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Original Research Article

Influence of Material Type, Thickness, and Cement Type on Optical Properties of CAD/CAM Laminate Restorations

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ABSTRACT

Aim: The long-term success of laminate restorations depends not only on their mechanical strength but also on the stability of their optical properties. This study aimed to evaluate the effects of CAD/CAM material type, thickness, and cement type on color change (ΔE00) and translucency parameter differences (ΔTP) of laminate restorations after UV aging.

Materials and Methods: A total of 200 specimens were prepared from five different CAD/CAM materials (CEREC feldspathic block, Cerasmart block, Vita Enamic block, Lava Ultimate block, and Grandio CAD/CAM block) and two thicknesses (0.7 mm and 1.2 mm). Specimens were divided according to cement type (dual-cure and light-cure). Color measurements (L*, a*, b*) were performed before and after UV aging, and color and translucency differences (ΔE_{00} and ΔTP) were calculated using the CIEDE2000 formula. UV aging was applied as an artificial aging procedure and was not included as an independent variable in the statistical analysis. Data were analyzed using three-way ANOVA according to material type, thickness, and cement type ($p < 0.05$).

Results: Material type significantly influenced color changes (ΔE_{00}) and the translucency parameter differences (ΔTP). Among the tested groups, the CEREC block (1.1 ± 0.3) demonstrated the least color change. In contrast, the Lava Ultimate block (12.7 ± 0.5) exhibited the most significant color change ($p < 0.05$). The lowest ΔTP differences were observed for Lava Ultimate block (-0.2 ± 0.2), Vita Enamic (-0.3 ± 0.4), and Cerasmart (-0.1 ± 0.4) ($p < 0.05$).

Conclusion: All groups exhibited color changes that exceeded both the perceptibility and clinical acceptability thresholds. Changes observed after UV aging indicated a decrease in translucency. Among the evaluated factors, material type was identified as the most critical factor affecting ΔE_{00} values, while specimen thickness was the main determinant of ΔTP.

Keywords: Computer-Aided Design; Cosmetic Dentistry; Dental Laminates; Prosthodontics

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INTRODUCTION

With the continuous evolution of aesthetic standards and the increasing adoption of digital systems for anterior laminate restorations, the optical properties of CAD/CAM glass-based blocks have become increasingly significant. Consequently, pre-sintered feldspathic ceramics, such as the CEREC block (Dentsply Sirona, Germany), which exhibit high color stability, are widely preferred for anterior restorations. Over time, the integration of resin components to enhance flexibility and strength has further improved the color stability of ceramics, resulting in the development of novel CAD/CAM glass-based materials.[1]

Hybrid ceramic blocks, such as the Vita Enamic (VITA Zahnfabrik, Germany) polymer-infiltrated ceramic network, are particularly noteworthy for their unique structure, in which polymer particles infiltrate a ceramic framework. In contrast, Cerasmart (GC, Japan) and Lava Ultimate (3M ESPE, USA) blocks, both classified as resin nanoceramic structures, differ from hybrid ceramics because their resin matri-

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ces are reinforced by embedding glass and ceramic fillers. Among advanced CAD/CAM restorative materials, Grandio blocks (VOCO, Germany) stand out for their nanohybrid composition, high particulate and filler load, superior flexural strength and wear resistance, polishability, and improved aesthetic qualities.[2]

The optical properties of laminate restorations, which are essential for achieving aesthetic success, are strongly influenced by the color compatibility, stability, and polishability of CAD/CAM blocks. Additionally, factors such as surface roughness, restoration thickness, and the cementation technique used play crucial roles in both the optical performance and long-term clinical success of these materials. To determine clinical success, *in vitro* studies are often conducted to simulate clinical and intraoral conditions and assess the optical behavior of restorative materials.[2, 3]

One widely used accelerated aging protocol for assessing the color stability of dental materials, particularly those intended for the anterior region, is ultraviolet (UV) exposure. [2, 3] This has been evaluated through both visual and instrumental methods in some studies.[4] The cementation materials used for laminates may statistically affect their optical characteristics. Therefore, the present study aimed to evaluate the effects of CAD/CAM material type, thickness, and cement type on the color change (ΔE_{00}) and translucency parameter (ΔTP) of laminate restorations after UV aging.

The null hypothesis was that CAD/CAM material type, specimen thickness, and cement type would not have a statistically significant effect on color change (ΔE_{00}) and translucency parameter differences (ΔTP) of laminate restorations after UV aging.

