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The Influence of Artificial Aging on the Color Stability of Light Cure and Dual Cure Luting Cement

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Abstract

Background: The long-term esthetic success of ceramic laminate veneer restorations largely depends on the color stability of the resin luting cement used for their cementation. Because ceramic veneers are thin and highly translucent, any discoloration of the underlying luting cement may become visible over time and compromise the final appearance of the restoration. Several factors, including the composition of the resin matrix, the type of polymerization, and water-related degradation, can influence the color stability of resin luting cements.

Aim: This in-vitro study was conducted to evaluate and compare the color stability of light-cure and dual-cure resin luting cements used for ceramic laminate veneer restorations after artificial aging in distilled water.

Material and Method: A total of 60 CAD/CAM-fabricated zirconia specimens measuring 10 × 10 mm with a thickness of 0.5 mm were prepared and equally distributed into three groups ($n = 20$). Group A was luted with Variolink N LC (Ivoclar), Group B with Fusion i-Seal (Prevest DenPro), and Group C with Fusion Ultra D/C (Prevest DenPro). Initial color measurements were obtained using a spectrophotometer based on the CIE L*a*b* color system. The specimens were then subjected to artificial aging by immersion in distilled water at 37°C for 30 days. After aging, color measurements were repeated, and the color difference (ΔE) was calculated. Statistical analysis included the paired *t*-test for intragroup comparisons and one-way ANOVA followed by Tukey's post hoc test for intergroup analysis.

Results: Artificial aging produced a statistically significant color change in all three groups. The lowest mean color difference was observed in Group A ($\Delta E = 4.42 \pm 0.73$), followed by Group B ($\Delta E = 6.22 \pm 0.91$). Group C exhibited the greatest color change ($\Delta E = 13.86 \pm 1.09$). Intergroup comparison demonstrated a highly significant difference among the three resin cements ($p < 0.001$).

Conclusion: Within the limitations of this in-vitro investigation, light-cure resin luting cements showed significantly better color stability than the dual-cure resin luting cement after artificial aging. These findings suggest that light-cure resin cements are a more suitable choice for ceramic laminate veneer restorations when long-term esthetic color stability is a primary clinical concern.

Keywords: Color stability; Resin luting cement; Ceramic laminate veneers; Light-cure resin cement; Dual-cure resin cement; Artificial aging; Spectrophotometer; CIE L*a*b* color system.

Introduction

Esthetic dentistry has witnessed remarkable advancements over the past few decades, driven by increasing patient expectations for conservative treatment options that restore both function and appearance. Among the available restorative procedures, ceramic laminate veneers have gained widespread acceptance because they provide excellent esthetics while preserving a substantial amount of natural tooth structure. These restorations are routinely indicated for the management of intrinsic tooth discoloration, enamel defects, diastema closure, malformed teeth, and minor positional discrepancies. Owing to their excellent biocompatibility, favorable mechanical properties, and high long-term clinical success rates, ceramic laminate veneers have become one of the most predictable treatment modalities in contemporary restorative dentistry. Long-term clinical studies have reported survival rates exceeding 90%, highlighting their reliability and durability in clinical practice. [1]

The esthetic outcome of a ceramic laminate veneer depends on the combined interaction of several optical factors rather than the ceramic material alone. Variables such as ceramic thickness, translucency, shade, surface characteristics, underlying tooth color, and the optical properties of the luting cement collectively determine the final appearance of the restoration. Because ceramic veneers are fabricated with minimal thickness to preserve enamel, they allow considerable transmission of light. As a result, the shade and color stability of the resin luting cement become critical determinants of the final esthetic result. Even slight discoloration of the luting cement may become visible through the ceramic restoration and compromise the overall appearance over time.[2]

Resin luting cements are currently regarded as the gold standard for bonding ceramic laminate veneers because they provide excellent adhesion, low solubility, favorable mechanical strength, and superior esthetic properties. Based on their polymerization mechanism, these materials are broadly classified into light-cure, dual-cure, and self-cure resin cements. Light-cure resin cements are generally recommended for veneer restorations because they exhibit enhanced color stability and do not require chemically activated aromatic tertiary amines, which are known to contribute to discoloration. In contrast, dual-cure resin cements utilize both light-activated and chemically activated polymerization, ensuring adequate curing even in areas where light transmission is reduced. However, the presence of chemical initiator systems has been associated with increased susceptibility to long-term color changes. [3,4]

