration of the surface from absorption or superficial penetration of staining agents passing through the oral cavity after chemical degradation

of the material surface or discolouration of the outer layers caused by superficial diffusion of hydrophilic colourings;⁴³

- internal discolouration derived from incomplete polymerisation;⁴³ and
- endogenous irreversible discolourations attributed to changes in the material's chemical structure.⁴³

In this in vitro investigation, the sample discolouration could be attributed to the extrinsic staining from absorption or the superficial penetration of the staining agents.

Table V. Pairwise comparisons between ΔE levels.

Group	(I) ΔE^a	(J) ΔE^a	Mean difference (I-J)	Standard error	Significance
A (water)	1	2	-0.145	0.098	0.452
		3	-0.041	0.122	1.000
	2	1	0.145	0.098	0.452
		3	0.104	0.117	1.000
	3	1	0.041	0.122	1.000
		2	-0.104	0.117	1.000
B (coffee)	1	2	-0.497*	0.098	0.000
		3	-1.799*	0.122	0.000
	2	1	0.497*	0.098	0.000
		3	-1.302*	0.117	0.000
	3	1	1.799*	0.122	0.000
		2	1.302*	0.117	0.000
C (tea)	1	2	-0.613*	0.098	0.000
		3	-1.423*	0.122	0.000
	2	1	0.613*	0.098	0.000
		3	-0.810*	0.117	0.000
	3	1	1.423*	0.122	0.000
		2	0.810*	0.117	0.000
D (red wine)	1	2	-0.248	0.098	0.053
		3	-0.337*	0.122	0.031
	2	1	0.248	0.098	0.053
		3	-0.089	0.117	1.000
	3	1	0.337*	0.122	0.031
		2	0.089	0.117	1.000
E (Coca-Cola)	1	2	-0.150	0.098	0.412
		3	-0.232	0.122	0.205
	2	1	0.150	0.098	0.412
		3	-0.082	0.117	1.000
	3	1	0.232	0.122	0.205
		2	0.082	0.117	1.000

^a1, $\Delta E(T_1 - T_0)$; 2, $\Delta E(T_2 - T_0)$; 3, $\Delta E(T_3 - T_0)$

*Statistically significant

Limited information is available regarding thermoplastic retainer colour change associated with staining agents and/or patient oral application. Substantial changes in retainer morphology have been reported, caused by speech, swallowing and bruxism, which alters the surface and structural characteristics of polyurethane material.^{11,15} External discolouration could be a function of time, temperature and pH while retainers are kept in mouth during the drinking of

acidic soft drinks, wine, coffee, tea, fruit juices or other liquids. Also adsorption of proteinaceous material and regional calcification of stagnation points, which have been shown to occur in the retainer's surface, could be factors influencing retainer colour.^{11,15} The stability of optical properties such as absorption, reflection, refraction and the scattering of light may be influenced by a number of factors existing in the oral cavity, including the continuous exposure to saliva,

crevicular fluid and the other organic and inorganic oral fluids,⁴⁴ while transparency loss of the retainer material has been shown to occur in vivo within a two-week wearing time.¹¹ It is also likely that internal discolouration could be caused by thermal energy and/or UV irradiation, which may induce physico-chemical reactions in the retainer polymer. However, there are no supportive studies available.

Care should therefore be taken in interpreting the results of in vitro studies concerning the effects induced by the oral cavity. The effects of staining agents on Vivera® retainers could be more prominent in vivo and could also be attributed to the type of thermoplastic material and its susceptibility to certain staining agents, while the magnitude of the effects could also increase over time with prolonged oral wear of the retainer. The results of the present investigation indicate the relative in vivo discolouration potential of coffee, tea and, to a lesser extent, red wine, on the specific material.

The influence of systematic and random errors on the quantitative evaluation of retainer colour and the precision of the spectrophotometric measurements constituted limitations of this in vitro trial. Systematic errors, which are inherent in all instruments,⁴⁵ are difficult to manage and can adversely affect instrument accuracy regardless of the control of the environment or the degree of precision.⁴⁶ The uncertainty of the measuring process is associated with random errors, which were minimised in this study by averaging repeated measurements and control of the methodological factors.⁴⁷

Knowledge of the effects of the staining potential on the retainer's surface could guide clinicians regarding the instructions provided to patients upon retainer insertion, so that better long-term retainer maintenance and colour stability are preserved. The present findings suggest that it is important for patients to avoid drinking staining beverages, such as coffee and tea, while keeping the retainers in the mouth. Further studies would be necessary to enhance the physical and optical properties of thermoplastic material when retainers are subjected to the hostile conditions of the oral cavity.

