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Effect of aging on color stability of amine-free resin cement through the ceramic laminate veneer

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ABSTRACT

Background: This study aimed to assess the color change of two amine-free dual-cure resin cements following aging in comparison with a light-cure resin cement.

Materials and Methods: This *in vitro*, experimental study evaluated 6 groups (n = 10), including three groups of cements bonded to feldspathic porcelain and three groups of resin cements alone. Panavia V5 (Kuraray) and G-CEM LinkForce (GC) dual-cure resin cements and Choice 2 (Bisco) light-cure resin cements were bonded to porcelain according to the manufacturers' instructions. The color parameters of the groups were measured before and after 5000 thermal cycles by spectrophotometry. Data were analyzed using two-way ANOVA and Tukey's *post hoc* test (α =0.05).

Results: The color change (ΔE) of the cement groups alone was significantly greater than that of porcelain-bonded cements. The ΔE of G-CEM LinkForce cement group was significantly higher than that of Panavia V5 group (P = 0.020), and the ΔE of the latter group was significantly higher than that of Choice 2 cement group (P = 0.021).

Conclusion: Considering the color change of cements evaluated in this study, Choice 2 and Panavia V5 cements bonded to porcelain showed acceptable color change, which indicates that they are suitable for cementation of esthetic dental restorations. Ceramic laminates have become an ideal esthetic treatment for anterior restorations. The resin cement discoloration can affect final appearance of these restorations. Besides that, exposed resin cement line can lead to the esthetic problem over time.

Key Words: Aging, color, resin cement, spectrophotometry

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INTRODUCTION

Ceramic laminate veneers are conservative indirect restorations used to improve the smile design and enhance the color, form, and function of unaesthetic teeth.[1-3] Resin cements are used for luting of these restorations because they bond to the tooth structure and have acceptable esthetics and high mechanical properties. Moreover, they are insoluble in the oral environment.[4]

The conservative tooth preparation design for laminate veneers is responsible for low thickness of these restorations. Different types of ceramic veneers are available that are made of feldspathic and glass

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ceramics, and are thin and translucent. Thus, they allow the passage of light.[5] Therefore, the color of the underlying tooth structure as well as the color of luting cement play a fundamental role in final esthetic appearance of the veneers, and their color match with the adjacent teeth.[6,7] Therefore, discoloration of resin cements used for bonding of laminates to tooth structure can compromise the esthetic appearance of these restorations and lead to treatment failure.[8,9]

Color change of resin cements is a common problem particularly for translucent restorations. Color change of restoration is the primary reason for the replacement of esthetic restorations.[10] Thus, the resin cement should have long-term color stability to guarantee acceptable esthetic results.

Discoloration of cement may occur due to some extrinsic and intrinsic factors.[3,10] Long-term exposure to extrinsic factors such as cigarette smoke and colored foods and drinks may lead to discoloration of the restorative material and/or cement (particularly at the margins). The severity of discoloration caused by extrinsic factors depends on physicochemical properties of the material (water sorption and surface roughness).[3,11] Oxidation of unreacted double bonds and the products of resin degradation following water sorption can cause internal discoloration of resin cement.[12]

The intrinsic factors that are responsible for discoloration of ceramic restorations are mainly related to the properties of the resin cement such as its chemical composition (photo-initiator, filler type, matrix composition), type of polymerization, conversion rate, and presence of unreacted monomers.[13] Moreover, long-term thermal alterations, UV radiation and moisture can cause internal discoloration via physicochemical reactions on the superficial and underlying layers of the material.[14]

Several types of resin cements are used for cementation of ceramic laminate veneers. Many dental clinicians prefer the light-cure cements because better control of the cement by the use of curing light can enhance the procedural steps and increase the clinical working time.[15] Dual-cure cements are used in hard-to-reach areas because they are polymerized in areas not accessed by the curing light.[14,15]

Dual-cure resin cements contain tertiary amine (aromatic amine) and benzoyl peroxide and tend to darken over time. In contrast, the color of camphorquinone photo-initiator and aliphatic amine that are commonly incorporated in the composition of light-cure resin cements is more stable.[3] In order to prevent discoloration, resin cements devoid of tertiary amine photo-initiator were introduced to the market. Recent investigations have confirmed that resin cements devoid of benzoyl peroxide/amine initiator system have higher color stability.[16] In the clinical setting, color change of completely polymerized resin cements may occur after a short while. Nonetheless, the majority of discolorations depend on intrinsic factors and chemical composition of cement. Despite the recognized effect of color of resin cement on the final restoration,[17] only limited studies have evaluated the role of resin cement ingredients in this respect. Knowledge about the discoloration potential of resin cements is imperative for proper selection of indirect esthetic dental restorations by dental clinicians. Considering the relatively recent introduction of Panavia V5 (Kuraray Dental, Japan) and G-CEM LinkForce (GC, Japan) to the market, lack of information regarding their properties, and the manufacturers' claims regarding optimal color stability of this generation of dual-cure resin cements due to elimination of tertiary amine from their composition, this study aimed to assess the effect of aging on color stability of these two dual-cure resin cements in comparison with a light-cure resin cement.

