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RESEARCH ARTICLE

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The effect of artificial accelerated aging on the color stability, microhardness, and surface roughness of different dental laminate veneer materials

Simge Taşın DDS[1] | Gozde Celik DDS, PhD[2] | Artur İsmatullaev DDS[3] | Aslihan Usumez DDS, PhD[4]

[1]Division of Prosthodontics, University of Istanbul Okan, Istanbul, Turkey
[2]Division of Prosthodontics, University of Bezmialem Vakif, Istanbul, Turkey
[3]Division of Prosthodontics, University of Kyrenia, Mersin, Turkey
[4]Division of Prosthodontics, Dentalplus Implant Clinics, Istanbul, Turkey

Correspondence
Simge Taşın, İstanbul Okan Üniversitesi, Diş Hekimliği Fakültesi, Gülbahar Mahallesi, Oya Sokak, No: 23, Şişli, İstanbul 34394, Turkey.
Email: simgetasin@gmail.com

Abstract

Objective: This study aimed to evaluate the effect of artificial accelerated aging (AAA) on color stability, surface roughness, and microhardness of three laminate veneer (LV) materials.

Materials and Methods: Specimens of ceramic LV (CLV-IPS E.max Press), hand-layered composite LV (hand-layered laminate veneer [HLV]-Tetric N-Ceram), and prefabricated composite LV (prefabricated laminate veneer [PLV]-Componeer Coltene) were prepared as discs ($n = 10$). CIE L^*, a^*, and b^* color coordinates, the Vickers microhardness, and surface roughness were measured 24 hours after preparation and reevaluated after aging for 300 hours in an ultraviolet (UV)-AAA system (Ci35 Weather-Ometer). Color difference (CIEDE2000 [ΔE_{00}]) was calculated. Data were statistically analyzed with the Shapiro-Wilk test and the Kruskall-Wallis test followed by the Mann-Whitney *U* tests ($\alpha = .05$).

Results: All of the LV groups showed significant differences in ΔE_{00} after AAA ($P < .001$). Comparing the color changes of the HLVs with the PLVs, no significant difference could be found ($P = .705$). There was a statistically significant difference in the means of changes in microhardness among the LVs materials ($P < .001$). The changes in surface roughness results showed a significant difference after AAA in all the LVs ($P < .001$).

Conclusions: Within the limitations of this in vitro study, the color stability, the microhardness, and surface roughness of tested LVs were influenced by AAA.

Clinical significance: The prefabricated composite LV system does not replace the individualized ceramic LV technique, but rather offers an alternative to hand-layered LVs, which is delicate and time-consuming technique.

KEYWORDS
color stability, laminate veneer, microhardness, surface roughness

1 | INTRODUCTION

The demand for esthetic and restorative needs in prosthetic dentistry has resulted in the development of several treatment options. Laminate veneer (LV) restorations have become a popular option for more esthetic and more conservative treatment.[1]

Laminate veneer restorations have two types of treatment protocols: direct and indirect. Direct LVs are applied on the prepared tooth surfaces directly in the dental clinic, indirect LVs are prepared in the laboratory, and various materials can be used in both protocols.[2] Dental ceramic, with its features of biocompatibility with surrounding tissues, natural light transmission, color stability, mechanical strength, and wear resistance, is considered to be the reference material for indirect LV restorations.[3] However, due to the difficulties in polishing after intraoral cementation, difficulties in repairing and the high cost of ceramic laminate veneers (CLVs), direct composite hand-layered laminate veneers (HLVs) is offered as an alternative treatment for the patients.[4] Dental composite materials contain reinforcing filler and an organic resin matrix based on different monomers, such as glycerolate dimethacrylate (Bis-GMA), urethane dimethacrylate (UDMA), and triethyleneglycol dimethacrylate (TEGDMA).[5,6] Several in vitro studies have shown that this composition might make it more prone to degradation in the oral environment. In addition, chemical degradation can cause color instability, marginal fracture, and surface properties disruption on LVs.[7-12]

