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Original article

Long-term color stability of light-polymerized resin luting agents in different beverages

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Abstract

Purpose: The purpose of this study was to evaluate the long-term color stability of light-polymerized resin luting agents stored in different beverages.
Methods: Eleven shades of two light-polymerized resin luting agents, Choice2 (A1, A2, B1, TRANSLUCENT, MILKY OPAQUE, and MILKY BRIGHT) and BeautiCem Veneer (H-Value, M-Value, L-Value, Ivory-D, Ivory-L) were selected in this study. Disk-shaped specimens were fabricated with 1.3 mm thickness and 15.0 mm diameter. A total of 198 specimens, 18 for each shade, were prepared and randomly divided into six storage conditions (purified water, coffee, cola, tea, red wine, and air). All shades of specimens were three times measured at three random locations (n = 9) at 24 h storage in air after specimen preparation and then measured after immersion at 1, 3, 6, 9, and 12 mos. using a colorimeter. Then, the color difference (ΔE) between the specimens at 24 h after preparation and after storage in each liquid for 12 mos. was calculated. Statistical analysis was performed using Steele–Dwass multiple comparison test of the ΔE values or one-way ANOVA and Tukey's honest significant difference test.
Results: For all immersion conditions, ΔE was significantly higher than air (control). The ΔE of the shades in the various storage conditions showed no significant difference between Purified Water-Cola and Coffee-Tea. Comparisons of the color components L*, a*, and b* for each shade showed different behaviors among the shades.
Conclusions: The results suggest that the color stability of light-polymerized resin luting agents may differ between different shades and beverages.

Keywords: *Light-polymerized resin cement, Color stability, Immersion tests, Veneer restoration, Shade selection*

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1. Introduction

In recent years, oral hygiene in advanced nations has been improving, and thus, the risk of developing severe caries has decreased. Therefore, the concept of minimal intervention, the so-called MI, has been recommended as a treatment strategy for mild caries [1]. A treatment option according to the MI concept is laminate veneer restoration [2], which treats not only caries but also discoloration, cracks, erosion, and deformities with a minimum removal of sound tooth structure. Laminate veneer restoration shows high esthetics and long-term clinical success [3]. In this technique, the removal of tooth structure is limited to the enamel, and laminate veneers made of ceramic or other highly esthetic materials are bonded to the enamel surface, most often with resin luting agent. The bonding of resin luting agent to enamel structure is usually of high strength [4] and long-term durability [5,6]. Owing to this, application of the laminate veneer has extended from anterior teeth to the posteriors. Clinical studies have suggested the effectiveness of laminate veneer in molars, called an overlay restoration and/or an occlusal veneer restoration.

With the widespread use of this technique, light-polymerized resin luting agent [7] has been developed for luting veneers that are less stable and difficult to adhere because of the preparation design on the abutment teeth compared to conventional fixed dental prosthesis. Light-polymerization of the resin luting agent will make it possible to control polymerization time, such that there is enough working time for accurate placement of the veneer. Furthermore, these agents have multiple shades such that chairside fine-tuning of the shade of restoration is possible.

The shade of these resin luting agents used in veneer restorations has been linked to prognosis [8], and the discoloration of resin luting agents may be noticeable, especially in thin restorations [9,10,11]. Peumans et al. [3] found that after 10 years of wear, 20% of porcelain laminate veneers developed marginal defects, with severe marginal discoloration (19%), or caries (10%) occurring in such areas. In other words, this study also showed that 80% of porcelain laminate veneers were succeeded more than 10 years. Furthermore, Olley et al. [2] reported that anterior ceramic veneers were showed over 50 years survival. From these reports, the exposure of resin luting agent is unavoidable, so that the long-term color stability of the resin luting agent is highly associated with esthetics. Previous studies on color stability of resin luting agent have often immersed less than 6 months [8, 10], which makes it possible to simulate only 10 years in clinical situations, and there are no studies simulate over 10 years affection for color stability of resin luting agent.

The purpose of this study was to evaluate the long-term color stability

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of two different light polymerized resin luting agents in 11 shades, stored in five different beverages. The null hypothesis is that the differences in 1) beverages and 2) shades are not affected by the color stability of resin luting agent.