MATERIALS AND METHODS

Based on the effect size (f = 0.06) reported by Arocha *et al.*[5], power analysis was performed using G*Power 3.1 (Heinrich-Heine University, Düsseldorf, Germany). With α = 0.05 and power = 0.80, the minimum required sample size was calculated as 10 specimens per group. In total, 200 specimens were prepared, with 40 from each CAD/CAM block.

Two hundred specimens of 12 × 14 mm were sectioned with a low-speed precision saw (IsoMet 4000, Buehler, Lake Bluff, IL, USA) under water cooling at two thicknesses (0.7 mm and 1.2 mm) to assess the optical properties. Four hybrid CAD/CAM blocks were used, including Cerasmart block (CS), Vita Enamic block (VE), Lava Ultimate block (LU), and Grandio block (GR), and one feldspathic block, CEREC Feldspathic block (CE). All blocks used were high-translucency (HT) and shade A2. Detailed material information is provided in Table 1.

Specimens were polished with 600-, 1200-, and 2000-grit silicon carbide papers (MetaServ, Buehler, Lake Bluff, IL, USA) under water cooling to ensure baseline roughness and surface standardization. For resin-containing specimens, an additional 20-second polishing step was performed using Sof-Lex discs (3M ESPE, St. Paul, MN, USA) at four grit levels (coarse, medium, fine, and extra-fine). Glazing of the CE group was performed following the manufacturer’s recommendations. Thereafter, all specimens were immersed in distilled water (St. Kearny, USA) and ultrasonically cleaned for 10 minutes.

A digital caliper (Electronic Digital Caliper, Shan, China; accuracy of ±0.1 mm) was used to measure the thickness of each specimen. Before cementation, the back surfaces of the resin nano-ceramic blocks were sandblasted with 50-μm Al_2O_3 at 0.15 MPa using a sandblasting device (Hager & Werken, Duisburg, Germany). The back surfaces of the hybrid ceramic and feldspathic blocks were etched with 9% hydrofluoric acid (Porcelain Etch, Ultradent, South Jordan, UT, USA) for 60 seconds, rinsed, and treated with ceramic primer (Calibra Silane, Dentsply Sirona, Charlotte, NC, USA) for 10 seconds, followed by air drying.[6] A universal adhesive (G-Premio Bond, GC, Tokyo, Japan) was then applied, gently air-dried for 5 seconds, and light-cured with an LED device (Elipar S10, 3M ESPE, St. Paul, MN, USA) at 1200 mW/cm^2 for 10 seconds.

Two different cements (dual-cure (DC) (Calibra Ceram; Dentsply Sirona, USA) and light-cure (LC) (Calibra Veneer; Dentsply Sirona, USA)) were applied to the subgroups, and the specimens were pressed onto pre-prepared glass plates. Resin cement was light-cured from the outer surface for 20 s to simulate clinical conditions. The final thickness was verified with a digital caliper (Electronic Digital Caliper, Shan, China), ensuring that any reduction

Table 1. Materials and compositions used in the study.

Materials	Compositions	Materials Type	Manufacturer
Cerasmart (CS)	Bis-MEPP, UDMA, DMA 71%, Silica (20 nm), barium glass (300 nm)	Resin nano ceramic	GC, Japan (Lot no: not mentioned)
Cerec (CE)	ZrO2, HfO, Yb2O3 >99 (by weight), Al (OH)3	Feldspar ceramic	Dentsply Sirona, Germany (Lot no: not mentioned)
Lava Ultimate (LU)	Bis-GMA, UDMA, bis-EMA, TEGDMA, 80% SiO2 (20 nm), ZrO2 (4-11 nm)	Resin nano ceramic	3M ESPE, USA (Lot no: not mentioned)
Vita Enamic (VE)	UDMA, TEGDMA, 86% feldspathic porcelain	Hybrid ceramic	VITA Zahnfabrik, Germany (Lot no: not mentioned)
Grandio (GR)	BisGMA, TEGDMA, Urethane-BisGMA, Silica, barium- aluminum borosilicate	Nano-ceramic hybrid	VOCO, Germany (Lot no: not mentioned)
Calibra Ceram Dual Cure (DC)	Urethane Dimethacrylate; Di- and Tri-Methacrylate resins; Phosphoric acid modified acrylate resin, Barium Boron FluoroAluminoSilicate Glass; Organic Peroxide Initiator; Camphorquinone (CQ) Photoinitiator; Phosphene Oxide Photoinitiator; Accelerators; Butylated Hydroxy Toluene; UV Stabilizer; Titanium Dioxide; Iron Oxide; Hydrophobic Amorphous Silicon Dioxide. Particles of inorganic filler range from 16nm to 7µm, average particle size 3.8µm, total filler 46.3%by volume.	Dual-Cure Resin Cement	Dentsply Sirona, USA (Lot no: not mentioned)
Calibra veneer Light Cure (LC)	Dimethacrylate Resins; Camphorquinone (CQ), Photoinitiator; Stabilizers; Glass Fillers; Fumed silica; Titanium Dioxide; Pigments. Particles of inorganic filler range from 0.02 to 1.3µm, total filler 44.9% by volume.	Light Cure Resin Cement	Dentsply Sirona, USA (Lot no: not mentioned)

