BIOMATERIAL INVESTIGATIONS IN DENTISTRY
2021, VOL. 8, NO. 1, 11–17
https://doi.org/10.1080/26415275.2020.1855077

ORIGINAL ARTICLE

Influence of resin cement on color stability of ceramic veneers: *in vitro* study

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ABSTRACT

Statement of the problem: Long-term success of ceramic veneers depends on the color stability of resin cement used for their cementation. Color change of cement may be seen through the ceramic and compromise esthetics.

Purpose: This study aimed to compare the color change of two resin cements and their visibility through the ceramic veneers after accelerated artificial aging.

Materials and methods: In this *in vitro* study, color change (ΔE) was measured in the following groups ($n = 10$) before and after accelerated artificial aging: group 1, IPS e.max press high translucent ceramic discs; groups 2, Variolink NLC resin cement discs; group 3, Choice 2 resin cement discs; groups 4, Variolink NLC discs bonded to e.max ceramic discs; group 5, Choice 2 disc bonded to e.max ceramic discs. Color change was measured using a spectrophotometer according to International Commission on Illumination Lab (CIELab). Data were analyzed using one-way ANOVA and Tukey's post-hoc test.

Results: Group 2 showed the highest ($\Delta E = 10.4 \pm 0.9$) and group 1 the lowest ($\Delta E = 0.9 \pm 0.4$) color change. The color change of Variolink was significantly greater than Choice 2 either alone ($p < .001$) or through the ceramic discs ($p < .004$). The color change of both cements was lower through the ceramic veneer and this reduction was statistically significant ($p < .001$).

Conclusion: Noticeable color change may be expected in areas of cement exposure for both cements studied. Also, in case of using Variolink cement, the color change may be seen through the ceramic veneers.

ARTICLE HISTORY
Received 25 June 2020
Accepted 19 November 2020

KEYWORDS
Ceramic; accelerated aging; color stability; resin cements

Introduction

Ceramic veneers are among esthetic, conservative and predictable dental restorations with a survival rate of around 10 years [1]. Color match and color stability are among decisive factors in success of esthetic restorations [2]. Silica-based glass ceramics are commonly used for the fabrication of esthetic restorations such as ceramic veneers due to their highly favorable esthetic properties and increased fracture resistance [3].

At present, light-cure resin cements are used for cementation of ceramic veneers due to their high strength, durable bonding and reinforcement of ceramic [4]. Evidence shows that light-cure resin cements are suitable for cementation of thin laminate veneers due to their more favorable color stability compared to self-cure and dual-cure cements [5]. Color change of resin cements can be seen through the ceramic veneers and affect the esthetic appearance of the restoration. Also, the color change of resin cements and ceramic veneers and their margins in the oral cavity is an important esthetic problem that may be encountered in the use of these restorations [6,7]. Considering the fact that these restorations are mainly in the esthetic zone, any discoloration can compromise their esthetics and necessitate restoration replacement, which is time consuming and costly for patients [8].

Nowadays the use of IPS e.max ceramic for veneering of the teeth is growing due to properties such as

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high strength, different color shades and high translucency [9]. High translucency of these ceramics might lead to showing the probable discoloration of the underlying cement [10]. The long term color change of cements negatively affects the color and so the success of esthetic restorations. This issue is especially faced when the veneers are more translucent or thinner [11].

Although several investigations have examined color changes in laminate veneers and resin cements, their results are not in line [1,2,6]. Today, Variolink NLC and Choice 2 are among frequently used resin cements. The manufacturer of these products claim that there will be no visible color change following the cementation of ceramic veneers with these resin cements. So this *in vitro* study aimed to compare the color change of IPS e.max ceramic veneers fixed with these commonly used light-cure resin cements after AAA. The null hypothesis was that there is no color difference between ceramic veneers fixed with these two cements.

Materials and methods

In this *in vitro* experimental study, the color change of light-cure resin cements alone and through the ceramic laminate veneers was evaluated after AAA. The composition of studied resin cements is presented in Table 1.