MATERIALS AND METHODS

Sample size calculation

According to the Dede *et al.*'s study (2016) and using one-way ANOVA Power Analysis PASS11, considering $\alpha = 0.05$ and $\beta = 0.2$, and the mean standard deviation $\Delta E = 0.57$ and Effect size = 0.5, the minimum sample required for each of the six group of study was 9 samples, in which increased to 10 in this study to have more power.

The study groups ($n = 10$) in this *in vitro* experimental study were as follows:

- Group 1: Choice 2 (Bisco) light-cure resin cement and medium-opacity feldspathic porcelain
- Group 2: G-CEM LinkForce (GC, Tokyo, Japan) dual-cure resin cement and medium-opacity feldspathic porcelain
- Group 3: Panavia V5 (Kuraray Medical, Tokyo, Japan) dual-cure resin cement and medium-opacity feldspathic porcelain
- Group 4: Choice 2 (Bisco) light-cure resin cement
- Group 5: G-CEM LinkForce (GC, Tokyo, Japan) dual-cure resin cement

- Group 6: Panavia V5 (Kuraray Medical, Tokyo, Japan) dual-cure resin cement.

Preparation of porcelain specimens

A total of 30 feldspathic porcelain specimens (Kuraray Noritake Dental Inc., Japan) with medium-opacity translucency and A1 color shade were fabricated in a laboratory with 10 mm diameter and 0.5 mm thickness. The porcelain surface was then glazed according to the manufacturer's instructions and then cleaned in an ultrasonic bath (Tecno-Gaz S.p.A., Parma, Italy) for 10 min. Each specimen was checked using a digital five-point caliper (Digital Caliper, Messen, Danyang, China) to have the above-mentioned thickness and evaluate with a stereomicroscope (Magnus, Magnus Opto Systems, India Pvt. Ltd.) to have no crack.

Preparation of resin cement specimens

Specimens were fabricated of Choice 2 light-cure resin cement (Group 4), and G-CEM LinkForce and Panavia V5 dual-cure resin cements (Groups 5 and 6) with translucent color, measuring 0.3 mm in thickness and 10 mm in diameter (minimum possible thickness for the respective tests). A stainless-steel mold with 0.3 mm depth was fabricated for this purpose. The resin cement was applied into the mold. A Mylar strip followed by a glass slab were placed over the resin cement to obtain a smooth surface. Next, 2.5 kg static load was applied for 20 s to standardize the thickness of all resin cement specimens. Next, light-curing was performed using an LED curing unit (Bluephase N, Ivoclar Vivadent, Liechtenstein) with a light intensity of 1200 mW/cm^2 for 40 s. Curing was performed in four points using the overlapping technique. The light intensity was checked prior to each time of use with a radiometer (LM1; Woodpecker, Japan).

Bonding of cement to porcelain

In 3 out of 6 groups, resin cement was bonded to porcelain specimens such that in all the respective 3 groups, the porcelain surface was first prepared according to the manufacturer's instructions. For this purpose, the porcelain surface was first etched with 9.5% buffered hydrofluoric (HF) acid (Porcelain Etchant, Bisco) for 90 s. The etchant was applied on the inferior surface of the disc. The surface was rinsed and dried after 90 s. Next, in Group 1 (Choice 2 resin cement), two-component silane was mixed and applied on the porcelain disc after 15 min. Porcelain Bond (Bisco, USA) was then applied. In Group 2 (G-CEM LinkForce resin cement), G-Multi Primer (GC) was applied on the porcelain surface after HF acid etching and dried with air spray. In Group 3 (Panavia V5 resin cement), Ceramic Primer (Kuraray Noritake Dental) was applied on the porcelain surface after HF acid etching and dried. The porcelain discs were then placed in stainless steel molds, and resin cement was applied over them. The cement was then covered with a Mylar strip and a glass slab was placed over it to obtain a smooth surface. Next, 2.6 kg static load was applied for 20 s to standardize the thickness of resin cement. Light curing was then performed using an LED curing unit (Bluephase N) with a light intensity of 1200 mW/cm^2 for 40 s. Curing was performed through the porcelain laminate. Light curing was performed at 4 points for 40 s using the overlapping technique, and the mold was then removed.