after polishing was compensated following cementation (±0.15 mm). The thickness of the cement layer ranged from 0.1 to 0.2 mm. Although lot numbers could not be recorded, all materials were obtained from the same commercial packaging to minimize potential batch-related variability.

For baseline color measurements of CAD/CAM materials, a spectrophotometer (Vita Easyshade, VITA Zahnfabrik, Bad Säckingen, Germany) was used under standardized lighting on a white background simulating dental tissue, in compliance with ISO 7491. Measurements were taken three times at room temperature (23 ± 1 °C), and mean values for L_1*, a_1*, b_1*, C_1, and h_1 were recorded.[7] A schematic illustration of the study design is presented in Figure 1.

To evaluate the translucency parameter (TP) the same specimens were used. Measurements were repeated on a black background.[8] After the initial color assessment, specimens were mounted on aluminum dies and subjected to accelerated UV aging (BGD 856, Biuged Guangzhou Co., Ltd., Guangzhou, China) for 300 hours with a total energy of 150 kJ/m^2. Aging was conducted at 10 cm from the light source under conditions of 50-60 °C and 95-50% humidity. A single cycle comprised 8 hours of light exposure and an additional 4 hours of light exposure combined with water/steam spray.[3] The UV aging device is shown in Figure 2. UV aging was applied to the same specimens following baseline measurements to simulate long-term clinical conditions. Color and translucency differences (ΔE_{00} and ΔTP) were calculated based on the measurements obtained before and after aging. Therefore, UV aging was not considered an independent variable but rather a procedure to induce optical changes.