2. Materials and Methods

Two types of light-polymerized resin luting agents comprising 11 shades were used in this study (Table 1). Six shades of Choice2 (BISCO, Schaumburg, IL, USA) (A1, A2, B1, TRANSLUCENT, MILKY OPAQUE, and MILKY BRIGHT), and five shades of BeautiCem Veneer (SHOFU, Kyoto, Japan) (H-Value, M-Value, L-Value, Ivory-D, and Ivory-L) were selected. Disk-shaped specimens were fabricated using a glass mold with hole of 1.3 mm thickness and 15.0 mm diameter to fill the agent. Light-polymerized resin luting agent was filled in the mold, and the mold was covered with glass plates from both sides. The covered mold was polymerized using a laboratory light-activated polymerization unit (LAVOLIGHT LV-3, GC, Tokyo, Japan) for 30 s. Specimens were removed from the mold and both sides were polished with #2,000 water-resistant SiC abrasive paper (Sankyo-Rikagaku, Saitama, Japan) and stored at 37 °C in air for 24 h. Using the same method, 198 specimens were prepared. The specimens were randomly divided into six groups of different storage conditions. One group was stored at 37 °C in air as control. The other five groups were immersed in five different beverages: purified water (Purified water, KENEI Pharmaceutical, Osaka, Japan), cola (Coca-Cola, COCA-COLA (JAPAN) COMPANY, Tokyo, Japan), coffee (Sugar Free Coffee, Seven & i HOLDINGS, Tokyo, Japan), tea (Sugar free earl grey, Seven & i HOLDINGS, Tokyo, Japan), red wine (CABERNET SAUVIGNON, Concha y Toro, Santiago, Chile). The specimens in beverages and in air were kept in an incubator to maintain the temperature at 37 °C, and all beverages were changed every week. The color of the specimens was measured 24 h after specimen preparation (starting point) and after storage for 1, 3, 6, 9, and 12 mos. using a spectrophotometer (CR-221, MINOLTA, Tokyo, Japan). The measurements were performed under light shielding plastic cover.

Color measurements were taken at three random locations in one specimen (n = 9), and the average value was considered for analysis. The specimens immersed in the beverages were cleaned under running water for 30 s, and then wiped off with a disposable tissue (Kim wipe, NIPPON PAPER CRECIA, Tokyo, Japan) before measurement. The obtained results were converted to the CIE L*, a*, and b* formats. Lightness is denoted by L*, and chromaticity is denoted by a* and b*. The color tone becomes red when a* is positive, green when it is negative, yellow when b* is positive, and blue when it is negative. Then, the color difference (ΔE) between the specimen at 24 h after preparation and the specimen stored for 12 mos. was calculated by following equation [12].

$$\Delta E = [(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2]^{1/2}$$

Statistical analysis was performed using the Steele–Dwass multiple comparison test on the average ΔE value of color difference in different storage conditions between 24 h and 12 mos. Furthermore, one-way ANOVA and Tukey's honest significant difference test was performed on the each ΔE value.

3. Results

Fig. 1 shows the color difference (ΔE) for different storage conditions between 24 h and 12 mos. For all immersion conditions, ΔE was significantly higher than air (2.5). There were no significant differences between purified water (14.1) and cola (11.5), and coffee (26.9) and tea (27.8). In the immersion condition, the highest ΔE was observed in red wine (42.1), and the lowest ΔE was observed in cola.

Fig. 2 shows the color difference (ΔE) value of different shades. For all storage conditions, there was a significant difference between all shades. In purified water, OPAQUE showed the highest ΔE value. In coffee, the highest ΔE was observed for the M-value. In cola, the highest ΔE was observed for the L-value. In tea, OPAQUE showed the highest ΔE value. In the red wine, OPAQUE showed a significantly higher ΔE than the other shades. In the control, H-Value and M-Value showed significantly higher ΔE than the other shades.

Fig. 3 shows the color changes of different storage conditions in L*, a*, and b*. For L*, a decrease was observed in all storage conditions except for cola, for which it slightly increased. The results obtained of purified water are similar to that of control. For a*, an increase was observed in red wine. For b*, an increase was observed in all storage conditions except for red wine, for which an increase was observed at only 1 mos., and then decreased until 12 mos.

