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In Vitro Color Stability of Provisional Crown and Bridge Restoration Materials

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Discoloration of provisional restorations can be an esthetic problem, especially when the treatment plan requires long-term provisionalization. In this study, therefore, we examined the effects of staining solution on the color stability of these provisional crown and bridge restoration materials: Structur, Temdent, and Tab 2000. Treatment solutions were namely carrot juice, tea, cola, light cola, and distilled water. Thirty samples were prepared for each type of provisional material, such that a total of 90 samples were prepared. The color value of each sample was measured with a colorimeter at baseline and after one day, one week, two weeks, and four weeks of immersion in various treatment solutions. Results were determined using the CIELAB system. Color change data were calculated and subjected to two-way analysis of variance. To examine significant interactions, one-way ANOVA and Tukey's multiple comparisons test were performed to identify differences between the solutions ($p \leq 0.05$).

After four weeks of treatment, color difference values were found to range from 0.20 to 3.99 ΔE^* units. The highest color difference values were obtained in carrot juice, cola, and tea with Structur samples after four weeks, where these values were categorized as "noticeable" and "unacceptable" color change values. Based on the results of this study, we do not recommend amine-containing Structur to be used as a provisional crown and bridge restorative material for treatments of a longer duration.

Key words: Color stability, Provisional restoration materials, Staining

INTRODUCTION

To achieve esthetic and functional excellence in fixed prosthodontics is the ultimate reward for meticulous attention to the minutest detail at each stage of the treatment. A crucial factor to this success is a high-quality provisional restoration. The interim crown or fixed partial denture must be a mirror image of the definitive restoration, where the only variable is the material[1]. In addition, a provisional restoration provides protection for the dentin-pulpal system, stabilizes occlusal relationships, serves as a temporary measure for periodontal prophylaxis as well as for functional and esthetic concerns until the fixed restoration is ready[2].

The mean duration of a provisional fixed prosthesis is approximately 20 to 30 days. However clinical delay, disease, and financial considerations may prolong this period, thus leading to substantial color alterations[3]. Ideally, provisional restorative materials should not change in color or appearance following fabrication, but clinicians are familiar with the color alteration problem of provisional restorative materials[4]. In particular, if the provisional material is to be used in an esthetically critical area, color stability of the material is a primary concern and significant criterion[5]. This is because discoloration of provisional material for fixed prosthodontics may lead to dissatisfaction of both the patient and the dentist, thereby translating to additional replacement expense[6].

When choosing a temporary restorative material, minimized color change should be a key consideration[7]. In general, there are three types of provisional restorative material (PRM) discoloration: 1) external discoloration due to the accumulation of plaque and surface stains; 2) surface or sub-surface color alteration implying a superficial degradation or a slight penetration and reaction of staining agents within the superficial layer of PRM (adsorption); or 3) body or intrinsic discoloration due to physico-chemical reactions in the deeper portions of the restoration[8−14]. For external staining, it can be caused by compounds which are incorporated into the pellicle and which produce staining due to their basic color, or it can be caused by compounds that induce staining due to chemical interaction at the tooth or provisional restoration surface[15].

Direct staining has a multi-factorial etiology with chromogens derived from dietary sources or being habitually placed in the mouth. These organic chromogens are taken up by the pellicle, and the natural color of the chromogen determines the color imparted. Tobacco smoking and chewing are known to cause staining, as are particular beverages such as tea and coffee. The color seen on the tooth and PRM is thought to be derived from polyphenolic compounds which provide the color in food. Indirect

external staining, on the other hand, is associated with cationic antiseptic and metal salts[15].

Several techniques have been employed to evaluate color changes of dental materials – using immersion solutions[5-14,16-23] and through accelerated aging[5,24-26]. For example, some researchers have used immersion solutions such as coffee[3,6,8,9,16,17,19,23], tea[9,16,17,19,23], cola[9,16,20,21], light cola[14,16,17], grape[7], carrot[12], orange juice[8,16], distilled water[6,8,9,14,16,18,23], clorhexidine[3,8], artificial saliva and artificial saliva-coffee[22] over measured time intervals to compare the effects on color stability of provisional and direct restorative resins. As for color measurement instruments, spectrophotometers and colorimeters are used primarily in dental research but not in clinical practice. However, instrumental color analysis offers a potential advantage over visual color determination in that instrumental readings are sensitive, repeatable, objective, can be quantified, and are obtained more rapidly[27].