New laboratory-made indirect composite LVs are defined as prefabricated laminate veneers (PLVs). Due to the developed polymerization process, manufacturers expect better mechanical properties and longer survival rate in PLVs rather than in situ curing of HLVs.[2,13,14] PLVs are restorations manufactured from the prepolymerized hybrid composite resin of various sizes that mimic the facial anatomical structure of the tooth.[15] The preshaped thin LVs between 0.3 and 1 mm allow direct veneering of one or more incisor tooth and premolars with minimal preparation in only one appointment.[16] Additionally, the polished surface provides a long-lasting esthetic to the restoration. Moreover, PLVs can be repaired using direct composite layering without removing the restoration, thus reducing the laboratory expenses.[17]

Despite recent material improvements in physical, mechanical, and esthetic properties, there is still a concern about the color stability and strength of materials used in veneer restorations after long-term oral environment exposure in dental restorative procedures.[18-22] Various studies have shown that the color stability of dental materials can be influenced by extrinsic and intrinsic factors. Dietary habits, food and liquid colorant, oral hygienic agents, and temperature changes may cause discoloration of dental materials over time.[9,23,24] For CLV materials, color stability depends on intensity and duration of the polymerization and composition of the composite material.[25,26] Color stability in CLVs is generally affected by intrinsic factors such as material composition and the glaze layer.[27]

The Commission Internationale de l'Eclairage (CIE) color system calculates chromaticity and describes the color of dental materials in a uniform three-dimensional space. Discoloration is determined through differences among the $L^*a^*b^*$ color parameters.[28] Because the CIEDE2000 color difference (ΔE) formula is recommended in vivo instrumental color analysis and dental researches as it fixes non-uniformity of the CIELab color space, especially in slight color differences.[28-30] Ghinea et al[29] reported that the CIEDE2000 color difference formula offered higher degree of fit than the CIELab formula for appraising the difference of color, acceptability and perceptibility judgments for dental ceramic. Color change can be judged visually or with color measuring devices. Color measuring devices including colorimeters and spectrophotometers eliminate the subjective interpretation of visual color comparison and offer numerical expression of color.[27]

In prosthetic dentistry, mechanical properties of the material as important as the color stability because the longevity of restoration depends on the material. Dental restorations are exposed to dynamic temperature fluctuation and mechanical load during routine eating, drinking, and breathing in oral environment. Generally, these dynamic changes lead to the formation of residual stresses in solid materials.[31] These residual stresses can cause changes in the mechanical properties and surface characteristics of dental restorations.[19,32]

Materials used in LV restorations have to be resistant against possible defects and fractures caused by residual stress; therefore, the physical and mechanical properties, including surface roughness and microhardness, are important for longevity.[19,33] Additionally, the surface roughness may cause clinical problems: discoloration due to extrinsic factors,[1,9,23,34,35] weariness of the antagonist tooth,[36,37] periodontal diseases by increasing plaque accumulation,[38,39] and smaller resistance to cracks propagation.[40]

Under standardized laboratory circumstances, a variety of aging methods can be applied to determine the mechanical strength and other physical properties of dental materials.[23,27,41] Methods, such as water or water-ethanol immersion, artificial saliva or several food staining solution immersions, thermocycling and ultraviolet (UV) accelerated aging system, allow the simulation of clinical long-term conditions as closely as possible in a short time period.[35,42,43] Artificial accelerated aging (AAA) system which contains visible light, UV radiation, use of wet and dry conditions, and heating cycles is applied for analyses of the behavior of nonmetallic materials.[19,32,44,45] During the AAA process, color changes, surface, and mechanical properties are probably influenced by intrinsic physical-chemical modifications in the materials.[27]

Recently manufactured PLVs, with improved physical and mechanical properties, seem to allow the use of indirect composite LVs as an alternative to HLVs[25,46] while there are no studies on mechanical and esthetic properties of the PLVs. The aim of this article was to evaluate and compare the effect of AAA on color stability, microhardness, and surface roughness of three LV materials: CLVs, HLVs, and PLVs. The null hypothesis was that aging would not cause color, microhardness, and roughness alteration in the LV materials.

2 | MATERIALS AND METHODS

Thirty disk-shaped specimens (10 mm in diameter × 1 mm in height) were prepared with three types of materials (n = 10). Characteristics of the materials are described in Table 1.