Fig. 4 and Fig. 5 show the color changes for each shade. For L*, an increase was observed in nine shades immersed in cola. For a*, the behavior of all shades was similar changes. For b*, all the shades immersed in red wine showed an increase at 1 mos.; however, a subsequent decrease distinct from the other shades was observed.

4. Discussion

Null hypothesis was that the differences in 1) beverages and 2) shades are not affected by the color stability of resin luting agents. Both hypotheses were rejected based on the present results ($p < 0.05$).

In this study, eleven shades were chosen from two light-polymerized resin luting agents. The resin luting agents Choice2 has nine different shades. In this study, A1, A2, and B1 were chosen as they are popular tooth color shades according to VITA standards. In addition, a high transmittance shade TRANSLUCENT that is usually used in cases in which the luting agents should not affect the shade of the veneer, and low transmittance shades MILKY OPAQUE and MILKY BRIGHT that are used with veneers that need additional brightness, were selected. All five shades of BeautiCem Veneer were selected, which included two tooth color shades and three transmittance color shades. The storage conditions for the light-polymerized resin luting agents were immersed in five different beverages, in addition to storage at 37 °C in air. Purified water was selected as the immersion condition without color and chemical effect. Coffee and tea were chosen as representatives of liquids that are highly colored. Coffee and tea have different polarity of the yellow colorant, and the higher polarity component in tea dissolves first and then adsorbs on the surface of the resin luting agents or other materials. On the other hand, the lower polarity component in coffee gets dissolved and absorbed later. This is known to cause differences, such as easier removal of stains by brushing [13,14]. Cola was chosen as a widely used carbonated beverage and representative of highly acidic liquids. Red wine was chosen as a colored alcoholic beverage, which is used worldwide [14,16,18]. The CIELab color system was used to evaluate the color tone. It was established by the International Commission on Illumination and is commonly used in studies on color tones of dental materials such as resin composites and ceramics [9,13-17]. The storage period for each specimen was 12 mos. This storage period is equivalent to 26 years of use in the oral cavity, as calculated based on the description by Ardu et al. [18].

As shown in Fig. 1, significantly high color differences were observed in coffee, tea, and red wine immersion conditions than in purified water, cola, and air. This is consistent with the results obtained by Kheraif et al. [17]. Mara da Silva et al. [19] reported that this may be due to the significant influence of the coloring substances in each beverage. In addition, all immersion conditions, including purified water, showed clinically unacceptable ΔE (> 2.7). Paravina et al. [20] described a discernible ΔE of 1.2 by 50% of dental professionals and an acceptable ΔE of 2.7. Um et al. [13], Kolbeck et al. [21], Sarafianou et al. [22], and Ruyter et al. [23], set the criterion for clinically unacceptable ΔEs as > 3.3. However, air, used as control exhibited a discernible and acceptable ΔE (2.5). Analyses based on these criteria indicate that prolonged exposure to purified water can also produce clinically unacceptable ΔEs. In addition, other storage conditions exhibited unacceptable ΔE (purified water: 14.1, cola: 11.5, coffee: 26.9, tea: 27.8, red wine: 42.1)." after "acceptable ΔE (2.5). The increase in color change of resin composites stored in distilled water with time may occur due to presence of water which tends to soften the polymer by causing swelling of the network and reducing the frictional forces between polymer chain [17]. This could be the cause of the ΔE seen in this study. On the

Table 1. Light-polymerized resin luting agents used in the study.

Material	Product Name	Shade	Lot No.	Code	Composition	Manufacturer
Light-polymerized resin luting agent	Choice2	A1	1700004181	A1	Glass filler, Amorphous Silica Bisphenol A Diglycidylmethacrylate Urethane Dimethacrylate Triethylene Glycol Dimethacrylate Tetrahydrofurfuryl Methacrylate	Bisco
		A2	1700003859	A2		
		B1	1700004182	B1		
		TRANSLUCENT	1700004508	TRANS		
		MILKYOPAQUE	1700003729	OPAQUE		
		MILKYBRIGHT	1700004010	BRIGHT		
	BeautiCem Veneer	H-Value	61804	H-Value	Glass filler, Bis-GMA Polymerization initiator Colorants, Others	SHOFU
		M-Value	61805	M-Value		
		L-Value	61805	L-Value		
		Ivory-D	61803	Ivory-D		
		Ivory-L	61803	Ivory-L		