The purpose of this study was to evaluate the color change of these chemically polymerizing provisional crown and bridge materials at one day, one, two, and four weeks after immersion in distilled water, coca cola, light cola, tea, and carrot juice solutions.

MATERIALS AND METHODS

Table 1 lists the trade name, code, manufacturer, composition, mixing ratio and polymerization time of the three provisional crown and bridge restorative materials evaluated in this study.

These three chemically polymerized provisional crown and bridge restoration materials were immersed in different staining solutions (carrot juice, tea, cola, light cola) and distilled water, where the detailed information of each treatment solution is given in Table 2. After one day, one week, two weeks, and four weeks, their color changes were measured with a Gardner XL 20 Tristimulus Colorimeter (Gardner Lab. Inc. Bethesda MD, Maryland, USA).

For each provisional fixed prosthesis material, 30

Table 1 Properties of the provisional crown and bridge materials used

Trade Name	Codes	Manufacturer	Composition	Mixing ratio Powder/Liquid	Polymerization Time (mm)
Structur (Cold curing resin)	ST	Voco Cuxhaven Germany	Methacrylate Benzoyl peroxide and amine	2 parts by v/ 1 part by v	10
Tab 2000 (Cold curing resin)	TAB	Kerr Italia	Methyl methacrylate N, N dimethyl, P-Toluidine	3 parts by v/ 1 part by v	9
Temdent (Cold curing resin)	TEM	Weil Dental GmbH Rosbach Germany	Poly methyl methacrylate and copolymer methyl methacrylate acid ester	Appropriate amount of p/ 1 drop	7

Table 2 Solutions used in this study

Product Name	Code	Ingre dients	Manufacturer
Carrot juice	CJ	100% fresh carrot juice	Freshly squeezed
Tea	T	10g tea/1L boiled water	Lipton Earl Grey Turkey
Cola	CO	Water, sugar (saccaroz/glycose syrup), carbondioxide, colorant (caramel), acid arranger (phosphoric acid), coca cola extract, cafein (0.150g/L)	The Coca Cola Company Turkey
Light Cola	LCO	Water, carbondioxide, colorant (caramel), aid arranger (phosphoric acid, citric acid), natural aromas, artificial sweetener (aspartam 0.240g/L), asesulfam-K 0.160g/L, sodium benzoat, cafein (0.150g/L), phenylalanine	The Coca Cola Company Turkey
Distilled water	DW		Gülhane Military Medical Academy Turkey

samples (8 mm in diameter, 2 mm in height) were prepared. The powder/liquid ratio, mixing procedure, and mixing time were done according to manufacturer's instructions. As surface finishing has a major influence on discoloration, samples were prepared in polytetrafluoroethylene ring between glass slides and Mylar strips (Du Pont, Wilmington, DE, USA) to ensure uniform surface finishing. Sample surfaces were polished by one operator using coarse pumice, flour of pumice (Whip-Mix Corp., Louisville, KY), and a high shine compound (Green Polishing Compound, Dixon Mfg., Carlstadt, NJ) with a dental lathe (KaVo Polishing Unit EWL 80, KaVo, Lake Zurich, Ill) operated at 1500 rpm. After visually examining the sample surfaces, they were rinsed with distilled water to remove any debris before immersion. Before immersing each sample into the solutions, they were stored in distilled water at 37±1℃ for 24 hours. Six samples from each provisional restorative material were immersed in four different staining solutions at 37±1℃ for a month in a dark room. The remaining six samples of each material, used as control, were immersed in distilled water at 37±1℃ for a month in a dark room. Color measurements of these samples were done at baseline, then one day, one week, two weeks, and four weeks after immersion.