A stainless-steel plate with a hole was prepared for the HLVs (A1). The composite resin material was packed into the hole in steel plate and pressed between two microscope glass slides covered with polyester matrix strips to ensure the excess of a composite resin material. All HLVs were cured with a LED (light-emitting diode; Planmeca Lumion, Mectron, Carasco, Italy, output 1400 mW/cm^2, wavelength range

TABLE 1 Materials used in the study

Material	Material type	Shade	Manufacturer	Composition
IPS E.max Press	Pressable glass ceramic	A1	Ivoclar-Vivadent	Lithium disilicate
Tetric N-Ceram	Microhybrid composite resin	A1	Ivoclar-Vivadent	Bis-GMA, UDMA, TEGDMA
Componeer	Prepolymerized hybrid composite	White Opaque	Coltene	Methacrylate, silanized barium glass, hydrophobized amorphous silicic acid

Abbreviations: Bis-GMA, glycerolate dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate.

between 440 and 465 nm) for 40 seconds. Before each curing, the intensity of the light curing device was evaluated using a handheld radiometer. Great attention was paid to avoiding a bubble formation. The top surface of all HLVs was polished with wet 360-, 600-, and 1200-grit silicon carbide abrasive paper and ultrasonically cleaned in distilled water for 10 minutes.

The CLVs (A1) and the PLVs (white opaque) were prepared according to the manufacturer's guidelines. The top surface of the all CLVs was coated with a layer of neutral-shade glaze, and fired at 765°C by an experienced dental technician and no mechanical polishing was performed. The PLVs were not polished due to its prefabricated pre-polished structure. The thickness of the samples was controlled with a digital caliper accurate to 0.1 mm (Digimatic CD-15DCX; Mitutoyo, Kawasaki, Japan). LVs of all materials were stored at 37°C in dark and wet conditions for 24 hours to allow optimal conversion.

Color parameters (L^*, a^*, b^*) of each LV were measured according to the Commission Internationale de l'Eclairage (CIE) system, against a neutral gray background[20] in a digital spectrophotometer (VITA Easyshade; Vita Zahnfabrik, Bad Sackingen, Germany) before and after AAA procedure. LVs orientation against the spectrophotometer head was standardized by a custom-made specimen holder in the center, and the color measurement was performed three times for each LV. After average color values were collected for each group (n = 10), the spectrophotometer was recalibrated. Color change values of each LV were calculated by using the CIEDE2000 (ΔE_{00}) color difference formula[28]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{K_L S_L}\right)^2 + \left(\frac{\Delta C^*}{K_C S_C}\right)^2 + \left(\frac{\Delta H^*}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C^*}{K_C S_C}\right)\left(\frac{\Delta H^*}{K_H S_H}\right)}$$

K_L, K_C, and K_H are the terms for the experimental conditions. For this study, the parametric factors of the CIEDE2000 color difference formula were set to 1.0. CIEDE2000 (ΔE_{00}) and the discoloration were evaluated on the basis of perceptibility and clinical acceptability thresholds. For this study, the perceptibility threshold was set to ΔE_{00} = 1.30 units and the clinical acceptability threshold was set to ΔE_{00} = 2.25 units.[29]

The microhardness of the LVs was measured with the Vickers Microhardness Test Machine (HMV-2T; Shimadzu, Kyoto, Japan) in three different points before and after AAA. Three indentations were made on the surface under 9.807 N load with a 15 seconds dwell time, and the reading was made at ×40 magnification. The average microhardness value for each LV was calculated. The baseline mean values were subtracted from those obtained after AAA for Vickers microhardness calculation. Each measurement was performed near the previously measured position.

The roughness values of each LV before and after AAA were measured with a profilometer (MarSurf M300; Mahr, Germany). The profilometer needle (10 μm diameter) was positioned over each LV, performing three measurements (cut-off: 0.8 mm; speed: 0.5 mm/s) at different locations of the LV surface, after which, the mean surface roughness of the LVs was obtained. The change in roughness (ΔR_a) was calculated with the differences between mean values obtained before and after AAA.