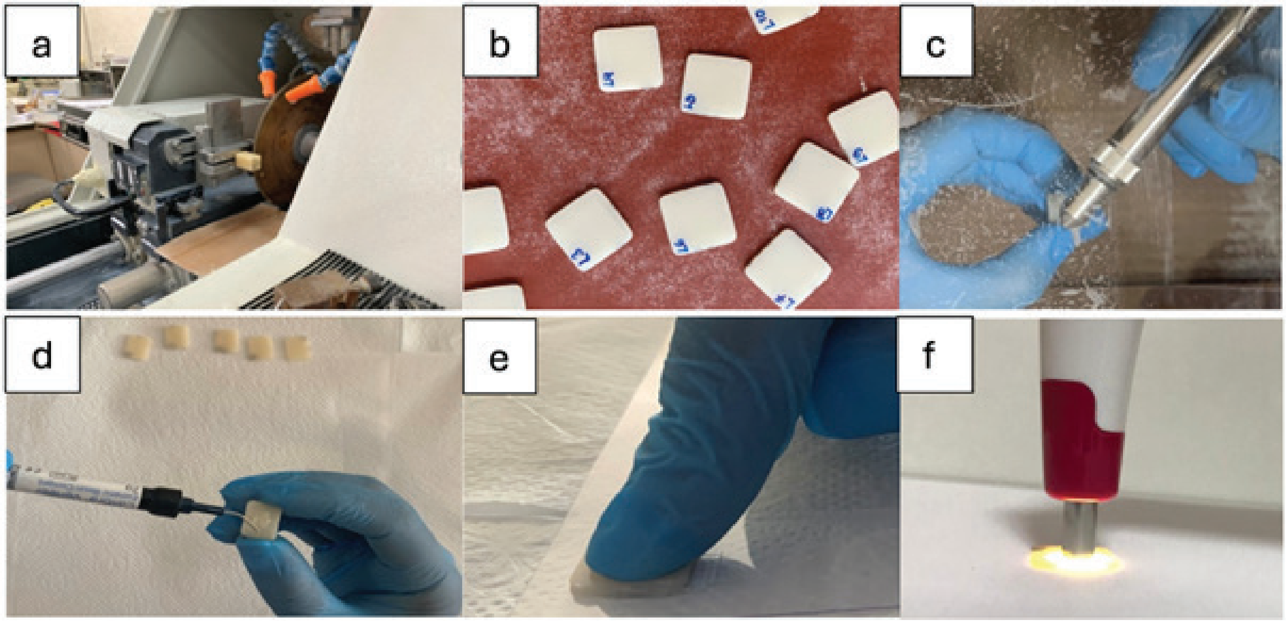

Figure 1. A schematic illustration of the study. a) CAD/CAM blocks were sectioned to predetermined thicknesses using a precision cutting device.b) The prepared specimens were subjected to a standardized grinding and polishing protocol to achieve surface standardization.c) The specimens were conditioned using pretreatment procedures appropriate to their material composition.d) Following surface pretreatment, luting cement was applied to the intaglio surfaces of the specimens.e) The specimens were pressed onto pre-prepared glass plates to ensure uniform cement thickness.f) Color measurements of the specimens were performed using a spectrophotometer before and after aging.

Figure 2. UV aging device, used for the aging procedure in the study.

After UV aging, a second set of color measurements was taken, recording L_2*, a_2*, b_2*, C_2, and h_2 values. Color differences (ΔE_{00}) were calculated using the CIEDE2000 color difference evaluation system according to the following formula:

$$\Delta E_{00} = [(\frac{\Delta L'}{K_L S_L})^2 + (\frac{\Delta C'}{K_C S_C})^2 + (\frac{\Delta H'}{K_H S_H})^2 + R_T(\frac{\Delta C'}{K_C S_C})(\frac{\Delta H'}{K_H S_H})]^{1/2}$$

The CIEDE2000 system was also used to calculate the TP. TP values were obtained from L*, a*, and b* measurements on black and white backgrounds before and after UV aging, and ΔTP was calculated as $TP_{uv} - TP_{00}$.

$$TP_{00} = \sqrt{\left(\frac{L'_B - L'_W}{K_L S_L}\right)^2 + \left(\frac{C'_B - C'_W}{K_C S_C}\right)^2 + \left(\frac{H'_B - H'_W}{K_H S_H}\right)^2 + R_T\left(\frac{C'_B - C'_W}{K_C S_C}\right)\left(\frac{H'_B - H'_W}{K_H S_H}\right)}$$

Data were analyzed using IBM SPSS Statistics 23 (IBM Corp., Armonk, NY, USA). The normality of data distribution was assessed using the Kolmogorov-Smirnov test, and homogeneity of variances was evaluated using Levene's test. When the assumptions of normality and homogeneity were satisfied, parametric tests were applied. Color change (ΔE_{00}) and translucency parameter difference (ΔTP) were considered as separate outcome variables. A three-way ANOVA was performed to evaluate the effects of material type, thickness, and cement type on ΔE_{00} and ΔTP values. Post hoc multiple comparisons were conducted using Tukey's honestly significant difference (HSD) test when significant differences were detected. Results were expressed as mean ± standard deviation (SD), and the level of statistical significance was set at $p < 0.05$. No additional ANOVA models were applied.

RESULTS

This study evaluated the color change (ΔE_{00}) and translucency parameter changes (ΔTP) of CAD/CAM blocks according to cement type, block thickness, and material type. Both the material type and thickness significantly influenced ΔE_{00} and ΔTP ($p < 0.001$). Among the tested groups, the feldspathic ceramic block (CE) showed the least color change, while the resin nanoceramic block (LU) showed the greatest ($p < 0.001$). In contrast, LU, VE, and CS block specimens demonstrated the lowest ΔTP (-0.5), whereas CE had the highest (-0.8). The statistical significance and mean ΔE_{00} and ΔTP values for different thicknesses and cements are detailed in Tables 2 and 3.

Negative values indicate a decrease in translucency. Thickness had a statistically significant effect on ΔTP ($p < 0.001$). The mean ΔTP was -0.8 ± 0.6 for specimens with a thickness of 0.7 mm and -0.4 ± 0.4 for those with a thickness of 1.2 mm. The lowest ΔTP was observed in the CS group at 1.2 mm (-0.2 ± 0.3), whereas the highest was found in the CE group at 0.7 mm (-1.2 ± 0.7). Moreover, the interaction between block type and thickness significantly influenced ΔTP values ($p = 0.002$).

Table 2. Mean ± SD ΔE_{00} values according to materials, thicknesses, and cementation techniques.