Solutions were refreshed at the beginning of every week. Additionally, to reduce precipitation in each solution, all solutions were stirred twice a day. Before each measurement, samples were ultrasonically cleaned (Ultrasonic Cleaner, HS Health-Sonics Corp., Livermore, CA) in a non-ionic multi-purpose ultrasonic solution (HS Health-Sonics Corp., Livermore, CA) for five minutes and blotted dry with tissue paper. This cleaning procedure was done to remove any loose sediments on the sample surface as a result of the immersion solution. After which, overall color arising from entire matrix discoloration and stain adsorption on sample surface was measured.

Testing procedure was done be evaluating the light directed to and reflected from the sample surface at a constant angle. Using a tungsten-halogen lamp as a light source, all measurements were done according to CIE standards[13,27,28]. Light reflected to the system was turned to electronic energy, and then computerized for evaluation purpose. The results were presented in the CIELAB color system. Before each measurement session, the colorimeter was calibrated according to manufacturer's instructions by using the supplied white calibration standard.

For each immersion period, the mean and standard deviation of ΔE^* values of each sample in each of the five treatment solutions were calculated. The colorimeter automatically generated three measurements from which it calculated a mean color measurement. Repeated measurements were performed on several individual samples to ascertain the instrument's accurate repeatability of measurement.

Table 3 NBS rating system

NBS Unit	Critical remarks of color differences
0.0~0.5	Extremely slight change/Trace
0.5~1.5	Slight change/Slight
1.5~3.0	Perceivable change/Noticeable
3.0~6.0	Marked change/Appreciable
6.0~12.0	Extremely marked change/Much
12.0 or more	Change to other color/Very much

The National Bureau of Standards (NBS)[23,25,28,29] rates the way a color change is evaluated by the human eye (Table 3). As such, the color change values of all the three provisional restorative materials in five different solutions were multiplied by a factor of 0.92 to obtain the NBS values. Interactions between material and solution with respect to different immersion times were compared using two-way analysis of variance (ANOVA). As the interactions were found to be statistically significant, the influence of solution on each material was further determined using one-way ANOVA and Tukey's multiple comparisons tests. All variance analyses ($p \leq 0.05$) were performed using SPSS software package.

RESULTS

At baseline, the mean L^*, a^*, and b^* values of three provisional crown and bridge restorative materials recorded from the colorimeter are presented in Table 4.

In Table 5, the mean and standard deviation of ΔE^* values and their corresponding NBS values of all the three provisional restorative materials are shown.

In Figs. 1 to 4, the mean ΔE^* values of all the three provisional crown and bridge restorative materials after each immersion period are presented in graphs.

Results of two-way ANOVA showed that there was an interaction between the three provisional restorative materials (ST, TAB, and TEM) and the five treatment solutions (CJ, T, CO, LCO, and DW)

Table 4 Color of provisional crown and bridge materials before treatment

		L^*	a^*	b^*
ST	Mean	30.86	−1.62	.99
	SD	.11	.04	.11
TAB	Mean	31.76	−1.87	1.36
	SD	.17	.04	.09
TEM	Mean	31.40	−2.04	1.07
	SD	.32	.05	.17