Color stability is one of the most important properties of resin-based luting materials, particularly in highly esthetic restorations such as ceramic veneers. Any change in the color of the luting cement may adversely affect the final shade of the restoration and reduce patient satisfaction. Discoloration of resin cements is a multifactorial process resulting from both intrinsic and extrinsic mechanisms. Intrinsic discoloration may occur because of oxidation of initiator systems, degradation of the resin matrix, incomplete polymerization, hydrolytic degradation, and deterioration of the filler–matrix interface. In contrast, extrinsic discoloration results from the absorption and adsorption of pigments from commonly consumed beverages and tobacco products, including coffee, tea, red wine, cola drinks, and cigarette smoke. The combined influence of these factors may significantly alter the optical properties of resin luting cements during clinical service.[5,6,7]

Among the intrinsic factors, the polymerization mechanism has been recognized as one of the primary determinants of long-term color stability. Previous investigations have demonstrated that light-cure resin cements generally exhibit superior color stability compared with chemically or dual-cure materials because they lack aromatic tertiary amines that are prone to oxidation. Several authors have reported progressive discoloration of dual-cure resin cements during aging, whereas light-cure materials have shown greater resistance to color change. These findings indicate that the composition of the polymerization system plays a crucial role in maintaining the long-term esthetic performance of resin luting cements. [3,4,9,10]

Hydrolytic degradation resulting from water sorption is another important factor affecting the color stability of resin-based materials. Water molecules gradually penetrate the polymer network, leading to plasticization, hydrolysis of ester bonds, degradation of the filler–matrix interface, and changes in the refractive index of the material. These alterations adversely affect the optical characteristics of the resin cement and contribute to clinically perceptible discoloration. The extent of water sorption depends on the composition of the resin matrix, degree of conversion, and filler content. Previous studies have demonstrated that prolonged water storage results in progressive color alteration in resin-based restorative materials, emphasizing the importance of evaluating their behavior under simulated oral conditions.[11,12]

Artificial aging procedures are widely employed in laboratory investigations to reproduce the effects of long-term clinical service within a relatively short experimental period. Among the available aging methods, immersion in distilled water at 37°C is considered one of the most clinically relevant techniques because it closely simulates the hydrolytic degradation occurring in the oral environment. Earlier investigations have shown that prolonged water storage can produce measurable changes in the physical and optical properties of resin-based materials, making it a reliable method for assessing the long-term color stability of resin luting cements. [13]

Recent studies have further highlighted the influence of resin cement composition on the esthetic performance of ceramic restorations. The shade, translucency, and opacity of luting cements have been shown to significantly affect the final color of thin ceramic veneers. Furthermore, investigations comparing different polymerization systems have consistently reported greater discoloration of dual-cure resin cements than light-cure materials following artificial aging. These observations reinforce the importance of selecting a luting cement with superior color stability, particularly for highly translucent ceramic restorations where even minor color alterations may become clinically evident. [14]

Although numerous studies have investigated the color stability of resin luting cements, relatively few have compared recently introduced light-cure and dual-cure materials under standardized artificial aging conditions. In addition, limited evidence is available regarding the performance of newer commercially available resin luting cements following prolonged water storage. Therefore, the present in-vitro study was undertaken to evaluate and compare the color stability of Variolink N LC, Fusion i-Seal, and Fusion Ultra D/C resin luting cements after artificial aging in distilled water using spectrophotometric analysis based on the CIE L*a*b* color system.

Materials and Methods

The present study was conducted as an in-vitro comparative study to assess and compare the color stability of different resin luting cements used for veneer restorations. The study specifically evaluated the changes in color exhibited by light-cure and dual-cure resin luting cements following exposure to an artificial aging environment using distilled water.

A total of 60 specimens were prepared for the study. The specimens were randomly allocated into three experimental groups, with 20 specimens in each group, according to the type and brand of resin luting cement used. Group A: Variolink N LC – light-cure resin luting cement, Group B: Fusion i-Seal (Prevest DenPro, India) – light-cure resin luting cement, and Group C: Fusion Ultra D/C (Prevest DenPro, India) – dual-cure resin luting cement. Random allocation was performed to minimize the possibility of selection bias and to ensure comparable distribution of specimens among the three groups.

Standardized zirconia specimens were designed digitally using Exocad software and subsequently fabricated using a computer-aided design and computer-aided manufacturing (CAD/CAM) system. Each specimen was standardized to a dimension of 10 × 10 mm, with a thickness of 0.5 mm. The selected dimensions were intended to simulate the thickness and surface area of a thin ceramic veneer restoration under laboratory conditions. After fabrication, the specimens were inspected to ensure uniformity and to exclude specimens exhibiting visible defects, cracks, or irregularities. A customized mold was prepared using polyvinyl siloxane (PVS) putty to provide a standardized space for the resin luting cement and zirconia specimen. The mold had a standardized surface dimension of 10 × 10 mm and a total depth of 1 mm. A zirconia specimen measuring 10 × 10 mm with a thickness of 1 mm was initially used to create the mold. The resulting 1-mm space was intended to accommodate 0.5 mm of resin luting cement and 0.5 mm of zirconia, thereby simulating the clinical configuration of a thin veneer restoration. The use of a customized mold ensured consistent specimen dimensions and helped maintain a uniform thickness of the resin cement layer throughout the study.