Color assessment

The L*, a* and b* color parameters were measured by a spectrophotometer (Ci64, X-Rite, Grandville, MI) against a white background using the CIE L*a*b* color space.

Aging and final color assessment

The specimens underwent thermocycling for 5000 thermal cycles between 5°C and 55°C with a dwell time of 30 s and a transfer time of 10 s in a thermocycler (Dorsa, Tehran, Iran). This protocol corresponded to 6 months of clinical service.[5] Next, the specimens were transferred to the spectrophotometer for final color assessment. Color change (ΔE) was then calculated using the formula $\Delta E=\sqrt{(\Delta a^2)+(\Delta b^2)+(\Delta c^2)}$.

Statistical analysis

Normal distribution of data was confirmed using Kolmogorov–Smirnov test. The effects of cement type, porcelain attendance, and their interactions on ΔE were evaluated by two-way ANOVA. Pairwise comparisons of tested groups were made with Tukey's *post hoc* test. The level of significancy was set on 0.05. Data were analyzed with SPSS software version 25 (SPSS Inc., Chicago, IL, USA).

RESULTS

The measures of central dispersion for the L*, a* and b* color parameters in the study groups before and after aging are presented in Tables 1 and 2, respectively. The results showed that all groups experienced a color change after aging. Table 3 presents the mean color change in each group. Color change (ΔE) in each of the six groups was analyzed by two-way ANOVA. The results revealed that the effect of cement type on discoloration was significant (P = 0.0001). Porcelain had a significant effect on discoloration as well (P = 0.0001). However, the interaction effect of cement type and porcelain on discoloration was not significant (P = 0.761). In other words, presence/absence of porcelain veneer played no role in superiority of one cement over the other, and the cement with lower discoloration yielded smaller ΔE than other groups, irrespective of the presence/absence of porcelain veneer.

Choice 2 and G CEM Linkforce showed the least and the most degree of discoloration respectively when they are considered without porcelain veneer. In a comparison of cement discoloration with a porcelain veneer, the same order was repeated and Choice 2 had the least ΔE, while G CEM Linkforce showed the most ΔE among other cements.

The Tukey's honestly significant difference test was applied for pairwise comparisons of the groups and revealed that the mean ΔE of Choice 2 (ΔE = 1.73) was significantly lower than that of Panavia V5 (ΔE = 3.13) (P = 0.021). The mean ΔE of Panavia V5 (ΔE = 3.13) was also significantly lower than that of G-CEM LinkForce (ΔE = 4.92) (P = 0.020). Moreover, the color change of porcelain-bonded cement groups was significantly lower than that of cement groups alone (P = 0.034) as illustrated in Figure 1.

Table 1: Mean and standard deviation of primary color parameters of the study groups

Group	Color parameter		
	L*±SD	a*±SD	b*±SD
Choice 2	64.38±1.52	−2.54±2.05	−2.85±0.19
Panavia V5	59.78±1.43	−3.03±0.17	0.66±0.56
G CEM Linkforce	55.86±2.16	−0.89±0.06	4.82±0.85
Choice 2 + porcelain	69.93±0.80	−1.44±0.08	8.21±0.40
Panavia V5 + porcelain	65.51±0.65	−1.83±0.09	8.93±0.47
G CEM Linkforce + porcelain	66.75±0.56	−0.53±0.25	8.39±0.94

SD: Standard deviation

Table 2: Mean and standard deviation of color parameters of the study groups after aging

Group	Color parameter		
	L±SD	a*±SD	b*±SD
Choice 2	66.82±2.58	−2.90±0.19	−2.48±0.34
Panavia V5	60.88±3.78	−2.65±0.25	1.13±0.56
G CEM Linkforce	56.99±4.01	0.11±0.42	8.41±1.88
Choice 2 + porcelain	69.17±0.8×8	−1.46±0.09	7.92±0.41
Panavia V5 + porcelain	64.03±0.76	−1.41±0.19	9.88±0.51
G-CEM linkforce + porcelain	70.13±0.95	−0.66±0.22	9.16±1.12

SD: Standard deviation

DISCUSSION

Increased demand for esthetic dental restorations has led to increased use of ceramic laminate veneers in contemporary dentistry. The color match of restoration with the adjacent teeth, its durability, and color stability are among the important factors in achieving patient satisfaction.[13] This study assessed the color change of two dual-cure resin cements namely Panavia V5 by Kuraray and G-CEM LinkForce by GC in comparison with Choice 2 light-cure resin cement. The results showed that Choice 2 light-cure resin cement experienced significantly lower color change after aging compared with dual-cure cements. In comparison of Panavia V5 and G-CEM LinkForce dual-cure resin cements, Panavia V5 experienced significantly lower color change than G-CEM LinkForce.