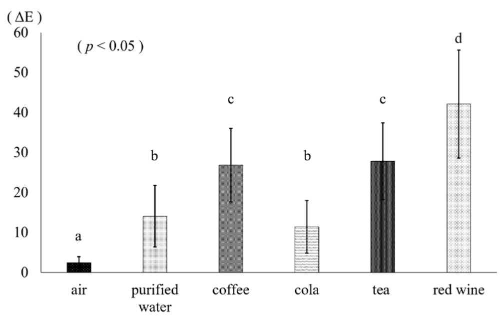

Fig. 1. Color difference (ΔE) of light polymerized resin luting agents under different storage conditions. Error bars indicate standard deviations and same superscript letter indicate no statistically significant difference.

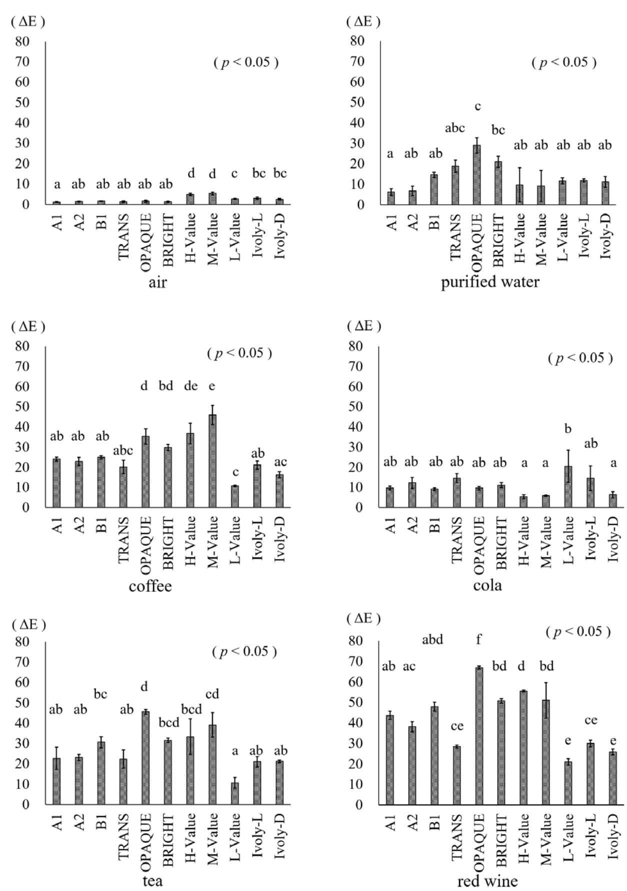

Fig. 2. Color difference (ΔE) of different shards. Error bars indicate standard deviations and same superscript letter indicate no statistically significant difference.