n=6

Table 5 Color changes of provisional crown and bridge materials

Treatments	Materials / Periods	ST				TAB				TEM			
		1D	1W	2W	4W	1D	1W	2W	4W	1D	1W	2W	4W
CJ	ΔE^*	0.65	0.94	1.49	3.99	0.41	0.68	0.88	1.22	0.73	1.14	1.41	1.67
	SD	.18	.14	.23	.26	.14	.12	.18	.19	.14	.09	.26	.19
	NBS unit	0.60	0.86	1.37	3.67	0.38	0.63	0.81	1.12	0.67	1.05	1.30	1.54
T	ΔE^*	0.42	0.58	0.64	3.30	0.31	0.63	0.62	0.96	0.35	0.63	0.68	1.16
	SD	.08	.05	.11	.18	.15	.15	.18	.17	.14	.20	.29	.26
	NBS unit	0.39	0.53	0.59	3.04	0.29	0.58	0.57	0.88	0.32	0.58	0.63	1.07
CO	ΔE^*	0.36	0.51	0.44	3.36	0.25	0.41	0.20	0.68	0.29	0.45	0.27	0.65
	SD	.05	.14	.09	.05	.09	.07	.13	.13	.07	.07	.07	.10
	NBS unit	0.33	0.47	0.40	3.09	0.23	0.38	0.18	0.63	0.26	0.41	0.25	0.60
LCO	ΔE^*	0.23	0.45	0.29	3.14	0.23	0.41	0.20	0.68	0.28	0.51	0.31	0.77
	SD	.07	.09	.07	.08	.01	.05	.07	.11	.08	.08	.12	.26
	NBS unit	0.21	0.41	0.27	2.89	0.21	0.38	0.18	0.63	0.26	0.47	0.29	0.71
DW	ΔE^*	0.21	0.39	0.25	2.60	0.20	0.38	0.20	0.60	0.22	0.44	0.26	0.46
	SD	.13	.08	.06	.16	.15	.07	.13	.19	.03	.03	.15	.06
	NBS unit	0.19	0.36	0.23	2.39	0.18	0.35	0.18	0.55	0.20	0.40	0.24	0.42

E^*: Color change value SD: Standard Deviation NBS unit: National Bureau of Standards unit

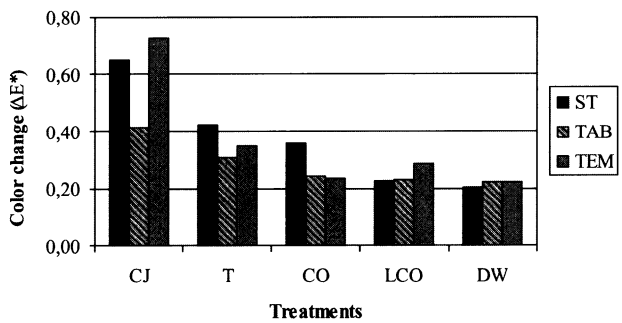


Fig. 1 Color changes of provisional crown and bridge restoration materials in treatment solutions after one day.

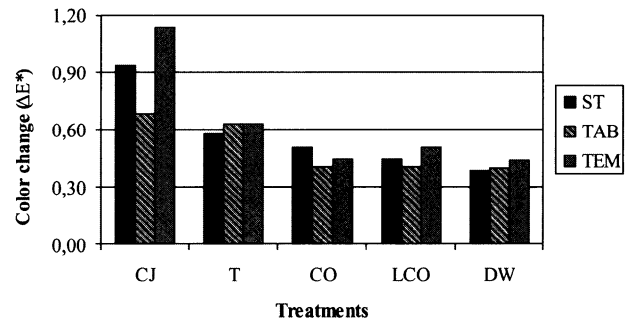


Fig. 2 Color changes of provisional crown and bridge restoration materials in treatment solutions after one week.

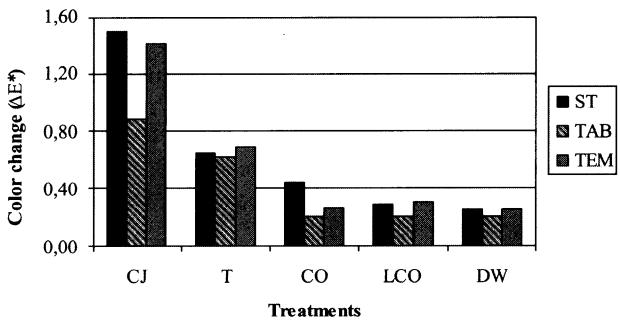


Fig. 3 Color changes of provisional crown and bridge restoration materials in treatment solutions after two weeks.