The polymerization of polymerizable resin components in dual-cure cements is influenced by the color of restoration and resin material.[3] Thus, clear-color resin cements and A1 medium-opacity feldspathic porcelain were used in this study for the purpose of standardization of specimens. In addition, color assessment was performed by spectrophotometry,

Table 3: Mean and standard deviation of change in color parameters of the six groups

Group	Color parameter			
	ΔL±SD	Δa*±SD	Δb*±SD	ΔE±SD
Choice 2	2.44±2.16	−0.36±2.11	0.37±0.20	2.62±1.99[a]
Panavia V5	1.09±4.92	0.37±0.22	0.46±0.57	4.37±2.26[b]
G CEM LinkForce	1.13±5.19	1.00±0.46	3.59±1.83	6.20±2.27[c]
Choice 2+porcelain	−0.76±0.47	−0.02±0.03	−0.29±0.04	0.84±0.43[d]
Panavia V5+porcelain	−1.47±0.63	0.42±0.21	0.95±0.49	1.89±0.55[e]
G-CEM LinkForce+porcelain	3.38±0.79	−0.13±0.11	0.76±0.48	3.64±0.83[f]

SD: Standard deviation

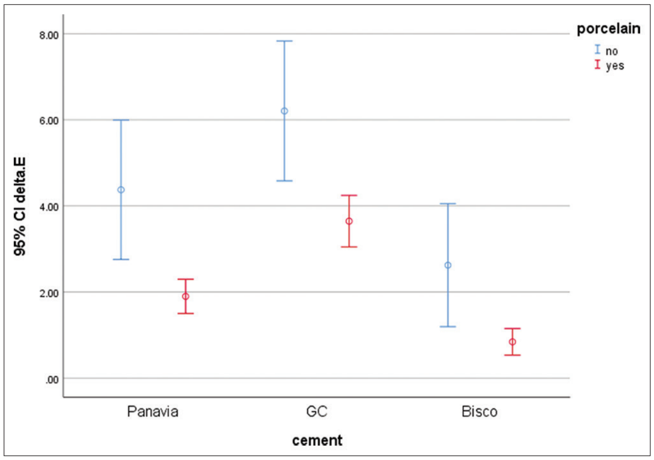

Figure 1: Comparison of ΔE of the study groups after aging.

which is the reference tool for color assessment due to its more objective nature and yielding quantitative results compared with the visual method. The spectrophotometers use the CIE L* a*b* color space to measure the L*, a* and b* color parameters and calculate the color change (ΔE) using ΔL (change in lightness), Δa (change in redness/greenness) and Δb (change in yellowness-blueness).[17] This system has many advantages. For example, it has all the perceivable colors, enables color perception similar to the human eye, and can quantify and convert the color parameters to numerical units.[18] High accuracy, reproducibility, and statistical applicability are among its other advantages. However, controversy still exists regarding the minimum perceivable color change by the human eye, which leads to variability in data interpretation by different studies. In this study, the minimum perceivable color change was considered to be ΔE =3.3.[19]

In order to assess the clinical performance of dental materials, *in vitro* studies should simulate the intraoral environment. Several methods have been suggested for aging of resin cements such as water storage, immersion in coloring agents such as coffee and grape juice, aging with xenon lamp and UV-B lamp, and thermocycling.[2,13,20] Thermocycling in 5°C–55°C water baths can simulate the oral clinical environment by exposure of the samples to humidity and thermal alterations,[3,20] which was performed for aging in this study.

Two series of specimens were evaluated in this study. The first series included resin cement specimens bonded to porcelain. Alkurt and Duymus,[13] and Ural *et al.*[16] did not bond the resin cement specimens to porcelain discs, which was different from our methodology. In this study, in order to simulate the clinical setting, the resin cement specimens were bonded to porcelain discs according to the manufacturers' instructions. The second series included resin cement specimens alone, which underwent color assessment against a white background and were then subjected to aging. The assessment of cement specimens alone resulted in standardization of the background and exposure of the entire specimen to external factors. The cement specimens alone are more exposed to the degrading factors,[17] which explains higher ΔE of cement groups alone, compared with cement specimens bonded to porcelain. Although a great portion of resin cement applied in the oral cavity is covered with porcelain, the cement is exposed at the restoration margins. Thus, discoloration of cement alone needs to be investigated, which was performed in this study.