All resin luting cements and surface-treatment materials were handled according to the respective manufacturers' recommendations. Prior to cementation, the zirconia specimens were treated with 5% buffered hydrofluoric acid etching gel (CeraEtch, Prevest DenPro). The etching agent was applied uniformly to the bonding surface and allowed to react for 30 seconds. Following etching, the specimens were thoroughly rinsed with water to remove residual etchant and were subsequently dried.

A thin layer of silane coupling agent (Silane-X, Prevest DenPro) was then applied to the treated surface using an applicator. The silane was allowed to react and dry for approximately 1–2 minutes, as recommended by the manufacturer.

The respective resin luting cement was then introduced into the customized mold. The zirconia specimen was carefully positioned over the cement layer to reproduce the configuration of a veneer restoration. A glass slab was placed over the assembly and gentle, uniform pressure was applied. This procedure helped distribute the cement evenly, minimize the formation of voids, and facilitate removal of excess cement.

For Groups A and B, which contained light-cure resin luting cements, polymerization was carried out using an LED light-curing unit. The curing time was maintained within the manufacturer's recommended range of 20–40 seconds. For Group C, containing the dual-cure resin luting cement, the material was initially exposed to light activation and was subsequently allowed to undergo the remaining chemical polymerization reaction according to the manufacturer's instructions. After polymerization, the specimens were carefully removed from the mold. Each specimen was visually inspected for surface irregularities, cracks, voids, or other fabrication defects. Specimens showing obvious defects were excluded from further analysis.

Baseline Color Measurement

The initial color of each specimen was recorded before artificial aging using a spectrophotometer based on the CIE L*a*b* color system. For measurement, each specimen was positioned consistently against a standardized white background. Care was taken to maintain the same orientation and measurement conditions for all specimens.

Three consecutive measurements were obtained for each specimen. The three readings were averaged to obtain a representative baseline value for each specimen. The following color coordinates were recorded:

- L* – represents lightness, ranging from black to white.
- a* – represents the red–green chromatic axis.
- b* – represents the yellow–blue chromatic axis.

These baseline measurements served as the reference values for determining the subsequent color changes produced by artificial aging.

Artificial Aging Procedure

Artificial aging was performed using a water-storage aging protocol. All prepared specimens were immersed individually in distilled water and maintained at a constant temperature of 37°C for 30 days. The water-aging protocol was selected to expose the resin luting cements to a controlled aqueous environment and to evaluate color changes associated with water absorption, hydrolytic degradation, and other aging-related changes that may occur within the resin matrix. The storage conditions, including temperature and duration, were standardized for all experimental groups to ensure comparable aging exposure.

Post-Aging Color Measurement

At the end of the 30-day aging period, the specimens were removed from the distilled water and gently dried to eliminate surface moisture. Color measurements were subsequently repeated using the same spectrophotometer, measurement conditions, background, and positioning protocol used for the baseline assessment. Three readings were obtained for each specimen, and the mean of the three measurements was recorded as the post-aging color value. The baseline and post-aging L*, a*, and b* values were then used to determine the overall color difference for each specimen.

The change in color produced following artificial aging was calculated using the conventional CIE L*a*b* color-difference equation:

$$\Delta E_p q = [(L^*_p - L^*q)^2 + (a^*_p - a^*q)^2 + (b^*_p - b^*q)^2]^{1/2}$$

Where:

- L^*_p, a^*_p, b^*_p = baseline color coordinates
- L^*q, a^*q, b^*q = color coordinates recorded after artificial aging
- ΔE_{pq} = overall color difference between baseline and post-aging measurements

A higher ΔE value indicated a greater change in color following artificial aging, whereas a lower ΔE value indicated comparatively greater color stability.

The recorded observations were systematically tabulated and subjected to statistical analysis using Statistical Package for the Social Sciences (SPSS) software.

Descriptive statistics, including mean and standard deviation, were calculated for the color-change values obtained for each experimental group.

For comparison of the color measurements within the same group before and after artificial aging, a paired t-test was employed. This analysis was used to determine whether exposure to the aging protocol resulted in a statistically significant change in color within each resin cement group. For comparison among the three experimental groups, one-way analysis of variance (ANOVA) was performed. When a statistically significant difference was identified by ANOVA, Tukey's post hoc test was used to determine the specific pairs of groups that differed significantly from one another. The level of statistical significance was established at $p < 0.05$ for all analyses.

