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The effect of UV aging on the color stability and translucency of luting agents cemented to different CAD/CAM materials

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Abstract

Background The color stability and translucency of dental restorations are influenced by several factors, including the type of cement used, the chemical composition of the materials, and their thickness. This study aims to assess the color stability and translucency of various adhesive systems and CAD/CAM materials after exposure to UV aging.

Methods A total of 140 specimens were prepared using five different CAD/CAM materials: CEREC (CE), Cerasmart (CS), Vita Enamic (VE), Lava Ultimate (LU), and Grandio (GR), with thicknesses of 0.5 mm and 1 mm. The specimens were randomly divided into two cementation techniques: Dual Cure (DC) and Light Cure (LC). The relative translucency parameter (RTP) was measured initially and after UV aging using the RTP_{00} formula, and (ΔRTP) was calculated. The specimens' color change (ΔE_{00}) was determined using the CIEDE2000 formula. Statistical analysis was conducted using Three-Way ANOVA with a significance level of 0.05.

Result CE exhibited the least color change (ΔE_{00}), while LU displayed the highest ΔE_{00} across all parameters. There was no significant difference between the DC and LC cementation techniques, except for CS, CE, and VE at a thickness of 0.5 mm, and for CS and CE at 1 mm. Most color changes observed in the groups, were out of clinically acceptable ranges, except for the CE group with a thickness of 1 mm and DC cementation technique. The lowest ΔRTP was noted in specimens with a thickness of 1 mm and DC cementation across all groups.

Conclusion The material structure had the most significant impact on ΔE_{00}, while thickness significantly affected the ΔRTP. The cementation technique had the least influence on ΔE_{00} and no effect on ΔRTP. New-generation cement materials, whether Light Cure or Dual Cure, showed similar effects on ΔRTP ($p < 0.05$).

Clinical trial number None.

Keywords CAD-CAM, Dental cements, Dentistry, Dijital dentistry, UV aging, Resin cement

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Background

The widespread use of CAD/CAM materials in aesthetic dentistry has led to an increase in the popularity of CAD/CAM restorations. These restorations offer several advantages, including rapid and precise production, predictability, and high aesthetics [1]. However, discoloration of restorations is inevitable over time due to factors such as temperature fluctuations, dietary habits, and light exposure in the oral environment, even if the initial color match was successful [1, 2]. Color stability and translucency are critical factors for achieving optimal aesthetic outcomes, especially for anterior restorations [3].

Various CAD/CAM materials with different properties and structures are available. Feldspathic ceramic structures, like Cerec, are commonly preferred for anterior restorations due to their translucency and color stability. In recent developments, the superior color stability of ceramic structures has been combined with the flexibility and strength of resins in a new generation of CAD/CAM blocks. Hybrid ceramic (HC) blocks, such as Vita Enamic, are particularly notable because they feature polymer particles infiltrated into a ceramic mesh. LAVA Ultimate and Cerasmart blocks are produced as resin nanoceramics (RNC) and differ from hybrid ceramic blocks in that their resin matrix is reinforced with ceramic and glass particles. Among the available CAD/CAM blocks, Grandio is recognized as a nano-ceramic hybrid block. It stands out due to its nano-hybrid structure, high filler content, resistance to bending and abrasion, excellent polish and repairability, and high aesthetic quality [1, 4].

Table 1 Chemical composition of CAD-CAM materials and cements used in this study provided by the manufacturers

Materials	Compositions	Materials Type	Manufacturer
Group Cerasmart (CS)	Bis-MEPP, UDMA, DMA 71% Silica (20 nm), barium glass (300 nm)	Resin nano ceramic	GC Europe, JAPAN
Group Cerec (CE)	ZrO2, HfO, Yb2O3 > 99 (by weight), Al (OH)3	Feldspar ceramic	Dentsply Sirona, GERMANY
Group Lava Ultimate (LU)	Bis-GMA, UDMA, bis-EMA, TEGDMA, 80% SiO2 (20 nm), ZrO2 (4–11 nm)	Resin nano ceramic	3 M ESPE, USA
Group Vita Enamic (VE)	UDMA, TEGDMA 86% feldspathic porcelain	Hybrid ceramic	VITA Zahnfabrik, GERMANY
Group Grandio (GR)	BisGMA, TEGDMA, Urethane-BisGMA, Silica, barium- aluminum borosilicate	Nano-ceramic hybrid	VOCO, GERMANY
Calibra Ceram Dual Cure Group (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 16 nm to 7 µm, average particle size of 3.8 µm, total filler of 46,3%by volume		Dentsply Sirona, ABD
Calibra veneer light Cure Group (LC)	Dimethacrylate Resins; Camphorquinone (CQ) Photoinitiator; Stabilizers; Glass Fillers; Fumed silica; Titanium Dioxide; Pigments. Particles of inorganic Filler ranges from 0.02 to 1.3 µm, total filler 44.9% by volume		Dentsply Sirona, ABD