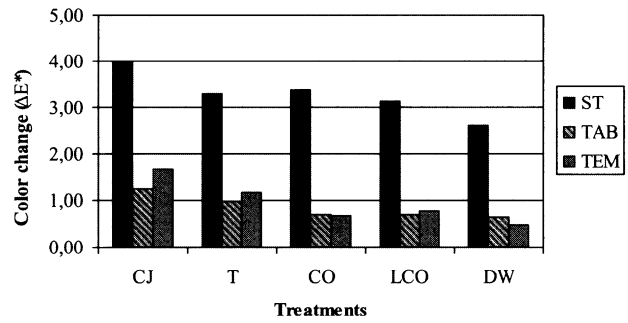


Fig. 4 Color changes of provisional crown and bridge restoration materials in treatment solutions after four weeks.

Table 6 Results of color change among materials for each treatment

Treatments	ST					TAB					TEM				
1st Day	DW	LCO	CO	T	CJ	DW	LCO	CO	T	CJ	DW	CO	LCO	T	CJ
	.21	.23	.36	.42	.65	.20	.23	.25	.31	.42	.22	.23	.29	.35	.73
		F=14.174 p<0.001					F=3.142 p=0.032					F=23.825 p<0.001			
1st Week	DW	LCO	CO	T	CJ	DW	CO	LCO	T	CJ	DW	CO	LCO	T	CJ
	.39	.45	.51	.58	.94	.39	.41	.41	.63	.68	.44	.45	.51	.63	1.14
		F=23.881 p<0.001					F=11.966 p<0.001					F=40.588 p<0.001			
2nd Week	DW	LCO	CO	T	CJ	DW	CO	LCO	T	CJ	DW	CO	LCO	T	CJ
	.25	.29	.44	.64	1.49	.20	.20	.20	.62	.88	.26	.27	.31	.69	1.41
		F=90.152 p<0.001					F=29.856 p<0.001					F=40.173 p<0.001			
4th Week	DW	LCO	T	CO	CJ	DW	LCO	CO	T	CJ	DW	CO	LCO	T	CJ
	2.60	3.14	3.30	3.36	3.99	.60	.68	.68	.96	1.22	.46	.65	.77	1.16	1.67
		F=82.800 p<0.001					F=15.235 p<0.001					F=37.064 p<0.001			

Materials connected by solid line are not significantly different

after every treatment period: $F=2.624$, $p=0.014$ for the first day; $F=5.000$, $p<0.001$ for the first week; $F=4.365$, $p<0.001$ for the second week; $F=9.836$, $p<0.001$ for the fourth week. As significant interaction was found in every immersion period (first day, first week, second week, and fourth week), the effect of solution on each provisional restorative material in every period was further examined by one-way ANOVA and Tukey's pair-wise comparison test. As seen in Table 6, after one day immersion for TEM, ST, and TAB, the most staining solution was CJ ($\Delta E^*=0.73$, 0.65, and 0.42 respectively) and the least was − as expected − DW ($\Delta E^*=0.22$, 0.21, and 0.20 respectively). T treatment exhibited the strongest staining effect on ST material ($\Delta E^*=0.42$) ($F=14.174$; $p<0.001$).

After one week, the most staining solution for TEM, ST, and TAB was CJ ($\Delta E^*=1.14$, 0.94, and 0.68 respectively) (Table 6). Following CJ, T showed the strongest staining effect on TAB ($\Delta E^*=0.63$) ($F=11.966$; $p<0.001$).

After two weeks, the most staining solution for ST, TEM, and TAB was again CJ ($\Delta E^*=1.49$, 1.41, and 0.88 respectively) (Table 6). Following CJ, T showed the strongest staining effect on TEM ($\Delta E^*=0.69$) ($F=40.173$; $p<0.001$).

After four weeks, the most staining solution for ST, TEM, and TAB was CJ (3.99, 1.67, and 1.22) (Table 6). Among the provisional restorative materials, ST also showed the highest color change values in other treatment solutions ($\Delta E^*_{CO}=3.36$, $\Delta E^*_{T}=3.30$, $\Delta E^*_{LCO}=3.14$, and $\Delta E^*_{DW}=2.60$) ($F=82.800$; $p<0.001$).