After baseline measurements of color, microhardness, and surface roughness were made, the LVs were artificially aged in a weathering machine (Ci35 Weather-Ometer; Atlas Electronic Devices Co, Chicago, Illinois). LVs were exposed to a controlled-irradiance xenon arc filtered through borate borosilicate glass of 0.55 W/m^2/nm measured at 340 nm. The aging conditions were as follows[36]: dry bulb temperature: 47°C (light) and 38°C (dark), humidity: 50% (light) and 95% (dark), black panel temperature: 70°C (light) and 38°C (dark), and water temperature: 50°C. The test cycle consisted of 40 minutes light only, 20 minutes light plus front water spray, 60 minutes light only, 60 minutes dark plus back water spray. The total exposure energy was 150 kJ/m^2, and the total exposure time was 300 hours. These conditions simulated 1 year of clinical service.[34,35]

All statistical analyses were performed using the NCSS (Number Cruncher Statistical System) 2007 software for Windows. Descriptive statistical methods (mean, SD, median, minimum, maximum) and distribution of the data were evaluated by Shapiro-Wilk test. Kruskall-Wallis test was used to compare mean color (ΔE_{00}), microhardness (ΔH), and surface roughness (ΔR_a) change values of LVs from each material. The Mann-Whitney *U* test was carried out for groups' comparison (α = .05). In the power analysis based on the significance test of the difference between the three means in the *G** Power 3.1.9.2 program, the power of the study was 81%.

3 | RESULTS

The mean ± SD, median, minimum, and maximum values of ΔE_{00}, ΔH, and ΔR_a for the tested materials are listed in Table 2. According to the Kruskall-Wallis test of the ΔE_{00}, ΔH, and ΔR_a values, the effects of the aging process were statistically significant in all materials ($P < .001$). The ΔE_{00} values for the CLV (1.12 ± 0.2) were below the perceptibility threshold (1.30). The ΔE_{00} values for the PLV (2.19 ± 0.4) were above 1.30, but lower than 2.25 (clinical acceptability threshold). For the HLVs, the ΔE_{00} values (2.41 ± 0.5) were above 2.25. Mann-Whitney *U* test results for ΔE_{00}, ΔH, and ΔR_a values of tested materials are shown in Table 2. The CLVs showed statistically significant less color change ($P < .001$), whereas no statistical difference ($P = .705$) was found between the color change of the PLV and the HLVs.

The mean ± SD values of microhardness and roughness before and after AAA are listed in Table 3. According to the Mann-Whitney test, a statistically significant difference was observed among CLV, PLV, and HLV in terms of changes in microhardness value ($P < .001$). The highest mean microhardness values (595 ± 33.3-586 ± 34) were observed in CLVs, and the difference was the lowest (−8.8 ± 1.2) before and after AAA. The mean of the changes in microhardness values was highest in the HLVs (31.3 ± 2.4).

The changes in surface roughness results showed a significant difference after AAA in all the LVs ($P < .001$). The mean roughness change values were lowest for the CLV (0.031 ± 0.008), followed by those for the P LV (0.98 ± 0.012) and then the HLV (1.5 ± 0.277).

TABLE 2 Mean ± SD, median, minimum, and maximum values of tested materials

		Mean ± SD	Median	Minimum	Maximum
ΔE_{00}	CLV	1.12 ± 0.2^{a}	1.12	0.73	1.36
	PLV	2.19 ± 0.4^{b}	2.28	1.32	2.76
	HLV	2.41 ± 0.5^{b}	2.26	2.05	3.59
ΔH	CLV	-8.8 ± 1.2^{c}	−9.3	−7.3	−10.7
	PLV	25.2 ± 2^{d}	25	21.7	28.3
	HLV	31.3 ± 2.4^{e}	31.3	26.4	34.5
ΔR_a	CLV	0.031 ± 0.008^{f}	0.03	0.019	0.045
	PLV	0.98 ± 0.012^{g}	0.98	0.96	1
	HLV	1.5 ± 0.277^{h}	1.47	1.07	1.89

Note: Mean difference significant at $P < .001$; letters indicate comparisons carried out with Mann-Whitney *U* test (vertical). Means with the same letters are not statistically different.

Abbreviations: ΔE_{00}, color change; ΔH, microhardness change; ΔR_a, roughness change; CLV, ceramic laminate veneer; HLV, hand-layered laminate veneer; PLV, prefabricated laminate veneer.