Although the color stability of restoration is thought to be dependent on the materials used, it may be due to the cementation technique or cement itself [3, 5] and insufficient polymerization or the presence of components like camphor quinone, which is inherently bright yellow may cause adhesive discoloration [6, 7]. Restorations with a 0.5–0.7 mm thickness can easily transmit light to the adhesive, allowing for optimal polymerization [8]. However, as a result of the thin structure of the restoration, the underlying cement is more exposed to UV aging in oral conditions, and discoloration of ultra-thin restorations may occur due to the reflection of the underlying structure. Many studies used thermal aging (thermocycling) to evaluate the thermal changes in underlying cements over time. However, not enough studies used UV aging, which simulates thermal changes, light exposure, and clinical conditions simultaneously better [2, 9–11]. Therefore, the purpose of study was to evaluate the color stability and translucency of different adhesive techniques applied to CAD/CAM materials using UV aging acceleration. The fisrt null hypothesis of the study was that cementation technique, thickness and materials structure have no effect on the color change of restorations. The second null hypothesis of the study was that cementation technique, thickness and materials structure have no effect on the translucency parameter of restorations.

Methods

In this study, the required sample size was calculated based on the effect size from a previous study by Choi et al. using parameters $\alpha = 0.05$ and 80% power. The minimum estimated sample size was determined to be $n = 5$, which was increased to 7 in this study to enhance statistical power [12]. The sample size calculation was performed using G*Power software (Version 3.1.9.2). Two different types of adhesive cement (Calibra ceram, Calibra veneer; Dentsply, Sirona, USA) and five different CAD/CAM materials were used in the study (Table 1). A total of 140 rectangular specimens with a diameter of 12 × 14 (± 0.2) mm were prepared in two different thicknesses: 0.5 mm and 1 mm. The specimens were prepared using a low-speed precision cutting machine (IsoMet 4000, Buehler; Lake Bluff, USA). Subsequently, the specimens were ground under constant water irrigation with silicon carbide paper (800, 1000, and 2500 grit) (Phonex Beta; Buehler, Lake Bluff, USA). They were then polished for 20 s using polishing kits (Opti-Disc; Kerr, Italy) in accordance with the manufacturer's instructions and were ultrasonically cleaned in distilled water for 10 min (L&R Mfg Co., Kearny, USA). The final dimensions of the specimens were measured using a digital caliper (Electronic Digital Caliper; Shan, China). The methodology procedure is illustrated in Fig. 1.

The surfaces of the specimens were treated according to the manufacturer's instructions prior to cementation. For resin content blocks, the cementation surface was prepared using 50-µm aluminum oxide (Al_2O_3) at a pressure of 0.15 MPa in a sandblasting device (Hager & Werken, Duisburg, Germany). Hybrid ceramic and feldspathic blocks were etched with 9% hydrofluoric acid (HF) (Porcelain Etch; Ultradent, USA) for 60 s, followed by rinsing. For clinical use, the cement thickness of laminate restorations generally ranges from 0.02 to 0.2 mm (20–200 µm). In vitro studies typically report resin cement thicknesses between 0.1 and 0.2 mm (100–200 µm) [13–15]. In this study, the cement thickness was standardized at 0.15 mm (150 µm). A thin layer of cement was applied to the specimens, which were then pressed onto pre-prepared glass plates using finger pressure to achieve a consistent cement thickness of ± 0.15 mm. The samples were polymerized for 40 s using a light source with an intensity of 1200 mW/cm² (Valo; Ultradent, USA). The position of the light and the samples were standardized and secured using a holding tip. The final thickness of the samples was measured with a digital caliper (Electronic Digital Caliper; Shan, China). The initial color parameters (L*, a*, and b*) of the specimens were recorded on white, black, and neutral gray backgrounds under D65 illuminant light using a spectrophotometer (VITA Easyshade Advance 4.0, VITA Zahnfabrik, Germany). To enhance accuracy, three measurements were taken from the center of each specimen, and the average values were calculated. The spectrophotometer was calibrated before each measurement. The initial relative translucency parameters were calculated using the RTP_{00} formula.;