DISCUSSION

Color changes can lead to esthetic problems when provisional crowns and bridges are intended to be used for a longer period. Discolorations seen in provisional restorations may be related to patient's dietary habits, oral hygiene, and the structural properties of the material used.

Color perception by visual assessment of objects is a subjective, physiologic, and psychological process that varies between and within persons. This variability in visual assessment is a result of several factors, including observed object and illuminant position relative to the observer and to each other, color characteristics of the illuminant, metamerism, fatigue, aging, and emotional state of the observer[23,27]. Colorimeters and spectrophotometers, on the other hand, could potentially eliminate these subjective errors of visual color assessment. Spectrophotometers provide measurements in CIELAB units − which, when analyzed mathematically, can compare the color parameters of different objects[27,28]. An equal distance across the CIE LAB color space represents an approximately equal color difference (or ΔE), an arrangement that makes the interpretation of color measurements more meaningful[30,31].

In the present study, before test samples were immersed into each staining solution, L^* values were positive (whiter), a^* values were negative (greener), and b^* values were positive (yellower) as shown in Table 4.

After one day, one week, and four weeks, the L^* values of all tested materials decreased (to black). However, at second week measurement, all the L^*

values increased (to white), except in CJ. For all immersion periods in CJ, the L* values of all test samples decreased (to black).

After one day and one week, the a* values of all test samples, except ST, decreased (to green) after immersion in LCO and DW. But, the a* values of all test samples, including ST, increased (to red) after two weeks and four weeks.

After one day, the b* values of all samples immersed in CJ and LCO increased (to yellow), but decreased (to blue) after immersion in DW. After one week and four weeks, the b* values of all samples in all solutions increased (to yellow). However, when immersed in CJ and T solutions, the b* values increased (to yellow) after only two weeks. For the same period, the b* values of these samples, except ST, decreased (to blue) in LCO and DW solutions.

The National Bureau of Standards (NBS) established a sophisticated rating system to describe color differences by NBS units. Assuming that color changes of $\Delta E^* < 1.0$ are within discernible limit and that $\Delta E^* = 3.3$ is an acceptable value, the tested color changes were therefore within visible range but still acceptable[13,25,28,29]. In this study, discoloration above $\Delta E^* = 3.3$ was rated as unacceptable. Color difference values of this *in vitro* study were converted into NBS units to facilitate comparison with clinical studies. The results based on NBS rating system are shown in Table 5.

After one day of CJ treatment, TAB showed an "extremely slight" color change value ($\Delta E^* = 0.42$). However, after one week, two weeks, and four weeks of CJ treatment, it revealed "slight" color change values ($\Delta E^*_{1W} = 0.68$, $\Delta E^*_{2W} = 0.88$, and $\Delta E^*_{4W} = 1.22$). For all of the immersion periods with the other four treatment solutions (T, CO, LCO, and DW), color change values of TAB material were under 1.00.

For TEM, after the first and second weeks of CJ treatment, color change values were determined as "slight change" ($\Delta E^*_{1W} = 1.14$ and $\Delta E^*_{2W} = 1.41$). However, after four weeks, color change of TEM material was recorded as $\Delta E^* = 1.67$ for CJ, $\Delta E^* = 1.16$ for T, and $\Delta E^* < 1.00$ for the other treatment solutions.

For ST, after two weeks of CJ treatment, a "noticeable" color change value of 1.49 was noted. After four weeks, ΔE^* values of ST material were found to be 3.99 for CJ, 3.36 for CO, and 3.30 for T – all of which considered as "marked changes" in NBS rating system.

In summary, for all the selected provisional restorative materials, their color change values after first day, first week, and second week with T, CO, LCO, and DW treatments were smaller than 1.00. As such, their color changes during these immersion periods with these treatment solutions were barely noticeable. On the other hand, ΔE^* values calculated after certain immersion periods (e.g., after four weeks) showed statistically significant differences. Until the end of the second week, all the materials (ST, TAB, and TEM) subjected to CJ, T, CO, and LCO staining treatments did not demonstrate unacceptable color changes. In fact, samples immersed in DW also showed color changes, but they were not statistically significant. These changes were suggested to be attributable to the water absorption characteristics of the sample material.