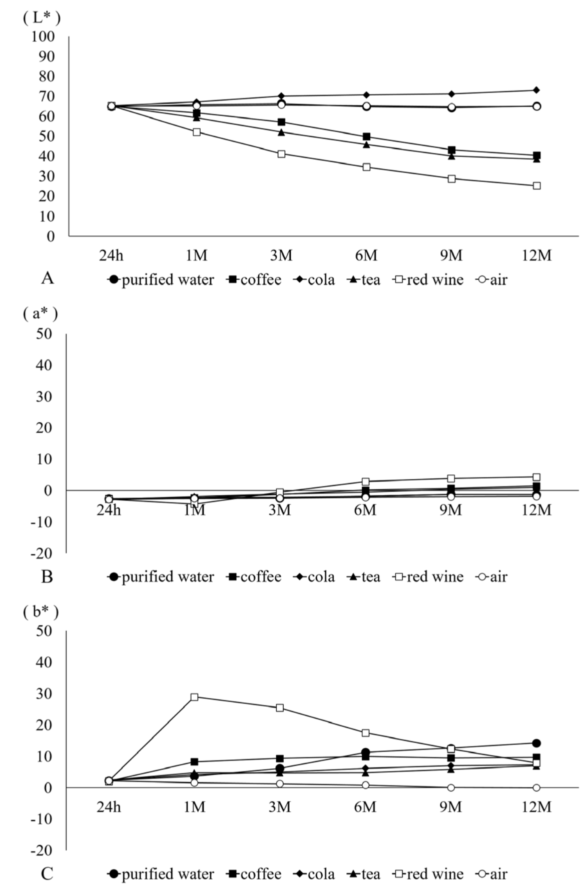

Fig. 3. Color changes of different storage conditions in L*, a* and b*. A: L*, B: a*, C: b*.

other hand, the ΔE in the cola-immersed condition tended to be less than that in the coffee and other colored beverages-immersed conditions. This is in agreement with the results of experiments using composite resins by Tavangar et al. [24] who reported that when resin composites were immersed in coffee, the colorants of the coffee penetrated the material along with water absorption by the resin monomer. Cola had the lowest pH (pH = 2.2) among the conditions used in this study; however, cola showed significantly less color difference than coffee, tea, and red wine. Savas et al. [25] in their experiments with glass ionomer-doped resin composites had pointed out that the color change after immersion in the dyeing solution depends multifactorial in nature, including the composition of the immersion media, titratable acidity, degree of maturation, and colorant absorption.

As shown in Fig. 2, a high color difference was observed in the four shades of OPAQUE, BRIGHT, H-value, and M-value in the immersed