Results

The present study evaluated the mean color change (ΔEpq) among three resin cement groups following artificial aging. Group A (Variolink N LC) demonstrated the least color alteration with a mean ΔEpq value of 4.42 ± 0.73, with values ranging from 3.20 to 5.50, indicating superior color stability after aging. Group B (Fusion i-Seal) showed moderate discoloration with a mean ΔEpq value of 6.22 ± 0.91 and values ranging between 5.00 and 8.00. In contrast, Group C (Fusion Ultra D/C) exhibited the highest color change with a mean ΔEpq value of 13.86 ± 1.09, ranging from 11.70 to 15.70, suggesting poor resistance to aging-induced discoloration. Intergroup comparison using One-way ANOVA revealed a statistically highly significant difference among the three study groups ($F = 588.463$, $p < 0.001$). Overall, Variolink N LC demonstrated the best color stability, whereas Fusion Ultra D/C showed maximum discoloration after artificial aging. Post hoc Tukey analysis was performed for pairwise intergroup comparison of mean ΔEpq values among the three study groups. The comparison between Group A (Variolink N LC) and Group B (Fusion i-Seal) revealed a mean difference of 1.80, which was statistically significant ($p < 0.001$). Similarly, comparison between Group A and Group C (Fusion Ultra D/C) demonstrated a mean difference of 9.44, indicating a highly significant difference in color change between the groups ($p < 0.001$). The comparison between Group B and Group C also showed a statistically significant mean difference of 7.64 ($p < 0.001$). These findings indicate that all three groups differed significantly from each other with respect to color stability after artificial aging, with Group A exhibiting the least discoloration and Group C showing the highest color change.

Table 1: Descriptive statistics of mean color change in different groups

Group	**Mean ΔEpq**	**SD**	**Min**	**Max**	**P value**
Group A – Variolink N LC	4.42	0.73	3.20	5.50	0.001
Group B – Fusion i-Seal	6.22	0.91	5.00	8.00	
Group C – Fusion Ultra D/C	13.86	1.09	11.70	15.70	

Table 2: Post hoc tukey test for intergroup comparison of ΔEpq values

Comparison	Mean Difference	P value
Group A vs Group B	1.80	<0.001
Group A vs Group C	9.44	<0.001
Group B vs Group C	7.64	<0.001

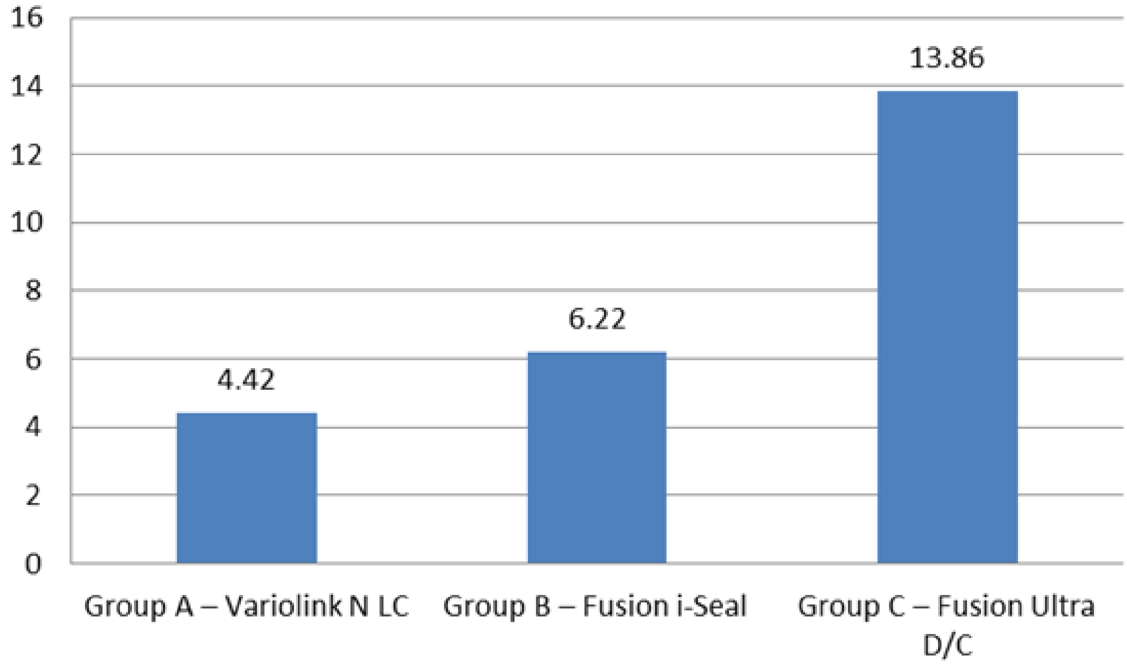


Table 3: Comparison Of Mean L*, A*, And B* Values Before And After Aging In Group A