Preparation of ceramic samples

Thirty ceramic samples were fabricated of A2 shade of IPS e.max Press high-translucent (HT) ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) with 0.5 mm thickness and 10 mm diameter. For the fabrication of ceramic discs, first, discs were fabricated of baseplate wax with the desired dimensions. After placing the wax pattern in the investment material and its setting for 45 min, the investment along with the embedded wax pattern was transferred to a furnace (Forno de Anel F3000 3 P Microprocessado, EDG, Sao Paulo, Brazil) and heated to 850 °C to eliminate the wax pattern and allow expansion of the mold. Ceramic ingots were then transferred to the furnace (Programat EP 5000, Ivoclar Vivadent AG, Schaan, Liechtenstein) and heated to 920 °C for 20 min with a heating rate of 60 °C/minute to become plasticized. Next, the ceramic material was pushed into the cavity created by wax burnout using a 0.4 MPa aluminum plunger. The complex was then allowed to slowly cool down to room temperature. The excess investment material was removed and the bottom surface of the ceramic samples was polished with 400, 800 and 1200-grit sand paper (Epitex, GC America Inc., Alsip, IL). The top surface of the samples was sprayed with Ceram Glaze (Ivoclar Vivadent AG, Schaan, Liechtenstein) as recommended by the manufacturer and heated in a furnace at 450 °C. The samples were cleaned in an ultrasonic bath (Cristofoli, Campo Mourao, PR, Brazil) for 10 min and their dimensions were measured by a digital caliper (Absolute 500; Mitutoyo Co., Tokyo, Japan). Group 1 included 10 ceramic discs not bonded to resin cement in order to assess the color stability of ceramic alone. Twenty other ceramic samples were bonded to the two resin cements ($n = 10$ in each group) to assess the color change of the resin cement through ceramic veneer.

Preparation of cement samples

In groups 2 and 3, the translucent shades of Variolink NLC (Ivoclar Vivadent) and Choice 2 (Bisco) light-cure resin cements were used, respectively. Resin cements were applied into a Teflon mold with 0.3 mm depth and 10 mm diameter. The cement surface was covered with a Mylar strip and a glass slab and a 2.5 kg weight was placed over it for 20 s in order to obtain a uniform thickness of cement and obtain a smooth surface. The top and bottom surfaces of the samples were light-cured using a LED light-curing unit (Demetron LC; Kerr, Orange, CA) with an intensity of 600 mW/cm^2 for 40 s. The light intensity was measured with a radiometer (Kerr Corporation, Orange, CA) before each time of use.

Bonding of resin cements to ceramic

In groups 4 and 5, resin cements were bonded to the ceramic surface. For this purpose, the ceramic surface was prepared according to the manufacturer's instructions. First, 5% hydrofluoric acid (Bisco Inc., Schaumburg, IL) was applied on the unglazed ceramic surface for 20 s and then rinsed and dried for 1 min. The two components of silane (Bis-Silane; Bisco Inc., Schaumburg, IL) were mixed and applied

Table 1. Composition of the materials used.

Material	Type	Monomer	Manufacture
Choice 2	Light cure	Bis-GMA (biphenyl glycol dimethacrylate)	Bisco Inc., Schaumburg, IL
Variolink NLC	Light cure	Dimethacrylate	Ivoclar Vivadent Schaan, Liechtenstein

on the surface of ceramic disc and dried for 30 s. Unfilled resin (Heliobond; Ivoclar Vivadent AG, Schaan, Lichtenstein) was applied on the silanized ceramic surface. Treated ceramic disc was placed in a Teflon mold with 0.8 mm height and 10 mm diameter and resin cement was then applied over it similar to the clinical procedure. The cement surface was covered with a Mylar strip and a glass slab and a 2.5 kg weight was placed over it for 20 s in order to obtain a uniform thickness of cement [10]. After removing the weight, the samples were cured through the ceramic disc at four points for 60 s using a LED light-curing unit (Demetron LC; Kerr, Orange, CA) with a measured intensity of 500 mW/cm^2 *via* ceramic discs by the overlapping technique. The light intensity was measured using a radiometer (Kerr Corporation, Orange, CA).

So the study groups ($n = 10$) were as follows:

Group 1 (ceramic group): IPS e.max Press high-translucent (HT) ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) discs

Group 2 (resin cement): Variolink NLC Clear Shade (Ivoclar Vivadent, Schaan, Liechtenstein) resin cement discs

Group 3 (resin cement): Choice 2 Translucent Shade (Bisco Inc., Schaumburg, IL, USA) resin cement discs

Group 4 (resin cement and ceramic): Variolink NLC Clear Shade (Ivoclar Vivadent, Schaan, Liechtenstein) and IPS e.max Press HT ceramic

Group 5 (resin cement and ceramic): Choice 2 Translucent Shade (Bisco Inc., Schaumburg, IL) and IPS e.max Press HT ceramic

Colorimetery

The primary color parameters of the samples were determined using a spectrophotometer (SP 64; X-Rite) and the color parameters were quantified according to the CIE L*a*b* system. This system quantifies the color using three color coordinates of L*, a* and b*. The L* coordinate indicates lightness or value, and a* and b* indicate the red-green and yellow-blue axes, respectively (+a*: red; -a*: green, +b* yellow and –b* blue) [12].