In this study, all groups showed changes in L*, a* and b* parameters after aging. The reduction in L* parameter is manifested by a reduction in lightness. The increase in a* and b* parameters indicate increased redness and yellowness of specimens, respectively. According to the current findings, the a* parameter decreased after aging in Choice 2 cement while it increased in dual-cure cements. In addition, the b* parameter increased in both dual-cure cements but remained constant in Choice 2 cement. Increased a* and b* factors and yellowness of specimens are due to the presence of unreacted camphorquinone and oxidized amines. Hydrolytic degradation of triethylene glycol dimethacrylate and bisphenol-A glycidyl dimethacrylate in resin cements is another reason for this finding.[21]

Resin cements are divided into three groups of chemical cure, light cure, and dual-cure based on the type of polymerization. Selection of the type of polymerization of resin cement is highly important because depending on the chemical composition of cement, it can cause irreversible color change of ceramic restoration. Most self-cure or dual-cure resin cements contain benzoyl peroxide and tertiary amine, that are responsible for the initiation of polymerization reactions.[13] In chemical polymerization, aromatic amines react with benzoyl peroxide while in light polymerization, aliphatic amines, which are more stable, react with camphorquinone. Nonetheless, double bonds of carbon with benzoyl peroxide or residual amine would cause discoloration of restoration over time.[22] Previous studies have shown that light-cure resin cements have higher color stability than dual-cure resin cements due to their chemical composition,[22,23] which is in line with the current findings since in our study Choice 2 experienced less discoloration than Panavia V5 and G-CEM LinkForce dual-cure cements.

Higher discoloration of G-CEM LinkForce than Panavia V5 can be due to the fact that Panavia V5 has a new initiator system for chemical polymerization. The formulation of this new initiator system has not yet been disclosed by the manufacturer; however, G-CEM LinkForce contains benzoyl peroxide in its formulation.[3] Considering the abovementioned properties of benzoyl peroxide, greater discoloration of G-CEM LinkForce (despite being devoid of amine) is probably due to the presence of benzoyl peroxide in its composition.

In a study by Alkurt and Duymus, Panavia V5 cement showed a discoloration below the clinically detectable threshold of $\Delta E < 3.3$, which was in agreement with the current findings in Panavia V5 plus porcelain group.[13] In the study by Alkurt *et al*., discoloration was only evaluated through a ceramic laminate veneer, which explains lower ΔE of specimens after aging. All groups in our study showed some degrees of discoloration. However, dual-cure cements showed maximum discoloration, which was in agreement with previous findings and highlights the fact that dual-cure resin cements experience greater discoloration after aging than light-cure resin cements.[23] Greater discoloration can be attributed to a number of factors such as degradation of residual amines and oxidation of residual carbon double bonds. These structural changes in the cement would lead to formation of yellow-color compounds. In this study, light-cure resin cement showed higher color stability, which was in agreement with previous findings.[18] Despite the significantly higher color change of Panavia V5 cement compared with Choice 2 light-cure cement, ΔE of Panavia V5 along with porcelain was lower than the clinically detectable threshold by the human eye, which makes it suitable for use in areas where the cement line at the margin of restoration is not visible.[23] The Panavia V5 cement benefits from the new amine-free initiator system. Furthermore, the cement tube does not contain 10-MDP, which is a hydrophilic water absorbing molecule. The dental primer of this cement is single-bottle, and the 10-MDP molecules in its composition are chemically more stable than the previous generations such as Panavia F2, which have a two-bottle primer. All these factors explain the lower color change of Panavia V5.[3,24]

Considering the scarcity of studies on color change of G-CEM LinkForce cement, the existing literature for comparison with the current findings was limited and controversial. In general, due to the new formulation of the two dual-cure resin cements evaluated in this study, and lack of adequate information regarding their discoloration, further studies are required to cast a final judgment regarding their quality and clinical service in the oral environment for cementation of esthetic ceramic restorations of the anterior teeth. Moreover, some limitations existed in this study. For example, just one thickness of porcelain and also one shade of porcelain and resin cement had been used for standardization. It was also very difficult to simulate aging like the oral environment. The effect of other external factors such as food discoloration, plaque accumulation, and exposure to different pHs had not been considered.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

1. Choice 2 light-cure resin cement experienced minimum color change among the study groups and its discoloration was below the clinically detectable threshold by the human eye in both groups with/without porcelain
2. Panavia V5 dual-cure cement showed acceptable color change when used with porcelain, which makes it suitable for use in areas where the restoration margin is not visible
3. Discoloration of dual-cure cements seems to be higher than light-cure cements and therefore, their application in the esthetic zone should be done with caution.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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