Parameter	Before Aging Mean ± SD	After Aging Mean ± SD	Mean Difference	P value
L*	75.69 ± 0.86	80.00 ± 0.53	-4.31	0.001
a*	-0.80 ± 0.14	-1.26 ± 0.15	0.46	0.001
b*	4.46 ± 0.32	3.46 ± 0.49	1.00	0.001

The comparison of mean L*, a*, and b* values before and after aging in Group A (Variolink N LC) demonstrated statistically significant changes in all color parameters following artificial aging. The mean L* value increased from 75.69 ± 0.86 before aging to 80.00 ± 0.53 after aging, with a mean difference of -4.31, which was statistically significant ($p = 0.001$). Similarly, the mean a* value changed from -0.80 ± 0.14 to -1.26 ± 0.15, showing a statistically significant mean difference of 0.46 ($p = 0.001$). The mean b* value decreased from 4.46 ± 0.32 before aging to 3.46 ± 0.49 after aging, with a mean difference of 1.00, which was also statistically significant ($p = 0.001$). These findings indicate that although significant changes occurred in the color coordinates after aging, Group A demonstrated comparatively minimal color alteration, suggesting superior color stability.

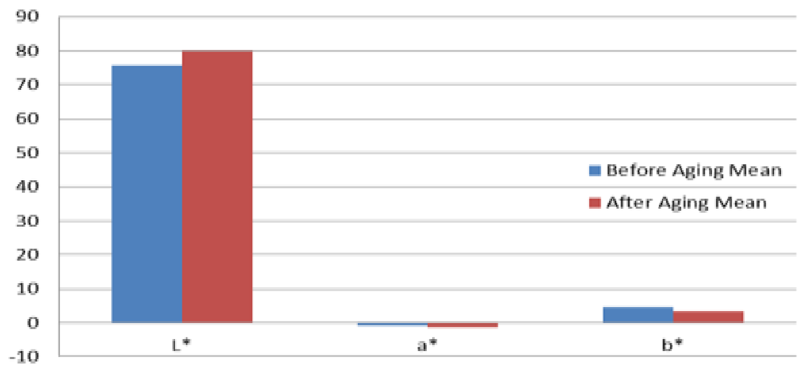


Table 4: Comparison Of Mean L*, A*, And B* Values Before And After Aging In Group B

Parameter	Before Aging Mean ± SD	After Aging Mean ± SD	Mean Difference	P value
L*	72.22 ± 0.64	75.51 ± 0.83	-3.29	0.001
a*	-1.19 ± 0.36	-3.22 ± 0.32	2.03	0.001
b*	1.24 ± 0.34	5.97 ± 0.73	-4.73	0.001

The comparison of mean L*, a*, and b* values before and after aging in Group B (Fusion i-Seal) revealed statistically significant changes in all color parameters following artificial aging. The mean L* value increased from 72.22 ± 0.64 before aging to 75.51 ± 0.83 after aging, with a mean difference of -3.29, which was statistically significant (p = 0.001). The mean a* value changed from -1.19 ± 0.36 to -3.22 ± 0.32, showing a statistically significant mean difference of 2.03 (p = 0.001). Similarly, the mean b* value increased markedly from 1.24 ± 0.34 before aging to 5.97 ± 0.73 after aging, with a mean difference of -4.73, which was also statistically significant (p = 0.001). These results indicate moderate discoloration and noticeable alteration in color coordinates after aging, suggesting reduced color stability of Fusion i-Seal compared to Group A.