Accelerated artificial aging

The samples underwent AAA in QUV Accelerated Weathering Tester (Q-Lab, US) according to ASTMG154 06 standards [13]. They were subjected to frequent cycles of UV fluorescent lamp irradiation at 340 nm wavelength and 0.89 W/mm^2 light intensity at 60 °C for 8 h followed by 4 h in 100% humidity away from light at 50 °C. This was repeated for 384 h corresponding to 1 year of clinical service [13]. Next, the samples were transferred to a spectrophotometer (SP64; X-Rite, USA) and the CIE L*a*b* parameters were measured again. The following formula was used for calculation of color change [14].

$$\Delta E = \sqrt{(\Delta a^2) + (\Delta b^2) + (\Delta L^2)}$$

Data were analyzed using one-way ANOVA and Tukey's test *via* SPSS version 22.0 (SPSS Inc., IL) at 0.05 level of significance.

Results

Table 2 shows the mean and standard deviation of color change in the study groups. Results showed that all groups experienced color change after AAA. Variolink resin cement showed the highest color change ($\Delta E = 10.4 \pm 0.9$) followed by Choice 2 resin cement ($\Delta E = 8.5 \pm 1.5$), Variolink and e.max ceramic veneer ($\Delta E = 4.7 \pm 0.7$), Choice 2 and IPS e.max ceramic veneer ($\Delta E = 3.3 \pm 0.7$) and IPS e.max ceramic veneer alone ($\Delta E = 0.9 \pm 0.4$).

Table 3 shows pairwise comparisons of the mean ΔE between the study groups. Variolink cement showed greater discoloration compared to Choice 2 ($p < .001$). The color change of both cements was lower through the ceramic veneer and this reduction was statistically significant ($p < .001$). The color change observed in Choice 2 was significantly less than that of Variolink through the ceramic veneer ($p < .004$).

Table 2. Mean and standard deviation of color change in the study groups.

Group	ΔL	Δa*	Δb*	ΔE
IPS e-max Press	0.74 (0.46)	0.36 (0.05)	0.24 (0.2)	0.9 (0.4)
Variolink cement	−3.8 (0.8)	3.5 (0.5)	8.3 (0.1)	10.4 (0.9)
Choice 2 cement	−2.4 (0.6)	0.5 (0.4)	8.1 (0.4)	8.5 (1.5)
Variolink cement + ceramic	−3 (0.8)	2.8 (0.27)	2.1 (0.6)	4.7 (0.7)
Choice 2 cement + ceramic	−2.4 (0.7)	0.96 (0.2)	2.31 (0.65)	3.3 (0.7)

Table 3. Pairwise comparison of mean and SD color change among the study groups.

Group	Mean ± SD	*p* value
Variolink cement	10.4 (0.9)	≤.001
Choice 2 cement	8.5 (1.5)	
Variolink cement	9.9 (0.4)	≤.001
Variolink cement + ceramic	4.7 (0.7)	
Choice 2 cement	8.5 (1.5)	≤.001
Choice 2 cement + ceramic	3.3 (0.7)	
Variolink cement + ceramic	4.7 (0.7)	≤.004
Choice 2 cement + ceramic	3.3 (0.7)	

ΔE: color change; SD: standard deviation.

Results showed a decrease in lightness values in all study groups after aging. This reduction was greater in Variolink compared to Choice 2 ($p < .005$) but there was no significant difference between groups 2 and 4 or groups 3 and 5 ($p = .33$) so covering the cement with ceramic did not make a difference in lightness. Regarding Δa, all samples underwent red discoloration. This discoloration was greater in Variolink compared to Choice 2 ($p < .0001$). Also the difference between groups 2 and 4 or groups 3 and 5 was significant ($p < .03$) so the amount of cement redness could decrease throughout the ceramic. Regarding Δb, all samples became more yellowish after aging. This discoloration was greater in Variolink compared to Choice 2($p < .005$) and the difference between groups 2 and 4 or groups 3 and 5 was significant in this respect ($p < .0001$). So the ceramic layer could mask the yellowish discoloration in cement to some extent.