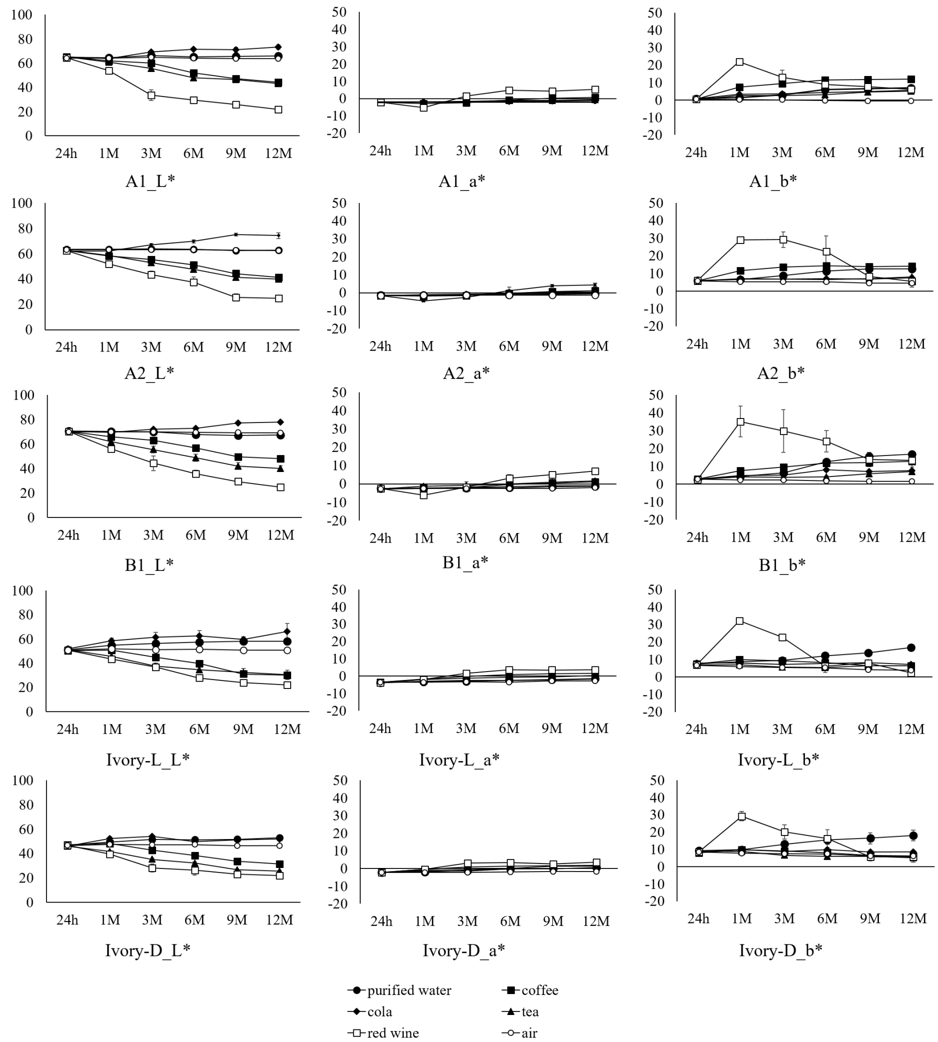

Fig. 4. Color changes of tooth color shade resin luting agents in L*, a* and b*.

conditions of coffee, tea, and red wine. Since these four shades were designed as low transmittance opaque shades, it is suggested that this mayhave affected their color stability. Pissaia et al. [7] had noted that light tones have less tonal stability than dark tones and are more likely to produce recognizable changes. According to this, the color changes in resin luting agent may be related to the amount of opacifiers and inorganic fillers in the material. The same trend is seen in the present experiment, suggesting that this may be the cause of difference in color.

Fig. 3, Fig. 4 and Fig. 5 show the color change for each color component L*, a*, and b*, under each storage condition, in a graph.

As shown in Fig. 3, different trends were observed for L*, a*, and b*. L* eventually decreased in all storage conditions except in cola; however, an increase was observed in cola. The decrease in L* with immersion in purified water and colored beverages were consistent with those reported by Silva et al. [26] Regarding the conditions under which L* was increased, Ozera et al. [27] noted that cola reduces the luster of the resin composites owing to its lower buffering capacity and lower pH than coffee and other beverages. Therefore, this behavior may have affected the color difference observed in this study. The highest change in a* was observed on immersion in red wine, while a slight increase in a* was also observed in other storage conditions. The increase in a* after immersion in red wine may have been influenced by the dye content [11]; however, the change in a* in this study was less than that of L* and b*. These results suggest that each storage condition, including red wine, may have a small effect on a*. There was no change or a slight decrease in b* in air. In the four liquids other than red wine, a moderate upward trend was observed. For purified water, it was suggested that b* may represent the color difference resulting from the swelling of the intermolecular network in the presence of water, as reported by Kheraif et al. [17] The increase in b* in the coffee and tea immersion conditions is thought to be due to the effect of the pigments present in each beverage [24]. In red wine, b* increased up to 1 mos. of immersion and then decreased. Ardu et al. [18] attributed the color change caused by red wine to its relative acidity and tannins. This factor may have influenced the behavior in this study.

In this study, the temperature was kept constant at 37 °C; therefore, the actual environment in oral cavity could not be reproduced. The oral cavity is subjected to a variety of stresses, including temperature and pH fluctuations with every meal and drink and regular brushing and cleaning. It is also possible that the color change may be further exacerbated by microcracking or matrix degradation [17,28]. Therefore, to establish the considerations of these factors, further studies are required.

The long-term color stability of resin luting agent is as key factor of esthetics in veneer restorations as the final esthetics of veneered teeth are clearly affected by agent color. The results of this study suggest that the color of the resin luting agent could change in any liquid environment. Immediately after luting, many kinds of beverages may get attached to the veneer restoration and marginal line. Then, the agent color will be changed, with a slight increase in a* and b* and decrease in L*. Therefore, during shade selection of luting agent, brighter and slightly green and blue shift