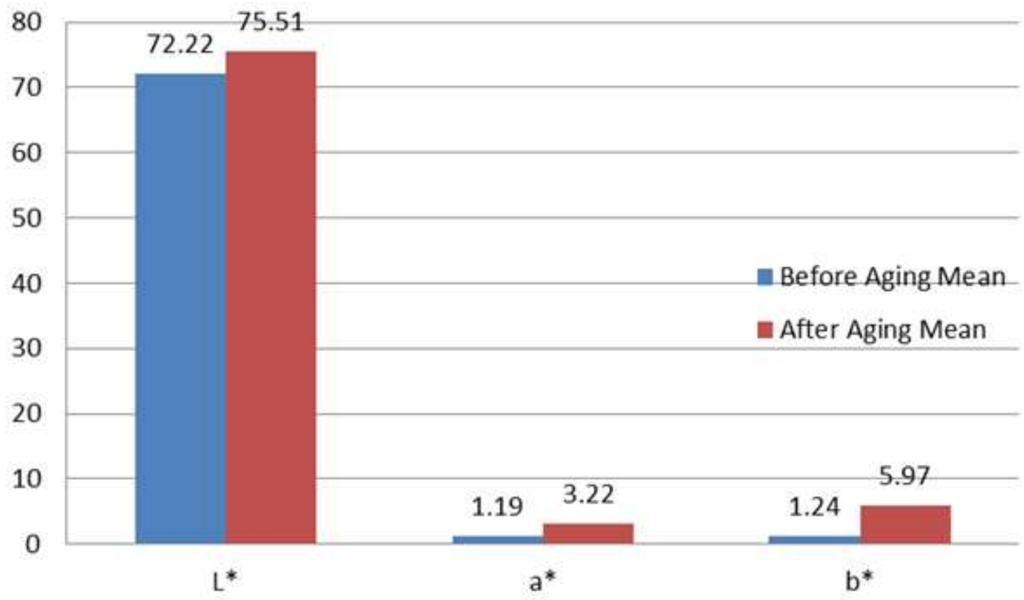
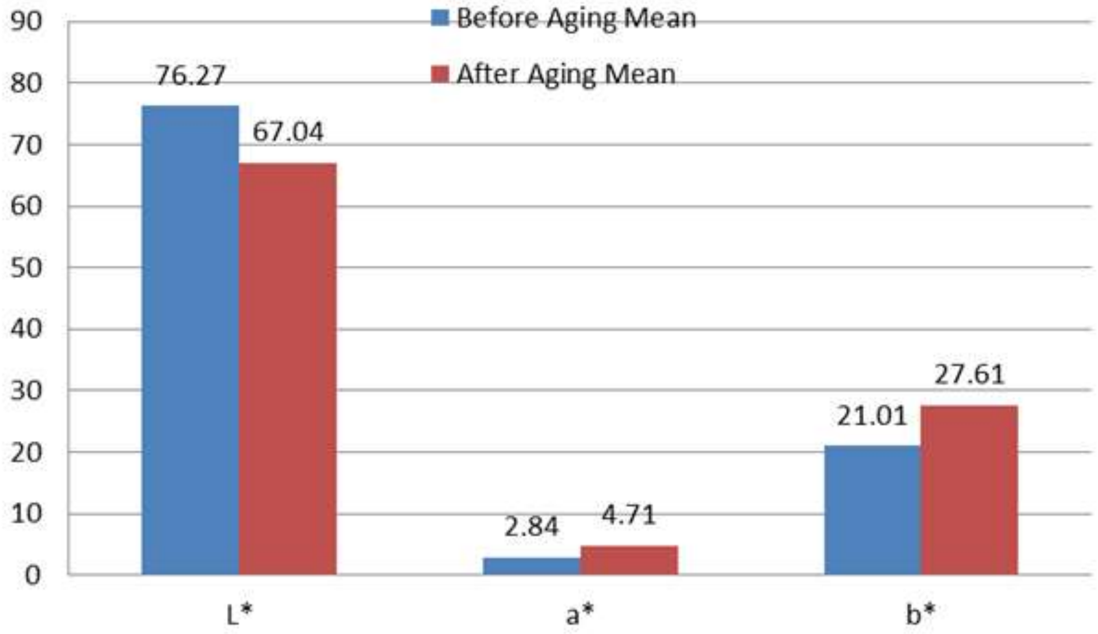


Table 5: Comparison Of Mean L*, A*, And B* Values Before And After Aging In Group C

Parameter	Before Aging Mean ± SD	After Aging Mean ± SD	Mean Difference	P value
L*	76.27 ± 1.02	67.04 ± 1.17	9.23	0.001
a*	-2.84 ± 0.38	4.71 ± 0.43	-7.55	0.001
b*	21.01 ± 0.62	27.61 ± 1.28	-6.60	0.001

The comparison of mean L*, a*, and b* values before and after aging in Group C (Fusion Ultra D/C) demonstrated statistically significant changes in all color parameters following artificial aging. The mean L* value decreased from 76.27 ± 1.02 before aging to 67.04 ± 1.17 after aging, with a mean difference of 9.23, which was statistically significant (p = 0.001). The mean a* value changed markedly from -2.84 ± 0.38 to 4.71 ± 0.43, showing a statistically significant mean difference of -7.55 ($p = 0.001$). Similarly, the mean b* value increased from 21.01 ± 0.62 before aging to 27.61 ± 1.28 after aging, with a mean difference of -6.60, which was also statistically significant ($p = 0.001$). These findings indicate extensive alteration in color coordinates after aging, demonstrating poor color stability and maximum discoloration in Fusion Ultra D/C compared to the other study groups.



Overall, the findings demonstrated that all resin luting cements underwent significant discoloration following artificial aging; however, light-cure resin cements exhibited superior color stability compared to dual-cure resin cements.