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

Reliable translucency thresholds, with the CIEDE2000 50:50% threshold (TPT_{00}) determined as 0.62 units, whereas the 50:50% threshold (TAT_{00}) is 2.62 units [16]. The specimens were placed in a UV aging machine (plate number 1, UV Light Accelerated Weathering Tester, Biuged Guangzhou Co., LTD, China) for a duration of 300 h, receiving a total exposure energy of 150 KJ/m². Throughout this period, the samples were continuously exposed to light while experiencing temperatures between 50 °C and 60 °C, with humidity levels fluctuating between 95% and 50%. The testing cycle included 8 h of light exposure solely, followed by 4 h of light exposure with steam spray. After UV aging, the final RTP values were calculated, and color change values were calculated using the following formula:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

Based on ISO standards (ISO/TR 28642), a 50% perceptibility threshold was defined as $\Delta E00 \leq 0.8$, while a 50% clinically acceptable threshold was set at $\Delta E00 \leq 1.8$ [11].

Statistical Data were analyzed with IBM SPSS V23. The normality of the data was evaluated by the Shapiro-Wilk test, and the homogeneity of the data was evaluated by Levene's test. The ΔE_{00} and ΔRTP values of the groups were analyzed with Three-Way ANOVA and posthoc Tukey test with Bonferroni correction (α:0.05), with a significance level of %5, using software (SPSS version 20 Inc., IBM Corp).

Results

According to the results of the three-way ANOVA, cement type, thickness, and material type affect ΔE_{00} values, and significant interaction was found between the factors. The LU group with a thickness of 0.5 mm had the highest color change. As illustrated in Fig. 2. The

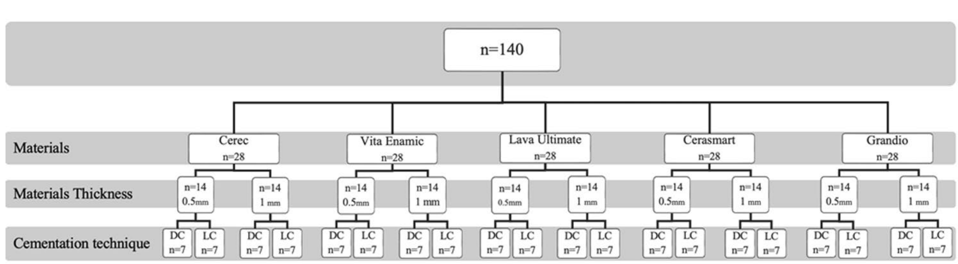

Fig. 1 Visual diagram of methodology. The first lane displays the number of samples determined through power analysis. The second row presents the materials used in the study. The third and fourth rows indicate the thickness of the samples and the cement groups applied. DC (Dual cure), LC (Light cure)