	Thickness	Dual Cure	Light Cure	M1
Group CS	0.7	$10.1 \pm 0.6^{a}_{-C}$	$10.3 \pm 0.3^{a}_{-C}$	$10.2 \pm 0.5_{C}$
	1.2	$7.2 \pm 0.3^{a}_{-FG}$	$7.4 \pm 0.2^{a}_{-EF}$	$7.3 \pm 0.3_{E}$
	M2	$8.7 \pm 1.5^{a}_{-BC}$	$8.8 \pm 1.5^{a}_{-B}$	$8.8 \pm 1.5_{B}$
Group CE	0.7	$3.0 \pm 0.5^{a}_{-J}$	$8.4 \pm 0.4^{a}_{-D}$	$5.7 \pm 2.8_{G}$
	1.2	$1.1 \pm 0.3^{a}_{-K}$	$2.5 \pm 0.7^{a}_{-J}$	$1.8 \pm 0.9_{J}$
	M2	$2.0 \pm 1.0^{a}_{-G}$	$5.4 \pm 3.1^{a}_{-D}$	$3.7 \pm 2.8_{C}$
Group LU	0.7	$12.5 \pm 0.4^{a}_{-A}$	$12.9 \pm 0.6^{a}_{-A}$	$12.7 \pm 0.5_{A}$
	1.2	$7.8 \pm 0.4^{a}_{-DFE}$	$8.1 \pm 0.2^{a}_{-DE}$	$7.9 \pm 0.4_{D}$
	M2	$10.1 \pm 2.4^{a}_{-A}$	$10.5 \pm 2.5^{a}_{-A}$	$10.3 \pm 2.4_{A}$
Group VE	0.7	$4.2 \pm 0.5^{a}_{-I}$	$5.7 \pm 0.6^{a}_{-H}$	$5.0 \pm 1.0_{H}$
	1.2	$2.3 \pm 0.1^{a}_{-J}$	$2.5 \pm 0.2^{a}_{-J}$	$2.4 \pm 0.2_{I}$
	M2	$3.3 \pm 1.0^{a}_{-F}$	$4.1 \pm 1.7^{a}_{-E}$	$3.7 \pm 1.5_{C}$
Group GR	0.7	$11.2 \pm 0.5^{a}_{-B}$	$10.0 \pm 0.6^{a}_{-C}$	$10.6 \pm 0.8_{B}$
	1.2	$6.6 \pm 0.2^{a}_{-G}$	$6.6 \pm 0.4^{a}_{-G}$	$6.6 \pm 0.3_{F}$
	M2	$8.9 \pm 2.4^{a}_{-B}$	$8.3 \pm 1.8^{a}_{-C}$	$8.6 \pm 2.1_{B}$
Mean Value	0.7	$8.2 \pm 3.9^{a}_{-B}$	$9.5 \pm 2.4^{a}_{-A}$	8.8 ± 3.3
	1.2	$5.0 \pm 2.8^{a}_{-D}$	$5.4 \pm 2.5^{a}_{-C}$	5.2 ± 2.6
	M	6.6 ± 3.7	7.4 ± 3.2	7.0 ± 3.5

Subscript uppercase letters indicate significant differences among groups within the same column ($\alpha = 0.05$). Identical letters indicate no significant difference.M1: Represents the mean ΔE_{00} values of specimens prepared using different cementation techniques at the same thickness. M2: Represents the mean ΔE_{00} values of specimens prepared with different thicknesses using the same cementation technique. Negative values indicate a decrease in translucency. Cerasmart (CS), Cerec (CE), Lava Ultimate (LU), Vita Enamic (VE), Grandio (GR).

Table 3. Mean ± SD ΔTP values according to materials, thicknesses, and cementation techniques.