Discussion

The esthetic longevity of ceramic laminate veneers is influenced by several factors, one of which is the long-term color stability of the resin luting cement beneath the ceramic restoration. Because veneer restorations are relatively thin and often translucent, any alteration in the color of the underlying cement can influence the overall appearance of the restoration. Therefore, maintaining color stability of the luting cement is particularly important in anterior esthetic procedures. The present in-vitro study was conducted to compare the color stability of two light-cure resin luting cements, Variolink N LC and Fusion i-Seal, with a dual-cure resin luting cement, Fusion Ultra D/C, following artificial aging in distilled water. [2,3,9]

The results showed that all three resin luting cements underwent a measurable change in color following 30 days of water aging. However, the extent of color alteration differed considerably between the materials. Variolink N LC demonstrated the lowest mean color change, with a ΔEpq value of 4.42 ± 0.73, followed by Fusion i-Seal with a mean ΔEpq of 6.22 ± 0.91. Fusion Ultra D/C showed the greatest color alteration, with a mean ΔEpq of 13.86 ± 1.09. The observed differences suggest that both the type of polymerization and the chemical composition of the resin cement can have an important influence on its resistance to aging-related discoloration.

The relatively better color stability observed with Variolink N LC may be associated with its light-activated polymerization system and resin formulation. Light-cure resin cements are commonly selected for veneer cementation because polymerization can be initiated and controlled using visible light, and these materials generally do not depend on the same chemically activated aromatic tertiary amine system used in many dual-cure cements. Aromatic amines may undergo oxidation during aging, which can contribute to yellowing of the resin material. In addition, adequate light activation can result in a high degree of polymer conversion, potentially reducing the amount of residual unreacted components that may contribute to subsequent discoloration. Similar findings have been reported by Kilinc et al., who observed greater color stability with light-cure resin cements than with dual-cure materials following artificial aging. Khalap et al. also reported lower ΔE values for light-cure resin cements compared with dual-cure cements used beneath lithium disilicate restorations.[4,14]

Fusion i-Seal also demonstrated a comparatively lower degree of discoloration than the dual-cure material, although its color change was greater than that observed for Variolink N LC. Since both materials belong to the light-cure category, the difference in their performance may be related to variations in their resin matrix, filler characteristics, photoinitiator system, or degree of polymerization. Differences in filler loading and the interaction between the resin matrix and filler particles can influence the amount of water absorbed by the material. With prolonged exposure to water, the polymer matrix may undergo plasticization and hydrolytic degradation, while deterioration at the resin-filler interface may further alter the optical characteristics of the cement. Buchalla et al. reported that prolonged water storage can affect the color stability of resin-based restorative materials. Similarly, Vichi et al. demonstrated that water aging may result in clinically detectable color changes, with the magnitude of change being influenced by the composition and water sorption characteristics of the material.[10,12]

Among the three materials investigated, Fusion Ultra D/C exhibited the highest degree of discoloration. The mean ΔEpq value of 13.86 ± 1.09 was considerably greater than that observed for either of the light-cure resin cements. One possible explanation for this finding is the presence of a chemically activated component in the dual-cure polymerization system. Dual-cure resin cements are designed to polymerize through both light activation and a chemical curing reaction. The chemically activated component may contain initiator systems involving benzoyl peroxide and aromatic tertiary amines. These amines can undergo oxidation during aging, producing colored by-products that may progressively shift the shade of the resin cement toward yellow or brown. Berrong et al. documented progressive discoloration of dual-cure resin cements during prolonged water storage and associated the change with oxidation of the chemical initiator system. Similar results were reported by Archegas et al., who found greater color alteration in dual-cure resin cements than in light-cure materials after accelerated aging. [9,8]

The present findings are also consistent with observations reported by Shiozawa et al. In their investigation of adhesive resin cements subjected to immersion in water and staining solutions, greater discoloration was observed in dual-cure resin cements. The investigators also identified an association between water sorption and the degree of color change. In the current study, the dual-cure cement similarly demonstrated considerably greater discoloration after exposure to distilled water. This suggests that changes associated with water uptake and aging of the resin matrix may contribute to the color instability of dual-cure materials even in the absence of external staining agents.[7]

Water sorption is considered one of the important mechanisms responsible for degradation and discoloration of resin-based dental materials. Water molecules can diffuse into the polymer network and cause swelling and plasticization of the resin matrix. Continued exposure may promote hydrolytic degradation, deterioration of the resin-filler interface, and loss of the original optical characteristics of the material. Changes in the refractive index of the resin matrix and filler components can further influence light scattering and transmission through the material. Sideridou et al. demonstrated that water sorption is strongly influenced by resin composition and filler characteristics, with materials exhibiting greater water uptake generally showing greater susceptibility to aging-related changes. The significant color alterations observed after 30 days of water storage at 37°C in the present investigation may therefore be partly explained by these hydrolytic processes.[11]