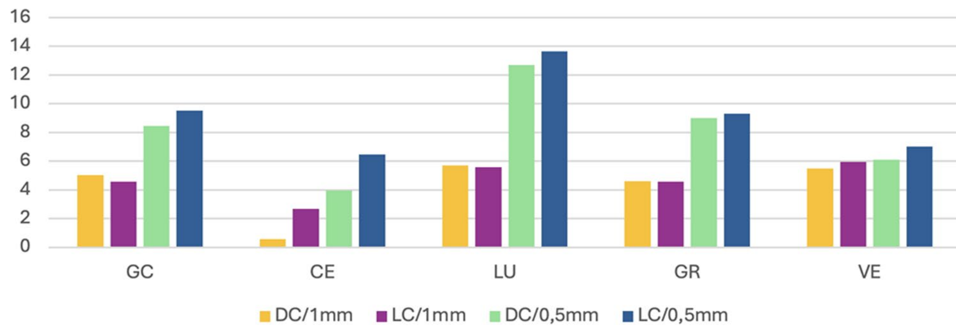

Fig. 2 The color change (ΔE_{00}) of different cements systems and CAD-CAM materials. there is significant difference between LC and DC cement regardless of materials ype and thicknesses. (ΔE_{00}) values changes in VE groups with hybrid ceramic structure were less than (ΔE_{00}) changes in LU Cerasmart (CS), cerec (CE), lava ultimate (LU), grandio (GR), vita enamic (VE), dual cure (DC), light cure (LC)

Table 2 Color change (ΔE_{00}) values (mean ± sd) for the groups. Different superscript letters, uppercase in the same columns Amd lowercase in the same lines, indicate statistical difference ($p > 0.05$)

Materials type	Dual Cure 1 mm	Dual Cure 0.5 mm	Light Cure 1 mm	Lignt Cure 0.5 mm
Cera Smart	5.04 ± 0.33^{Aa}	8.44 ± 0.33^{Ab}	4.56 ± 0.21^{Ac}	9.53 ± 0.20^{Ad}
Cerec	0.58 ± 0.11^{Ba}	3.95 ± 0.50^{Bb}	2.69 ± 0.21^{Bc}	6.45 ± 0.42^{Bd}
Lava ultimate	5.71 ± 0.16^{Ca}	12.69 ± 0.32^{Cb}	$5.59 \pm 0,42^{Ca}$	13.64 ± 0.54^{Cb}
Grandio	4.60 ± 0.33^{Da}	9.01 ± 0.24^{Db}	4.57 ± 0.45^{Aa}	9.31 ± 0.55^{Ab}
Vita enamic	5.49 ± 0.39^{Ca}	6.09 ± 0.33^{Ea}	5.94 ± 0.61^{Ca}	7.03 ± 0.66^{Bb}

Table 3 Translucency Cahnges (ΔRTP) values (mean ± sd) for the groups. Calculating the values as negative indicates a reduction in translucency and an increase in opacity. Different superscript letters, uppercase in the same columns amdlowercase in the same lines, indicate statistical difference ($p > 0.05$)

Materials type	Dual Cure 1 mm	Dual Cure 0.5 mm	Light Cure 1 mm	Lignt Cure 0.5 mm
Cera smart	-0.22 ± 0.12^{ABa}	-0.81 ± 0.64^{ABb}	-0.41 ± 0.29^{Aab}	-0.5 ± 0.20^{Aa}
Cerec	-0.06 ± 0.08^{Ba}	-0.36 ± 0.22^{Aab}	-0.22 ± 0.17^{Aab}	-0.34 ± 0.27^{Ab}
Lava ultimate	-0.34 ± 0.17^{ACa}	-0.80 ± 0.79^{ABa}	-0.39 ± 0.22^{Aa}	-0.62 ± 0.43^{Aa}
Grandio	-0.16 ± 0.17^{ABa}	-1.02 ± 0.52^{Bb}	-0.21 ± 0.17^{Aac}	- 0.77 ± 0.64^{Abc}
Vita enamic	-0.37 ± 0.35^{ADa}	-0.73 ± 0.17^{ABa}	-0.44 ± 0.39^{Aa}	-0.68 ± 0.60^{Aa}

samples with a thickness of 0.5 mm, regardless of cement type, demonstrated the highest color change across all materials. The CE group showed the least ΔE_{00}. Material type and thickness were identified as the primary factors influencing color change ($p < 0.05$). Among the specimens with a thickness of 0.05 mm, the color change in the LC groups was higher compared to the DC groups except in the LU and GR groups. No statistical difference was found in specimens with a thickness of 1 mm, except in the CS and CE groups. CE group with 1 mm thickness and the DC cementation technique with (0.58 ± 0.11) ΔE_{00} value were in clinically acceptable range (Table 2) [11].

Regardless of the cementation technique, materials type and thickness significantly affected ΔRTP values. The highest ΔRTP value was observed in the specimens with a thickness of 0.5 mm with the DC cementation technique, while the lowest ΔRTP was recorded in the DC group with a thickness of 1 mm. The CE group showed the lowest ΔRTP values, regardless of cementation technique and thickness. According to the study by Salas et al., all the groups were in the clinically acceptable range in ΔRTP (Table 3; Fig. 3) [16].