		Dual Cure	Light Cure	M1
Group CS	0.7	-0.7 ± 0.5 $_{BC}$	-0.8 ± 0.6 $_{BC}$	-0.8 ± 0.5 $_{BC}$
	1.2	-0.1 ± 0.4 $_{A}$	-0.3 ± 0.2 $_{A}$	-0.2 ± 0.3 $_{A}$
	M2	-0.4 ± 0.6 $_{B}$	-0.6 ± 0.5 $_{B}$	-0.5 ± 0.5 $_{B}$
Group CE	0.7	-1.1 ± 0.6 $_{C}$	-1.3 ± 0.8 $_{C}$	-1.2 ± 0.7 $_{C}$
	1.2	-0.3 ± 0.2 $_{AB}$	-0.5 ± 0.4 $_{AB}$	-0.4 ± 0.3 $_{AB}$
	M2	-0.7 ± 0.6 $_{A}$	-0.9 ± 0.7 $_{A}$	-0.8 ± 0.7 $_{A}$
Group LU	0.7	-0.6 ± 0.5 $_{AB}$	-0.6 ± 0.4 $_{AB}$	-0.6 ± 0.4 $_{AB}$
	1.2	-0.2 ± 0.2 $_{AB}$	-0.3 ± 0.3 $_{AB}$	-0.3 ± 0.3 $_{AB}$
	M2	-0.4 ± 0.4 $_{B}$	-0.5 ± 0.3 $_{B}$	-0.5 ± 0.4 $_{B}$
Group VE	0.7	-0.3 ± 0.4 $_{AB}$	-0.8 ± 0.5 $_{AB}$	-0.6 ± 0.5 $_{AB}$
	1.2	-0.5 ± 0.4 $_{AB}$	-0.5 ± 0.3 $_{AB}$	-0.5 ± 0.4 $_{AB}$
	M2	-0.4 ± 0.4 $_{B}$	-0.7 ± 0.4 $_{B}$	-0.5 ± 0.4 $_{B}$
Group GR	0.7	-0.8 ± 0.4 $_{AB}$	-0.6 ± 0.7 $_{AB}$	-0.7 ± 0.5 $_{AB}$
	1.2	-0.6 ± 0.4 $_{AB}$	-0.7 ± 0.5 $_{AB}$	-0.6 ± 0.4 $_{AB}$
	M2	-0.7 ± 0.4 $_{AB}$	-0.6 ± 0.6 $_{AB}$	-0.6 ± 0.5 $_{AB}$
Mean Value	0.7	-0.7 ± 0.5	-0.8 ± 0.6	-0.8 ± 0.6
	1.2	-0.4 ± 0.4	-0.5 ± 0.4	-0.4 ± 0.4
	M	-0.5 ± 0.5	-0.7 ± 0.5	-0.6 ± 0.5

Different superscript lowercase letters indicate significant differences between Dual Cure and Light Cure within the same row ($p < 0.05$). Different subscript uppercase letters indicate significant differences among groups within the same column ($p < 0.05$). Identical letters indicate no significant difference. M1: Represents the mean ΔTP values of specimens prepared using different cementation techniques at the same thickness. M2: Represents the mean ΔTP values of specimens prepared with different thicknesses using the same cementation technique. Cerasmart (CS), Cerec (CE), Lava Ultimate (LU), Vita Enamic (VE), Grandio (GR).

DISCUSSION

The findings obtained after UV aging demonstrated that CAD/CAM material type, specimen thickness, and cement type significantly influenced color change (ΔE_{00}) and translucency parameter differences (ΔTP) of laminate restorations. Material type and thickness were identified as the primary factors influencing both ΔE_{00} and ΔTP values, while the effect of cement type was comparatively limited. Accordingly, the null hypothesis was rejected.

Resin-based CAD/CAM materials are generally more susceptible to discoloration, primarily due to their inherent water absorption, which allows pigments to be absorbed from the oral environment. The organic polymer matrix in composite resins has been identified as the leading cause of this instability. Advances in CAD/CAM technology have thus focused on reducing the organic content of resin-based and polymer-infiltrated ceramics to improve long-term color stability. [9] Furthermore, translucency in resin-based materials is highly dependent on filler particle size, resin matrix composition, reinforcement strategies, and the use of infiltrating monomers with different refractive indices. Notably, smaller filler particles (~20 nm) promote more effective light transmission, thereby improving translucency.[10, 11]

In contrast, ceramic-based CAD/CAM materials displayed superior resistance to discoloration and better maintenance of translucency. In particular, the feldspathic ceramic (CEREC feldspathic group) demonstrated the most stable color performance in this study. These results align with those of Li *et al*.[12], who noted that the glass matrix composition and pre-sintering processes of ceramic blocks significantly influence their color stability. This correlation underscores the importance of microstructural features in ceramics for their optical durability under aging conditions.