4 | DISCUSSION

This in vitro study compared the changes in color, microhardness, and surface roughness values of three LV materials, CLVs, PLVs, and HLVs after aging process. For restoration conditions in the oral environment to be simulated, the LV specimens were submitted to AAA for 300 hours which is reported to be equivalent to 1 year.[34,35] The null hypothesis that the final color, microhardness, and surface roughness of simulated LV restorations would not be influenced by the AAA process was rejected.

Although CLVs are highly esthetic restorations with appropriate patient and material selection, the different survival rates have been reported in the literature. Fracture, debonding, unfavorable esthetics, and periodontal complications are among the reasons for failure in clinical researches which assess CLVs.[38,39] Restorative protocol with HLVs is a well-known alternative for patients who are unsuitable for CLV or cannot afford the cost of this treatment. However, the time required to perform the HLVs and the color instability of material might discourage the dentist from employing the technique.[8,10]

The PLVs are manufactured under calibrated and controlled laboratory conditions in terms of temperature, pressure, and light. These procedures increase the degree of polymerization of the composite resin and lead to significant improvements in their mechanical and physical properties.[1,14,41] Previous clinical studies reported several indications for PLV manufactured with the Synergy D6 composite resin.[15-17] However, very few in vitro studies concerning the properties of PLVs are published in the literature.[2]

The roughness and the microhardness parameters are used to evaluate the surface property of restorative materials, as it determines the esthetic stability and durability of restorations.[1,18] In previous studies, it has been found that the lowest surface roughness is obtained when the composite resin material is polymerized in direct contact with a matrix strip.[5] However, some studies have determined that the resin rich top layer of polymerized material may have poor physiomechanic properties.[7] In this in vitro study, the top and bottom surface side of the all HLVs were abraded with silicon carbide abrasive papers under running water to remove the resin rich layer.[7]

The majority of previous researches reported that background color may affect color perception.[20-23] However, there is no consensus about which is the best background for color research. According to Kim et al,[21] the chromatic values backed by a white plate background would be considered as the colors of LV placed on the lining

TABLE 3 The mean ± SD values of microhardness and roughness before and after AAA

	Microhardness		Roughness	
Materials	24 hours	300 hours AAA	24 hours	300 hours AAA
CLV	595 ± 33.3^{Aa}	586 ± 34^{Ba}	0.43 ± 0.07^{Cc}	0.47 ± 0.07^{Dc}
PLV	63 ± 7.1^{Ab}	88 ± 7.3^{Bb}	0.35 ± 0.06^{Cd}	1.32 ± 0.07^{Dd}
HLV	54 ± 10.4^{Ab}	85 ± 11.3^{Bb}	0.64 ± 0.14^{Ce}	2.13 ± 0.26^{De}

Note: Mean difference significant at $P < .001$; means with the same letters are not statistically different. Uppercase letters for horizontal, lowercase letters are for vertical comparisons.

Abbreviations: AAA, artificial accelerated aging; CLV, ceramic laminate veneer; h, hour; HLV, hand-layered laminate veneer; PLV, prefabricated laminate veneer.

material in the oral environment. However, Ardu et al[20] and Zhang et al,[22] reported that the white background may cause a larger increase in the ΔE than a gray and black background, because of its highly reflective character. In the current study, a gray plate was selected for the background. The color change data was determined using CIEDE2000 formula because recent dental literatures[29,30] reported that in the assessment of acceptability and perceptibility thresholds for dental materials, CIEDE2000 color difference formula displayed better fit than the CIELab formula.[29,30]

Results of the current study showed that the aging procedure has a significant effect on color values ($P < .001$). In agreement with the current research, previous studies[9,23,27] reported that ceramic materials exhibit lower ΔE values than composite materials. CLV material demonstrated the highest color stability among the tested materials. Color change due to AAA for the CLV material was not visually perceivable ($\Delta E_{00} < 1.30$). Color change for PLV was perceivable but acceptable ($1.30 < \Delta E_{00} < 2.25$). Color change in HLV material was clinically unacceptable ($\Delta E_{00} > 2.25$).[29]

Higher ΔE_{00} values of two composite LVs can depend on the amount of unreacted monomer stability,[6] degree of water absorption[23,26] and composition of the material. The monomer TEGDMA in the HLV exhibits higher degree of predisposition to water absorption, which results in discoloration. The efficiency of composite LV polymerization can also influence color stability because it establishes the amount of unreacted monomer that indicates higher discoloration.[6] Clinically acceptable color stability of the PLV material may be related to developed polymerization process and its composition.[41] However, in the current study, these differences were not evident, as no significant difference in color change was noted between the tested PLV and HLV materials.