Conclusion

This study indicates that the colour of Vivera® retainers exhibited changes induced by several staining

solutions, especially coffee, tea and, to a lesser extent, red wine. In the rejection of the null hypothesis, the CIE colour parameters L^* , a^* , and b^* of retainers showed statistically significant differences.

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References

1. Melrose C, Millett DT. Toward a perspective on orthodontic retention? *Am J Orthod Dentofacial Orthop* 1998;113:507-14.
2. White LW. Retention strategies: a pilgrim's progress. *J Clin Orthod* 1999;33:336-8.
3. Heier EE, De Smit AA, Wijgaerts IA, Adriaens PA. Periodontal implications of bonded versus removable retainers. *Am J Orthod Dentofacial Orthop* 1997;112:607-16.
4. Wang F. A new thermoplastic retainer. *J Clin Orthod* 1997;31:754-7.
5. Lindauer SJ, Shoff RC. Comparison of Essix and Hawley retainers. *J Clin Orthod* 1998;32:95-7.
6. Sheridan JJ, Gaylord RE, Hamula W, Hickham JH, Kokich VG, Tuversen DL. JCO Roundtable: finishing and retention. *J Clin Orthod* 1992;26:551-64.
7. Gill DS, Naini FB, Jones A, Tredwin CJ. Part-time versus full-time retainer wear following fixed appliance therapy: a randomized prospective controlled trial. *World J Orthod* 2007;8:300-6.
8. Jäderberg S, Feldmann I, Engström C. Removable thermoplastic appliances as orthodontic retainers—a prospective study of different wear regimens. *Eur J Orthod* 2012;34:475-9.
9. Thickett E, Power S. A randomized clinical trial of thermoplastic retainer wear. *Eur J Orthod* 2010;32:1-5.
10. Hichens L, Rowland H, Williams A, Hollinghurst S, Ewings P, Clark S et al. Cost-effectiveness and patient satisfaction: Hawley and vacuum-formed retainers. *Eur J Orthod* 2007;29:372-8.
11. Gracco A, Mazzoli A, Favoni O, Conti C, Ferraris P, Tosi G et al. Short-term chemical and physical changes in Invisalign appliances. *Aust Orthod J* 2009;25:34-40.