The hybrid ceramic structure of the Vita Enamic block, composed of feldspathic ceramic and aluminum oxide–reinforced urethane dimethacrylate (UDMA) with triethylene glycol dimethacrylate (TEGDMA), contributed to its favorable color stability. The comparable ceramic-rich structures of Vita Enamic and CEREC may explain the similarity in their ΔE_{00} values. Although CEREC and Vita Enamic blocks exhibited differences in TP values, their ΔE_{00} values were closely aligned, suggesting that cementation exerted minimal influence on discoloration. This discrepancy indicates that translucency and color stability are not always directly correlated. While TP is primarily influenced by filler particle size, matrix composition, and the refractive index mismatch between the resin and ceramic phases, color stability is more strongly associated with the ceramic network's chemical durability and the reduced presence of hydrophilic resin components. [13] In a recent *in vitro* study [14], it was demonstrated that both Vita Enamic and Lava Ultimate CAD/CAM blocks exhibited color changes beyond clinical acceptance after immersion in staining solutions such as tea and grape juice. Notably, Vita Enamic and Lava Ultimate showed higher ΔE_{00} values compared to more stable ceramic groups such as Vita Suprinity and Crystal Ultra. These findings were further corroborated by another study, which showed that Lava Ultimate experienced significantly greater discoloration across all beverage groups and storage periods than Vita Enamic. Moreover, an *in vivo* study [15] comparing Vita Enamic and Cerasmart over one year of service reported that both materials remained within the clinically acceptable limit of $\Delta E_{00} < 3.3$. However, Vita Enamic showed slightly higher light and hue shifts.

Lava Ultimate block, classified as a resin nano-ceramic, is composed of nanoparticles (approximately 80% ceramic, 20% silica, composite, zirconia) embedded within a matrix. While this structure enhances mechanical properties, the hydrophilic nature of the resin phase, particularly due to its monomer composition, facilitates the penetration of colorants. As a result, Lava Ultimate is more prone to discoloration than ceramic-dominant CAD/CAM materials. [15] The high translucency of Lava Ultimate is primarily attributed to its nanofiller particles, which are smaller than the wavelength of visible light and therefore reduce scattering and absorption. Similar findings were reported by Turgut *et al.*[16], who demonstrated that smaller filler size and homogeneous distribution improve light transmission and translucency in resin-based ceramics.

The monomeric composition of CAD/CAM materials has a critical impact on their optical performance. UDMA has been shown to provide superior resistance to color changes compared to bisphenol A-glycidyl methacrylate (Bis-GMA), owing to its lower water absorption and superior solubility profile. This reduced hydrophilicity minimizes pigment uptake, thereby enhancing long-term color stability.[17-19] In contrast, TEGDMA, commonly used as a diluent monomer, is more hydrophilic and prone to water absorption.[20] This property increases the likelihood of pigment penetration and contributes to discoloration over time. Therefore, CAD/CAM blocks with a higher proportion of UDMA and reduced contents of Bis-GMA and TEGDMA demonstrate superior resistance to staining and better maintain their aesthetic properties in the long term. [20, 21] The discoloration observed in resin nano-ceramic CAD/CAM blocks such as Lava Ultimate is likely linked to the presence of Bis-GMA, whereas the UDMA in Vita Enamic enhances its color stability. Comparative studies have reported ΔE_{00} values exceeding clinical acceptability thresholds ($\Delta E_{00} > 2.24$) for nanoceramic resin and resin nano-ceramic materials. In contrast, Vita Enamic shows better performance, particularly due to its hybrid ceramic structure, consisting of ~86% inorganic ceramic and 14-26% polymer matrix. [22]

Cementation remains a debated issue in studies evaluating the discoloration of CAD/CAM materials.[23] The complex interaction among material thickness, translucency, and cement shade can either enhance or reduce discoloration. In the present study, the dual-cure cement achieved the lowest ΔE_{00} values, indicating superior color stability compared to light-cure cements. Amine-free dual-cure formulations exhibit improved long-term stability due to the absence of tertiary amines, which are prone to yellowing. In contrast, traditional dual-cure systems with benzoyl peroxide/amine initiators may display more discoloration than light-cure cements. [24, 25] Moreover, dual-cure systems offer handling advantages, such as an extended gel phase (up to 45 seconds), which facilitates easier removal of excess cement, an advantage particularly noted for self-adhesive systems. [26]

Modern dual-cure formulations incorporate alternative activators such as organic peroxides, camphorquinone-amine mixtures, phosphine oxide photoinitiators, and UV stabilizers, all of which enhance color stability over time. The incorporation of UV stabilizers in modern resin cements, combined with the UV aging protocol applied in this study, likely enhanced the accuracy of the results by better simulating long-term clinical conditions. In contrast, thermal cycling systems, in which cements remain in continuous contact with water, often overestimate discoloration and introduce variability, representing a limitation of some earlier investigations.[2,3]

Discoloration and aging are strongly associated with the degradation of unreacted amine initiators within the resin matrix. Under UV irradiation, these residual amines undergo photodegradation, producing yellowish chromophores that reduce optical stability and intensify discoloration. Previous studies [26, 27] have confirmed that tertiary amine photoinitiators are particularly susceptible to this degradation pathway, which contributes to the long-term aesthetic deterioration of resin-based materials.