Several *in vitro* studies indicated that the concentration of and the exposure time to a staining solution may affect the discoloration degree of provisional restorative materials[5–14,26,32]. It is difficult to relate the results of these *in vitro* studies with clinical studies. Kaumjian *et al.*[33] evaluated provisional complete dentures made of seven commercially available resins *in vivo*, and reported that tested materials showed no observable stains after five weeks and some degree of stain after nine weeks. They also stated that auto-polymerizing methyl methacrylate resins had significantly less stain than bisacryl and light-cured composite resins – but these could be subjective evaluations of color changes made under the limitations of their study.

Powder of chemically activated provisional restorative resins contains beads of PMMA ($<50\,\mu m$), a chemical initiator (often a peroxide) and a pigment, whilst the liquid consists of methylmethacrylate monomer and a chemical activator (often tertiary amine)[34]. It has been found that the color change of chemically activated materials is associated with the type and quantity of amine involved in the polymerization. Further, the inhibitor has been found to play a role. Besides amine and inhibitor, it has been conjectured that the monomer content and peroxide may be the leading causes for internal discoloration[14]. Although the use of stabilizers has decreased the occurrence of chemically induced color changes, provisional restorative materials are prone to absorbing liquids – from which staining can easily produce color changes[8,9].

Brauer[26] compared the color stability of composites by exposing them to various energy sources. He found that visible light-cured composites were more color stable than chemically cured restoratives containing tertiary aromatic amine accelerators. Based on these observations, he reported that composites were more color stable. Likewise in this study, amine-containing ST samples were the least color stable material – an evaluation supported by previous studies[8,9,14,26,34].

Polymethyl methacrylate tends to absorb water in its inhibition process. Its non-crystalline structure processes a high internal energy. As a result, molecular diffusion into the resin can occur since less activation energy is required. Furthermore, the polar carboxyl group, even though esterified, can form a hydrogen bridge to a limited extent with

water. As both absorption and adsorption are involved, the term sorption is usually used to describe the entire phenomenon. Typical dental methacrylate resins show an increase of approximately 0.5 wt% after one week in water. Higher values have been reported for a series of methyl methacrylate polymers. Though sorption of water is nearly independent of temperature from 0℃ to 60℃, it is markedly affected by the molecular weight of the polymers. The greater the molecular weight, the smaller the weight increase[4].

In the present study, though the samples immersed in DW showed color changes, they were not statistically significant. These color changes were assumed to be due to water absorption characteristics of the sample material. In DW, ST showed the most extreme color change after four weeks ($\Delta E^*=2.60$). The reason for ST samples having a higher color difference value higher than the other tested materials was suggested to be a result of its relatively large water sorption value than the other tested materials. Seher *et al.*[12] had stored 14 polymerized methacrylates in different staining solutions (coffee, cur cumin, carotene) and then exposed them to UV. They described that PMMA and diurethane dimethacrylate had better color stability than the experimental resins. They reported that the smaller molecular size of coffee and cur cumin (as compared to carotene) coupled with the water absorption characteristic of the tested materials created a stronger staining effect.

Carrot juice, a regularly consumed beverage, has a serious staining ability. As such, it was selected as a treatment solution in the present study. Indeed, based on our evaluation results, the most staining solution proved to be carrot juice among the four treatment solutions – in accordance with the results of similar *in vitro* tests performed by Seher *et al.*[12]. In carrot juice, ST showed the most discoloration at the end of four weeks ($\Delta E^*=3.99$). The results of this study indicated that the higher staining susceptibility of ST could be primarily attributed to its chemically activator (amine) content, relatively high water sorption value and surface topography. Indeed, there were studies concluding that staining is a result of the adsorption or absorption of beverages like tea, coffee, cola, and light cola at the surface of restorative materials[1,6,9,12,14,16-18,20,21,23].