12. Gardner GD, Dunn WJ, Taloumis L. Wear comparison of thermoplastic materials used for orthodontic retainers. *Am J Orthod Dentofacial Orthop* 2003;124:294-7.
13. Pascual AL, Beeman CS, Hicks EP, Bush HM, Mitchell RJ. The essential work of fracture of thermoplastic orthodontic retainer materials. *Angle Orthod* 2010;80:554-61.
14. Eliades T, Eliades G, Watts DC. Structural conformation of in vitro and in vivo aged orthodontic elastomeric modules. *Eur J Orthod* 1999;21:649-58.
15. Schuster S, Eliades G, Zinelis S, Eliades T, Bradley TG. Structural conformation and leaching from in vitro aged and retrieved Invisalign appliances. *Am J Orthod Dentofacial Orthop* 2004;126:725-8.
16. International Commission on Illumination, ed. Colorimetry, Official Recommendations of the International Commission on Illumination. Publication CIE No. 15 (E-1.3.1). Paris: CIE, 1971.
17. Hunter RS, Harold RW. The Measurement of Appearance. 2nd edn. New York: John Wiley & Sons, 1987.
18. Paul S, Peter A, Pietrobon N, Hämmerle CH. Visual and spectrophotometric shade analysis of human teeth. *J Dent Res* 2002;81:578-82.
19. Munsell AH. A colour notation. Baltimore: Munsell Colour, 1961.
20. Seghi RR, Johnston WM, O'Brien WJ. Spectrophotometric analysis of colour differences between porcelain systems. *J Prosthet Dent* 1986;56:35-40.
21. Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. *Color Res Appl* 1979;4:83-91.
22. Seghi RR, Hewlett ER, Kim J. Visual and instrumental colorimetric assessments of small colour differences on translucent dental porcelain. *J Dent Res* 1989;68:1760-4.
23. Ho R. General Linear Model: Repeated Measures Analysis. In: Ho R. Handbook of Univariate and Multivariate Data Analysis and Interpretation with SPSS. Boca Raton: Chapman and Hall/CRC, 2006:117-82.
24. Indrayan A. Approaches for Measuring Quantitative Agreement. In: Indrayan A. Medical Biostatistics. Boca Raton: Chapman and Hall/CRC, 2008:564-7.
25. Dahlberg G. Statistical methods for medical and biological students. London: George Allen and Unwin Ltd, 1940:122-32.
26. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. *J Dent Res* 1989;68:819-22.
27. Chan KC, Fuller JL, Hormati AA. The ability of foods to stain two composite resins. *J Prosthet Dent* 1980; 43:542-5.
28. Cooley RL, Barkmeier WW, Matis BA, Siok JF. Staining of posterior resin restorative materials. *Quintessence Int* 1987;18:823-7.
29. Ertaş E, Güler AU, Yücel AC, Köprülü H, Güler E. Color stability of resin composites after immersion in different drinks. *Dent Mater* 2006;25:371-6.
30. Khokhar ZA, Razzoog ME, Yaman P. Color stability of restorative resins. *Quintessence Int* 1991;22:733-7.
31. Luce MS, Campbell CE. Stain potential of four microfilled composites. *J Prosthet Dent* 1988;60:151-4.
32. 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.
33. Polyzois GL, Yannikakis SA, Zissis AJ. Color stability of visible light-cured, hard direct denture reliners: an in vitro investigation. *Int J Prosthodont* 1999;12:140-6.
34. Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. *Quintessence Int* 1991;22:377-86.
35. Koksall T, Dikbas I. Color stability of different denture teeth materials against various staining agents. *Dent Mater J* 2008;27:139-44.
36. Chan KC, Hormati AA, Kerber PE. Staining calcified dental tissues with food. *J Prosthet Dent* 1981;46:175-8.
37. Scotti R, Mascellani SC, Forniti F. The in vitro color stability of acrylic resins for provisional restorations. *Int J Prosthodont* 1997;10:164-8.
38. Nordbo H. Discoloration of dental pellicle by tannic acid. *Acta Odontol Scand* 1977;35:305-10.
39. Joiner A, Muller D, Eloffson UM, Malmsten M, Arnebrant T. Adsorption from black tea and red wine onto in vitro salivary pellicles studied by ellipsometry. *Eur J Oral Sci* 2003;111:417-22.
40. Inokoshi S, Burrow MF, Kataumi M, Yamada T, Takatsu T. Opacity and color changes of tooth-colored restorative materials. *Oper Dent* 1996;21:73-80.
41. Yap AU, Sim CP, Loganathan V. Polymerization color changes of esthetic restoratives. *Oper Dent* 1999;24:306-11.
42. Vogel RI. Intrinsic and extrinsic discoloration of the dentition (a literature review). *J Oral Med* 1975;30:99-104.
43. Eliades T, Gioka C, Heim M, Eliades G, Makou M. Color stability of orthodontic adhesive resins. *Angle Orthod* 2004;74:391-3.
44. Karamouzos A, Athanasiou AE, Papadopoulos MA, Kolokithas G. Tooth-color assessment after orthodontic treatment: a prospective clinical trial. *Am J Orthod Dentofacial Orthop* 2010;138:537.e1-8.
45. Berns RS. Measuring color. In: Berns RS, ed. Billmeyer and Saltzman's Principles of Color Technology. New York: John Wiley and Sons, 2000:95-105.
46. Douglas RD. Precision of in vivo colorimetric assessments of teeth. *J Prosthet Dent* 1997;77:464-70.
47. Karamouzos A, Papadopoulos MA, Kolokithas G, Athanasiou AE. Precision of in vivo spectrophotometric colour evaluation of natural teeth. *J Oral Rehabil* 2007;34:613-21.