Discussion

This study compared the color stability of two resin cements and their visible discoloration through ceramic veneers after AAA. Variolink showed higher color change compared to Choice 2 resin cement, so the null hypothesis was rejected.

Increased patient demands for esthetic restorations makes selection of the treatment of choice even more challenging. Application of ceramic veneers is increasing due to their ideal esthetics [14,15]. The final color of ceramic veneers depends on the type of ceramic used, the veneering thickness, degree of translucency and opacity of ceramic, the cement color and color of the underlying tooth structure. Color change over time is a common problem of adhesive resin cements used for bonding ceramic veneers. This discoloration is especially important at the margins of the veneers [16].

Change of color parameters (Δa, Δb and ΔL) and overall color change (ΔE) are often evaluated before and after AAA to assess the color stability of dental materials. In general, $\Delta E < 1$ is not detectable by the human eye, ΔE between 1 and 3.3 can be perceived by the experts and is clinically acceptable, while $\Delta E > 3.3$ is perceivable by the laypeople and is therefore clinically unacceptable [12]. Another study considered the gold standard for ΔE to be 2 [17]. However, most studies believe that $\Delta E \leq 3.3$ is clinically acceptable [18]. $\Delta E \leq 3.3$ was also considered acceptable in the current study. ΔE values above the clinically acceptable threshold were obtained in the two resin cement groups after AAA. In other words, if these resin cements are exposed to the oral environment for any reason; such as a gingival recession or supragingival position of restoration margins in the esthetic zone, color change of restoration margins would be clinically detectable. It is important because it can significantly compromise the esthetic appearance of restorations [19]. Also, the color change was significantly less in groups with ceramic veneers; the e.max ceramic group showed slight color change, which was within the clinically acceptable range.

The CIE L*a*b* color space has long been used as an acceptable method of color measurement because each color has its own specific location in the three-dimensional CIE L*a*b* color space [4]. The majority of studies on color change of dental materials have used the CIE L*a*b* color space [4,6].

Time is an important factor in discoloration of resin cements. Ceramic restorations in the oral cavity are exposed to thermal alterations, internal and external chemical agents such as foods and saliva constituents. The anterior teeth are also exposed to visible and UV light. All these factors can cause color change of resin cements used for bonding of ceramic restorations. The AAA is suitable for the assessment of changes that occur in physical, chemical and optical properties of non-metal dental materials such as resin cements [9,20]. It exposes the samples to crucial conditions in terms of lighting, temperature and moisture to cause irreversible color change in them. Evidence shows that 340 nm UVA best simulates the sunlight [19]. In this study, the samples were subjected to AAA in QUV/spray according to the ASTMG 154-06 standards. According to the ASTM recommended protocol, 384 h of AAA corresponds to 1 year of clinical service [14,19]. According to previous studies, UV light and high temperature in dry environment cause intense changes in materials. Thus, AAA is expected to cause greater color change in resin cements due to aging compared to the oral environment [19]. In this study, severe color change of resin cements under aging confirmed this statement. Kilinc et al. [6] evaluated the color stability of resin cements and reported results similar to ours. They demonstrated that all resin cements experienced color change after aging and a percentage of this color change was masked by the ceramic veneers. However, the ΔE value obtained in their study was smaller than the value found in our study, which may be due to limited aging time in their study which was only 65 h. In our study, the thickness of cement discs was 0.3 mm which was greater than the actual thickness of cement layer in clinical practice. This was due to the special architecture of the device used for accessing the color change. Another possible limitation of the present study might be the limited oxygen inhibited layer formed on the resin discs duo to the oxygen molecules adhered to the surface of Mylar strip. However, the procedure was the same for both groups.