The water-aging method used in the present study was based on the principle that prolonged exposure to an aqueous environment can accelerate degradation processes relevant to resin-based dental materials. Asmussen previously demonstrated the usefulness of water storage as an accelerated aging method for evaluating changes in restorative resin materials. Exposure to elevated temperature and water over a controlled period can accelerate processes such as water uptake and hydrolytic degradation, thereby allowing the behavior of restorative materials to be evaluated within a shorter experimental period. The significant changes observed in the present study further demonstrate the usefulness of controlled water aging for investigating the color stability of resin luting cements.[13]

Changes in the individual CIE L*a*b* coordinates following aging provide additional information regarding the nature of the observed discoloration. In the present investigation, Group C showed a reduction in L* values, indicating a tendency toward reduced lightness or darkening. At the same time, increases in the a* and b* coordinates indicated a shift toward reddish and yellowish tones. Such alterations collectively contributed to the higher overall ΔEpq value observed in the dual-cure group. Lee and Powers similarly demonstrated that aging can modify the L*, a*, and b* coordinates of resin-based restorative materials and consequently increase the overall color difference.[1]

Koishi et al. also evaluated color changes in different polymerization systems and demonstrated differences in color stability between chemically cured, light-cured, and dual-cured materials. Although the extent of discoloration varied among the materials, these findings collectively suggest that the chemical components involved in polymerization can contribute to changes in color during aging.[3]

Apart from the intrinsic properties of resin cements, environmental exposure can also influence their color stability. Previous investigations have demonstrated considerable discoloration of resin-based materials following exposure to commonly consumed beverages such as coffee, tea, and red wine. Ertas et al. reported significant color changes after exposure to these staining solutions, with red wine producing particularly pronounced discoloration.

The resin luting cement forms an integral optical component of a veneer restoration, particularly when the ceramic is thin or highly translucent. Chang et al. demonstrated that the shade and opacity of the luting cement can influence the final color of all-ceramic restorations, with the effect being more pronounced when thinner ceramic materials are used.[2]

Hoorizad et al. investigated color stability following accelerated aging of ceramic veneers and resin cements and reported that resin cements could undergo greater color changes than the ceramic materials themselves. Although the overlying ceramic can partially mask changes occurring within the cement layer, it may not completely eliminate their visual effect, particularly when the ceramic is thin and translucent. This observation is clinically relevant to laminate veneer restorations, where the underlying luting cement contributes to the final optical appearance of the restoration. The results of the present study therefore reinforce the importance of selecting a resin cement that demonstrates adequate resistance to discoloration during aging.[15]

From a clinical perspective, the results of this study highlight the importance of considering the polymerization mechanism and composition of resin luting cement when cementing ceramic laminate veneers. Because veneers are commonly fabricated with minimal thickness and may possess considerable translucency, changes in the underlying cement can potentially become visible through the restoration. In the present study, Variolink N LC demonstrated the lowest color change among the materials evaluated, suggesting that it may offer an advantage when long-term color stability is a major treatment objective, whereas Fusion Ultra D/C showed substantially greater discoloration under the conditions tested. Therefore, clinicians should carefully consider the potential for aging-related color change when selecting dual-cure resin cements for highly esthetic anterior restorations.

The present investigation should, however, be interpreted in light of certain limitations. As an in-vitro study, the experimental conditions cannot completely reproduce the complex oral environment. In the oral cavity, resin luting cements are exposed to multiple simultaneous challenges, including fluctuations in temperature, variations in pH, dietary staining agents, salivary components, mechanical stresses, and changes in humidity. The present study evaluated only distilled-water aging and therefore did not assess the effect of thermal cycling, ultraviolet exposure, or dietary staining substances. In addition, only three commercially available resin luting cements were included. Further investigations involving a greater number of materials, longer aging periods, thermocycling, ultraviolet aging, different staining solutions, and clinical follow-up would provide a more comprehensive understanding of the long-term color behavior of resin luting cements.

Within the limitations of the present investigation, the findings indicate that resin luting cements do not exhibit identical color stability when subjected to artificial water aging. Both the polymerization mechanism and the formulation of the material appear to influence the extent of aging-related discoloration. The two light-cure resin cements evaluated in this study demonstrated considerably lower color changes than the dual-cure resin cement, with Variolink N LC showing the most favorable color stability. These findings support the use of appropriately selected light-cure resin luting cements in thin, highly esthetic veneer restorations where maintenance of the original shade over time is a major clinical consideration.

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