Discussion

The study assessed the color and translucency change of different CAD/CAM materials and adhesive systems subjected to UV aging. The findings of the present study demonstrate that the cementation technique, materials type, and thickness significantly affect the ΔE_{00} value of the restorations. Consequently, the first null hypothesis was rejected. According to the study's results, among the three parameters, material structure and thickness affected ΔRTP, while cement had no effect on ΔRTP. Therefore, the second hypothesis was partially rejected.

Thickness is identified as the most critical factor affecting translucency [17–19]. In this study, the thickness of the specimens was set at 0.5 mm and 1 mm, which are commonly used in clinical non-preparation or minimal preparation laminate techniques. As thickness increases beyond 1 mm, light transmission decreases. This particular thickness allows for optimal polymerization of the underlying cement, thereby eliminating any limitations due to inadequate polymerization [17]. In this study, the ΔRTP values of the specimens in DC and LC groups with a thickness of 0.5 mm were similar to those of the specimens with a thickness of 1 mm, except CS with DC cementation. Significant differences between the ΔE_{00} values can be attributed to the color stability of the underlying cement. Similar to the results of this study, previous studies reported excessive discoloration

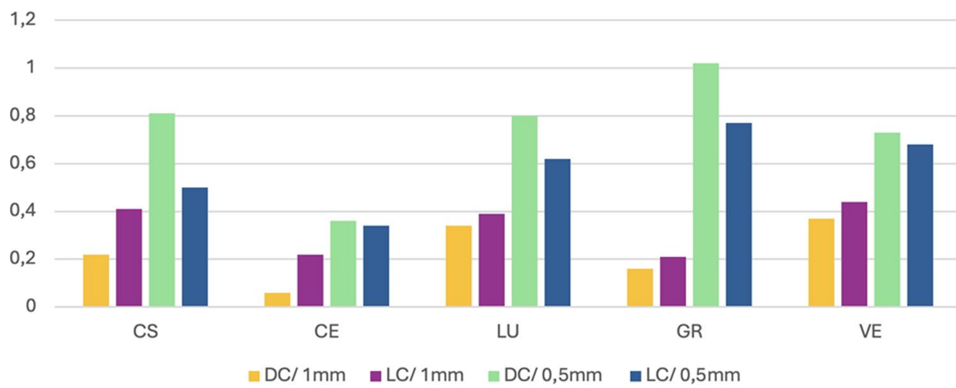

Fig. 3 The translucency changes (ΔRTP) in different cementatipn technique and CAD-CAM materials, in each group. Samples with thickness of 0.5 mm and dual cure cementation technique was shown higher ΔRTP. Samples with thickness of 1 mm and light cure cementation technique was shown least ΔRTP. Cerasmart (CS), cerec (CE), lava ultimate (LU), grandio (GR), vita enamic (VE), dual cure (DC), light cure (LC)

of the luting agents after thermocycling aging [18, 20–22]. After cementation, luting agents are generally not directly exposed to oral fluids unless there are gaps or cracks, and ultra-thin restorations, due to their light-transmitting properties, allow light to transmit to the underlying cement [23, 24]. The chemical composition, such as stabilizer and initiator, and chemical properties, such as degree of conversion (DOC) of monomers and even viscosity, in dual-Cure and light-Cure resin cement affected their curing performance, optical properties, and long-term success in restoration [25]. For example, resin cement' low viscosity enhances monomers' mobility, increasing the likelihood of termination during the initial polymerization stages. Consequently, this may result in reduced curing efficiency [26]. Chemically, DC cements contain tertiary amines, which play a crucial role in their polymerization process. The degradation of residual amines and the oxidation of residual carbon double bonds ultimately form yellowing components [27]. However, since the DC cement used in this study is amine-free, this cycle is not expected to occur, and thus, the formation of yellow components is unlikely. We believe that this characteristic contributes to the role of DC cement in color stability. This finding has been supported by Ramos et al. 's study [28]. According to the study's results by Cho et al., a statistically significant difference was observed in the DOC between DC and LC cement for blocks prepared at a thickness of 1.2 mm. The study argues that in clinical usage, when the thickness of laminate ranges between 0.3– 0.9 mm, no statistically significant difference would be observed in the DOC between DC and LC cement [29]. In the meta-analysis conducted by Harden et al. in 2023, 23 studies investigating the discoloration of LC and DC cements were evaluated. In 86% of the studies, DC cement exhibited more significant color changes than LC cement, which was attributed to inadequate polymerization. According to the study results, LC cements were suitable for thin or ultra-thin restorations [30]. Considering the results of the two aforementioned studies and the findings of this study, it is believed that the thickness of the prepared samples, being 0.5 mm and 1 mm, allowed a high DOC in monomer participation in polymerization, thereby reducing the amount of residual monomers. Consequently, this supports the argument that DC cement exhibits enhanced color stability. Therefore, the statistical difference in color stability between DC and LC cements in our study can be explained. Finally, parallel to the previous studies, it can be concluded that the shade of the cement and its color stability become critical factors that significantly influence the optical properties of ultra-thin restorations [17, 20, 31–34].