Thickness is another crucial factor for optical performance. Awad *et al*.[1], demonstrated that translucency is significantly influenced by both thickness and surface treatments. More recent studies have confirmed that reduced thickness increases light transmission but simultaneously enhances the impact of background color. Alharbi *et al*.[28], also reported that surface treatments, such as glazing and polishing, alter light scattering patterns, thereby affecting translucency. Similarly, Çömlekoğlu *et al*.[29], found that cement shade and thickness had minimal influence on ΔE_{00} in the cervical and middle thirds but significantly impacted the incisal region, where light transmission is greater. In this study, thinner laminates (0.7 mm) enhanced cement-related discoloration, whereas thicker laminates (1.2 mm) reduced this effect by attenuating light transmission. Accordingly, thicker specimens demonstrated diminished color perception changes despite similar cement conditions. [30-32]

To address the limitations of this study, different aging protocols, such as hydrochloric acid and thermal cycling, could be compared to provide a more comprehensive understanding of material performance. Newly developed materials on the market could also be included in future studies. Finally, since this study was *in vitro*, corroborating the findings with future *in vivo* studies under clinical conditions is necessary.

CONCLUSION

All CAD/CAM materials showed color changes exceeding clinically acceptable thresholds after UV aging, accompanied by a reduction in translucency. Among the evaluated variables, material type and specimen thickness were the most influential factors affecting optical properties, while the effect of cement type was limited.

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CAD/CAM Lamina Restorasyonlarda Materyal Tipi, Kalınlık ve Siman Türünün Optik Özellikler Üzerindeki Etkisi

ÖZET

Amaç: Lamina restorasyonların uzun dönem klinik başarısı, yalnızca mekanik dayanımlarına değil; aynı zamanda renk stabilitesi ve translüsentlik gibi optik özelliklerinin korunmasına da bağlıdır. Bu çalışmada, UV yaşlandırma sonrası CAD/CAM materyal tipi, kalınlık ve siman türünün lamina restorasyonların renk değişimi (ΔE_{00}) ve translüsensi parametresi değişimleri (ΔTP) üzerindeki etkilerinin değerlendirilmesi amaçlanmıştır.

Gereç ve Yöntemler: Toplam 200 örnek, beş farklı CAD/CAM materyalinden (CEREC feldspatik blok, Cerasmart blok, Vita Enamic blok, Lava Ultimate blok ve Grandio CAD/CAM blok) ve iki farklı kalınlıkta (0.7 mm ve 1.2 mm) hazırlandı. Örnekler, simantasyon türüne göre (dual-cure ve light-cure) gruplara ayrıldı. Renk ölçümleri (L*, a*, b*) UV yaşlandırma öncesi ve sonrası gerçekleştirildi; renk ve translüsensi farkları (ΔE_{00} ve ΔTP) CIEDE2000 formülü kullanılarak hesaplandı. UV yaşlandırma, bir yaşlandırma prosedürü olarak uygulanmış olup istatistiksel analizde bağımsız değişken olarak değerlendirilmemiştir. Veriler, materyal tipi, kalınlık ve siman türüne göre üç yönlü ANOVA kullanılarak analiz edildi ($p < 0.05$).

Bulgular: Materyal tipi, ΔE_{00} ve ΔTP değerlerini istatistiksel olarak anlamlı düzeyde etkiledi. Gruplar arasında en düşük renk değişimi CEREC'te (1.1 ± 0.3) izlenirken, en yüksek renk değişimi Lava Ultimate'te (12.7 ± 0.5) saptandı ($p < 0.05$). En düşük ΔTP değerleri ise Lava Ultimate (-0.2 ± 0.2), Vita Enamic (-0.3 ± 0.4), ve Cerasmart (-0.1 ± 0.4) gruplarında saptandı ($p < 0.05$).

Sonuç: Tüm gruplarda, algılanabilirlik ve klinik olarak kabul edilebilirlik eşiklerinin üzerinde renk değişimi saptandı. UV yaşlandırma sonrasında elde edilen bulgular, translüsensinin azaldığını ortaya koymuştur. Değerlendirilen faktörler arasında, CAD/CAM materyal tipi ΔE_{00} değerlerini etkileyen en kritik faktör olarak belirlenirken, örnek kalınlığı ΔTP değerlerinin temel belirleyicisi olarak bulundu.

Anahtar Kelimeler: Bilgisayar Yardımlı Tasarım; Kozmetik Diş Hekimliği; Diş Laminatları; Prostodonti