Compounds present in tea play an important role on the color characteristics of provisional restorative materials. Tea plants contain large quantities of flavonoids – phenolic methyl xanthine compounds which impact the unique flavor and functional properties of tea. Tea then consists of flavonoids (flavanols, and flavanol glycosides), phenolic compounds (gallic acid, its quinic acid ester, and theogallin), caffeine (2.5-4%), other xanthines (smaller quantity), theanine (3%), and other amino acids. Flavanols are water-soluble and colorless. However, caffeine forms complexes with the polymeric constituents in tea and these complexes have poor solubility and often precipitate under cold storage[35].

Um and Ruyter[13] evaluated the staining properties of resin-based materials in solutions like filtered coffee, boiled coffee, and tea. They reported that tea produced a yellow-brown stain while coffee stain was yellowish. Discoloration from tea was probably due to the adsorption of polar colorant from tea at the surface of composite resin materials. However, in other studies[3,16,19,20], coffee was found to be a more chromogenic material than tea. Joiner *et al.*[36] studied the adsorption from black tea and red wine onto *in vitro* salivary pellicles. They concluded that tea and red wine components had a profound effect on *in vitro* pellicle maturation, causing build-up of thickened layers of stained material which could not be readily removed by mouth rinses.

Other factors that may influence color change results include tea preparation and concentration of the staining solution. In the present study, the solutions were prepared closer to real drinks. Nonetheless, present findings indicated that while TAB and TEM showed acceptable color changes after four weeks, ST showed unacceptable color change in tea.

Cola and light cola are low-pH media (acidic soft drinks) used in previous color stability studies[9,14,16,17,19-21]. Abu-Bakr *et al.*[14] evaluated the effect of various media (orange juice and coca cola) on the color stability of compomers and reported that low-pH media affected the surface integrity of compomers. This was because under acidic conditions, the compomer surface was appreciably softened by loss of structural ions from the glass phase. Their study demonstrated that individual particles dissociated from each other, thereby resulting in a rough surface with the presence of voids. In the present study, TAB and TEM showed slight color change at the end of four weeks in two low-pH soft drinks (CO and LCO), while ST showed noticeable change in LCO and marked change in CO.

As methacrylate resins are not filled, they are more subject to wear and hence more responsive to traditional polishing techniques. As such, a homogenous, void-free surface can be obtained[36]. Haselton *et al.*[37] evaluated the surface roughness of five methacrylate and seven bisacryl resins after storing them in artificial saliva and artificial saliva-coffee solution for two weeks. There were significant differences in surface roughness among the provisional crown materials when polished under the same conditions. They reported that methacrylate resins, in general, exhibited smoother surfaces after initial polishing. However, after storage in either moist environment, surface roughness increased for nearly all the tested materials.

Thus far, based on the results of the *in vitro*

staining tests performed under various physicochemical conditions, it has been shown that the staining susceptibility of PMMA-based resins or chemically activated provisional restorative materials was related to their composition, surface properties and exposure time to staining solutions. A low staining susceptibility was generally related to a low water absorption rate and a satisfactory gloss after polishing. In addition, time was found to be a critical factor that affected the color stability of ST material. In the present study, results of the ST material showed that as immersion time increased to four weeks, its color changes in all the staining media became more intensive. Extrapolating from the results of this *in vitro* study, it can be said that ST is not suitable as a provisional crown and bridge restorative material for treatments of a longer duration.

Among the three tested materials, TAB showed the most color-stable results. However, to investigate their color stability performance in a clinical setting, these results should be supported by *in vivo* studies.

CONCLUSIONS

Three commercially available provisional crown and bridge restorative materials were evaluated after immersing in various staining solutions for one day, one week, two weeks, and four weeks. Within the limitation of this *in vitro* study, the following conclusions were drawn:

1. Factors that significantly affected color stability were namely: composition of provisional material, type of staining solution, and exposure time.

2. Of the provisional materials tested, amine-containing ST material showed the most discoloration, while TAB showed the least after exposure to the staining solutions for four weeks ($p \leq 0.001$).

3. CJ was found to be a more effective staining solution than the others.

4. Color shift of all materials in CJ and T was predominantly in the b^* axis (yellow-blue).

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