Archegas et al. [21] showed that cements had a yellowish discoloration following aging, which was in line with our findings. Similarly in our study, all samples showed yellowish discoloration after AAA and this color shift towards yellow was much greater in the resin cement groups compared to the groups with ceramic veneers. In other words, ceramic veneers masked a high percentage of yellowish discoloration of cements. Evidence shows that yellowish discoloration of samples after aging can be due to the presence of camphorquinone in cement formulation. Also, this yellowish discoloration can be due to the presence of Bis-GMA in the cement subjected to UV light radiation and heat. Moreover, degradation of residual amines and oxidation of unreacted carbon double bonds are among other reasons for yellowish discoloration of samples [19,22]. On the other hand, presence of UDMA in the composition of cement may be associated with lower percentage of TEGDMA and can lead to less water sorption and subsequently less discoloration [16]. In the present study, the b* parameter significantly increased in both cement groups and this increase was greater in Variolink cement group. This may be due to its lower filler percentage compared to Choice 2 [18,21]. The percentage of yellowish discoloration was significantly less in laminate veneering groups. In other words, laminate veneers can mask the color change of resin cements to some extent such that the amount of color change in Choice 2 group with ceramic veneers was within the clinically acceptable range. Nonetheless, the color change of resin cements would still be visible at the margins of ceramic veneers.

Almedia et al. [23] studied the color stability of resin cements and found no significant difference regarding color change among different light-cure resin cements. All groups showed $\Delta E > 3.3$. They also demonstrated that the color of dual-cure resin cement shifted to red and yellow after aging but no such color change was noted for light-cure cements. In this study, all samples showed a shift in color towards red; this shift was greater in Variolink group. This redness was less in the two groups with ceramic veneers than that in cement groups. In the study by Almedia et al, aging was performed by thermocycling while in our study, aging was performed using QUV device, which better simulates the clinical setting because it uses a combination of UV light radiation and heat. This may explain why Almedia et al. did not find red and yellow discoloration in light-cure resins.

Turgut et al. [24] evaluated the color change of ceramic alone and reported a ΔE value of 0.5 to 1 for HT ceramic, which was close to the value found in our study. In other words, color change of ceramic after aging was insignificant and within the clinically acceptable range. They indicated that the higher the ceramic thickness, the lower the visibility of discolored resin through the ceramic would be. However, it should be noted that by an increase in ceramic thickness, its translucency decreases, which may compromise the esthetic appearance of restoration. Moreover, optimal curing of resin cement through thick ceramic is questionable and may not be achieved [8]. Also, their results showed that ceramic with 0.5 mm thickness better masks the color change of resin cements. Kurklu et al. [25] stated that 0.5–1 mm ceramic thickness shows clinically acceptable color change when used with clear shade cements. Paula et al. [26] evaluated the color stability of resin cements and concluded that ceramic thickness is an important factor affecting the visibility of cement discoloration over time. The translucency of ceramic is highly important during cementation due to the need for complete curing of light-cure resin cements. Considering the mentioned reasons, 0.5 mm thick HT ceramic was used in this study, which perfectly simulates a vital tooth and its degree of translucency guarantees complete polymerization of resin cement and achieving a high degree of conversion [26].

Ghavam et al. [27] reported no significant color change in any cement group after aging and demonstrated that the ΔE values in all groups were within the clinically acceptable range. This finding was different from our results, which may be due to the short duration of aging in their study.

Ai et al. [28] indicated that all cements experienced discoloration after aging, although the difference among the groups was not statistically significant. However, the color change of Variolink cement was higher than Rely X cement. This finding was in agreement with our results.

In resin cements, a low degree of conversion could explain discoloration [29]. Resin cement discoloration is influenced by some factors related to the material such as type of filler, resin matrix chemistry and photoinitiator. Variolink NLC contains a thiocarbamide photo-initiator derived from dibenzoyl germanium (Ivocerin). This is categorized as type II photoinitiator which is used to enhance the color stability of resin cements [30]. The current study showed greater color change for Variolink NLC. This result may be contributed to the chemical structure of cements including differences in content of fillers or monomer composition of cements. As there is no furthered information available regarding the composition of these two luting resin agents, future studies seems necessary to thoroughly investigate properties of the cements.

Duo to the complexity of the oral cavity, the generalization of the results from *in vitro* studies to the clinical condition is not always reliable. Keeping this in mind, within the limitation of this study, noticeable color change may be expected in areas of cement exposure. Also, in case of using Variolink cement, the color change may be seen through the ceramic veneers.

Conclusion

Considering the results of this study, although ceramic could mask the color change of resin cements to some extent, it should be noted that color change of light-cure resin cements tested in our study was clinically unacceptable after AAA; this color change, especially at the margins, can seriously compromise the esthetic appearance of restorations. It is also concluded that discoloration of resin cement whether alone or throughout the ceramic is greater in Variolink cement compared to Choice 2 cement.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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