Conversely, anterior restorations are exposed to light throughout the day. In this situation, the underlying cement is indirectly exposed to light, including UV rays, which affects the long-term optical success of the luting agent. Therefore, the difference between previous studies could be attributed to the effect of the thermal aging system that might lead to excessive discoloration of the cement due to the chemical composition and water absorption that may occur over time. UV aging is an appropriate alternative to thermal aging. 300 h (150 kJ/m2) of UV aging test equivalent to 1 year of clinical service [27, 35].

The present study used three types of CAD/CAM materials. The LU material with an RNC structure exhibited the highest discoloration. In contrast, the CE material with a feldspathic ceramic structure showed the lowest discoloration, regardless of the cementation techniques and thicknesses. The RNC structure of LU consists of 20% composite, with zirconia and silica monomers infiltrating a cross-linked resin matrix. This structure gains hydrophilicity to LU and makes it more prone to discoloration. Colorant permeated to the resin structure and caused discoloration. This characteristic makes the LU less suitable for anterior laminate restorations [6, 36, 37].

The CE blocks contain a Feldspathic ceramic matrix, Al_2O_3, Zirconium dioxide, and ytterbium oxide, which is thought to play the main role in ΔE stability [38]. The color and translucency alterations observed in CAD/CAM blocks after UV aging likely result from UV light-induced degradation of unreacted amines trapped within the polymer matrix [39].

Monomers in the structure of CAD/CAM blocks affect the ΔE and ΔRTP of restorations. Monomers such as urethane dimethacrylate (UDMA) are more resistant to discoloration than bisphenol A-glycidyl methacrylate (Bis-GMA) due to their lower water absorption and hydrophilicity [4, 40, 41]. The VE blocks have feldspar ceramic, aluminum oxide-reinforced, UDMA, and trimethylene glycol dimethacrylate (TEGDMA) in their structure, which causes stable ΔRTP. Acar et al. reported that resin components like BIS-GMA monomers are associated with more significant discoloration. The ceramic content and high ceramic ratio positively impact color stability and translucency parameters [19]. In laminate restorations, the translucency parameter of CAD/CAM blocks is just as important as color stability.

Limitations

The main limitation of this study was its in vitro design. A new study could be planned using an in vivo approach. Currently, many blocks with varying properties are produced, but only a limited number of blocks with specific characteristics were used in this study. The intraoral conditions were partially simulated in this study. Future research could focus more specifically on assessing UV aging. Additionally, color changes could be analyzed separately for different types of cement. Various application protocols for cement could be developed to achieve better results.

Conclusions

Within the study's limitations, the following conclusions can be drawn. Both DC and LC cement showed clinically acceptable ΔRTP, so both of them can be recommended for clinical usage. The Cerec group with DC cementation and 1 mm thickness showed clinically acceptable ΔE_{00}.

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All authors gave final approval and agreed to be accountable for all aspects of the work.

Author contributions

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Data availability

The data supporting this study's findings are available from the corresponding author upon reasonable request.

Declarations

Human ethics and consent to participate

This study was conducted following the Helsinki Declaration, and ethical approval was not required as it did not involve any materials obtained from humans or animals.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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