Corroborating the results of the current study, Tang et al[45] and Hampe et al[19] observed significant decrease in the microhardness values of IPS E.max materials after AAA. It can be speculated that the thermal fluctuation-induced residual stress at the surfaces of ceramic which leads to microcracks decreases the cohesion and strength of heterogeneous composition with different heat conductivity.[19] In this study, there was significant difference between the mean values of microhardness measured before and after AAA in PLVs ($\Delta H = 25.2 \pm 2$) and HLVs ($\Delta H = 31.3 \pm 2.4$), which is parallel with the previous study. The published literature revealed different effects of the aging procedure on the microhardness of composite LVs, where values might increase[1] or decrease[32,44] after AAA. In this study, both groups of composite LVs showed a significant increase in microhardness values after the AAA. A previous study showed that the secondary cure treatment increased the degree of conversion within the composite as a result of an increase in the covalent bonds between free radicals and methacrylate groups.[25] Assuming the AAA as a secondary curing, it is expected that microhardness will increase after this treatment.[1,13,41]

Surface treatment of dental restorations is an important step in restorative dentistry. Several investigations have identified different polishing techniques for dental materials. In this study, the glaze material was applied to CLVs, and the HLVs were polished with sequentially abrasive paper. Previous reports suggested contrasting results regarding surface roughness values resulting from glazing in relation to mechanical polishing.[23,24,33,36,37] In the current research, Ra values varied between 0.342 and 2.742 μm. These values were higher than the plaque accumulation threshold of R_a value of 0.2 μm in surface roughness suggested by Bollen et al,[38] whereas it was lower than the clinically unaccepted value of 10 μm identified by Kaplan et al.[39]

The AAA was able to change significantly the surface roughness of the tested materials. These results are similar to the study of Power et al[43] and in contrast with the study of Catelan et al[40] and Roselino et al.[42] According to present study, there was significant difference in the mean values of ΔR_a among all tested LV materials and CLVs showed the significantly lowest ΔR_a values. Increased surface roughness due to AAA was attributed to abrasion of the composite resin[11] and presence of porosities.[12] The ΔR_a values of PLV were significantly lower than HLVs. This difference may be related to increase in abrasion resistance as a result of developed polymerization process.[1,41,46]

A limitation of this study is that a single type of material for each group was tested; different types of material might reveal different results. Furthermore, the color stability and mechanical properties of LVs depend on the resin composites used in cementation. Therefore, different LV materials should be evaluated with different resin cement systems. The other limitation of the current research was the limited time of the AAA to simulate the clinical life of the LVs and LVs were not exposed to any chemical and coloring agent during AAA. Next study should be carried out for a longer amount of time with saliva, colored drinks, cigarettes, and various enzymes for a better simulation of clinical conditions.

5 | CONCLUSIONS

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

1. The aging process significantly influenced the color stability, microhardness, and surface roughness values of the studied LV materials ($P < .001$).
2. The lowest ΔE_{00} values were obtained for the CLVs ($P < .001$). There was no difference between the PLV and HLV ($P = .705$). The CLVs showed discoloration below perceivable level ($\Delta E_{00} < 1.30$), whereas HLV exhibited a clinically unacceptable color change ($\Delta E_{00} > 2.25$).
3. The hardness significantly decreased in CLV and increased in PLV and HLV after 300 hours AAA compared with 24-hours water storage ($P < .001$).
4. For all tested materials, AAA increased surface roughness ($P < .001$) but provided clinically acceptable surface roughness changes ($\Delta R_a < 10$ μm).

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ORCID

Simge Taşın https://orcid.org/0000-0002-0483-2520

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