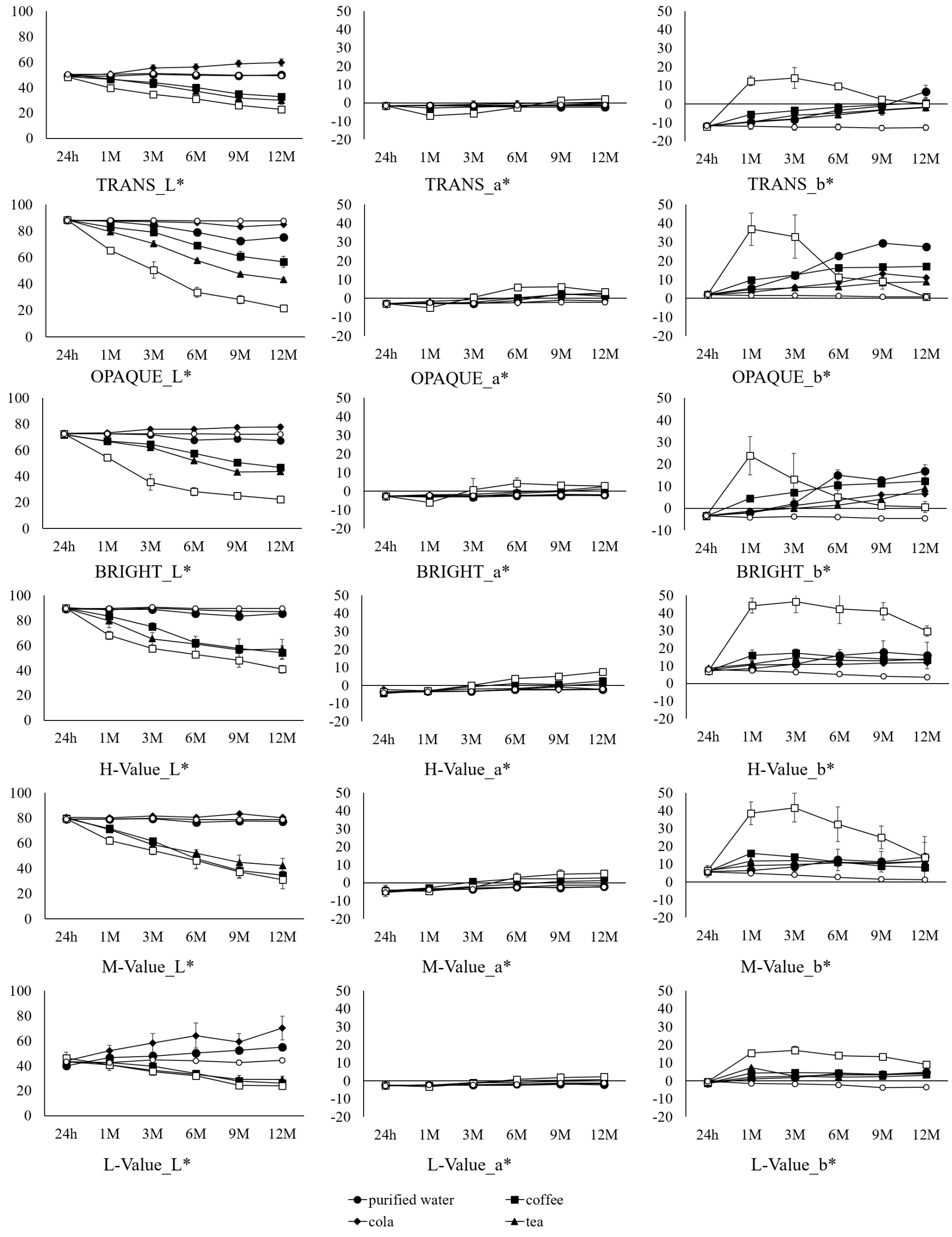

Fig. 5. Color changes of transmittance shade resin luting agents in L*, a* and b*.

shades should be considered for better long-term color matching.

While using tooth color shades, the tendency of color change is the same as the mean values. In high transmittance shades, the color change is lower and stability is higher. However, for low transmittance shades, there many factors can lead to higher color change. Therefore, it is necessary to understand the features of each shade before luting agent selection. Red wine is not recommended as a daily beverage while having veneer restorations to maintain color stability.

5. Conclusion

Within the limitations of this in-vitro study, the following conclusions were made:

1. There were no significant differences in mean color differences between purified water - cola and coffee-tea. Among the immersion conditions, red wine showed the highest, and cola showed the lowest color change.
2. Significant difference was observed in all tested shades.
3. There were color changes under different storage conditions in the CIE L*, a*, and b*. L* tended to decrease, while a* and b* eventually increased slightly.
4. The CIE L*, a*, and b*of the studied shades showed different behaviors in each beverage.

Conflict of interest statement

The authors state that there are no conflicting interests to declare.

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