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Home and in-office bleaching effect on stained hybrid nanoceramic and zirconia-reinforced lithium disilicate CAD-CAM materials

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Objectives: This study aimed to assess the impact of staining and bleaching procedures on the color alteration of hybrid nanoceramic and zirconia-reinforced lithium disilicate CAD-CAM materials. Materials and Methods: A total of 64 samples (12×14×1.5 mm³) were prepared from A2 shade hybrid ceramic (Cerasmart) and zirconia-reinforced lithium silicate (Celtra Duo) CAD-CAM blocks. After immersion in coffee solution for seven days, each material group was split into two subgroups, then subjected to home or in-office bleaching protocols (n=16). Color measurements were taken at baseline, after coffee staining, and after bleaching, and recorded as L, a, b values. Color differences were calculated as ΔE. Data were analyzed using Kolmogorov-Smirnov and three-way repeated measures ANOVA. Pairwise comparisons between groups were performed using the Bonferroni test. Results: After staining, Cerasmart demonstrated significantly greater discoloration than Celtra Duo (p<0.001). Material differences significantly affected the color change values in terms of staining and bleaching processes. The interactions of time factor with both material and bleaching agent were statistically significant. Conclusions: Hybrid ceramics are more prone to discoloration than lithium silicates. Both home and office bleaching agents are effective in reversing discoloration, with no significant clinical difference between the two methods in achieving initial color values.

Keywords: Bleaching, CAD-CAM, ceramic, color stability, staining.

Introduction

Computer-aided design and manufacturing (CAD-CAM) systems have gained prominence in prosthetic dentistry, offering enhanced workflow efficiency and delivering aesthetic, consistent indirect restorations in less time. With the continuous development of digital technologies and the increasing interest of individuals for aesthetic restorations, millable restorative materials with different structures have been introduced in dentistry [1, 2]. Due to patient preference for metal-free fixed restorations, there are many CAD-CAM block alternatives, including ceramic, zirconium, composite, hybrid ceramic and their combinations [3].

Zirconia-based ceramics exhibit superior mechanical performance, making them particularly suitable for the fabrication of 3-4 unit fixed restorations especially in the posterior region [4]. Celtra Duo is a zirconia-reinforced lithium silicate ceramic (ZLS) containing approximately 10% zirconia in addition to lithium oxide and silica [5]. As the zircona is homogeneously distributed within the ceramic glass phase, it prevents crystallization and the formation of an opaque appearance, allowing the restoration to achieve a high degree of translucency. The 10% zirconium content is molecularly dissolving and enhances the mechanical features of the material. During the crystallization phase, it provides easier grinding and polishing, resulting in high translucency which contributes to the aesthetic appearance of the restoration [6, 7].

Cerasmart is a hybrid ceramic block designed to merge the positive characteristics of ceramic and composite materials. Its flexible matrix structure allows forces to be distributed homogeneously and evenly. Its high flexibility ensures good marginal adaptation and provides high strength after cementation. It contains approximately 71% silica and 29% composite [8].

Recent advances in hybrid and nanohybrid restorative materials have focused on optimizing translucency, polishability, and wear resistance through the use of nanoscale ceramic fillers and enhanced resin matrices. These developments aim to address the clinical challenges related to esthetics and material longevity in the oral environment, where thermal fluctuation, pH variation, and mechanical stress are persistent factors [9].

Although the aesthetic properties of the materials have been improved, their exposure to external discoloration over long periods of time remains esthetically major disadvantage. Internal factors causing discoloration generally due to the chemical composition and structure of the material, while external factors are closely related to contamination from foods and beverages consumed [10]. The surface properties of the material and polishing process are factors that determine the severity of

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discoloration [11]. Recent studies have raised concerns regarding the resin content of hybrid dental materials, as residual monomers and organic matrix components may influence not only biocompatibility but also susceptibility to discoloration and surface degradation under clinical conditions [12].

Tooth whitening treatments are among the most conservative methods of dental aesthetic applications, as they preserve the natural tooth structure much better than composite/ceramic veneers or crowns and effectively responds to patient concerns about tooth color [13, 14]. The action mechanism of bleaching agents is that the agent is incorporated into tooth structure, reacts with molecules that show discolouration, and then this whole chain of reactions on the surface of tooth changes the optical properties of tooth by providing different reflection of light [15].

Bleaching applications can be categorized into two main groups: in-office and at-home bleaching. In-office bleaching generally consists of high-concentration (30-35%) hydrogen peroxide (HP) or carbamide peroxide (CP), while at-home bleaching involves lower concentrations (10-16%) applied over longer periods of time [16]. Although the impact of bleaching agents on natural tooth tissue are well-known, their effects on different restorative materials remain controversial. Particularly, the response of modern restorative materials such as CAD-CAM ceramics, resin-based composites, and hybrid ceramics to bleaching agents can directly affect their clinical success and longevity [17, 18].

The effect of different bleaching agents on the colour change of different CAD-CAM blocks is evaluated in this study. The null hypotheses are as following:

a) Staining and bleaching procedures do not compromise the color change of the CAD-CAM specimens.

b) There is no difference in efficacy between hydrogen peroxide and carbamide peroxide-based bleaching treatments.

Experimental

The type, composition and manufacturer's details of the materials used in this study are given in Table 1. The samples were prepared from zirconia-reinforced lithium disilicate (CD) and hybrid ceramic (CS) CAD-CAM blocks of shade A2 with dimensions of 12×14×1.5 mm^3 (N=64) [19]. The surface smoothness of the specimens was achieved under water cooling using silicon carbide abrasive papers (600-1000 grit). Thickness measurements were verified using a digital caliper. Following this, each sample was then ultrasonically cleaned for one minute in distilled water and slightly air dried.

Color measurements were taken using the Vita Easyshade Advance spectrophotometer from the center of each sample over a gray background, with three measurements taken and averaged. Color values were expressed using the CIELAB coordinates: L*, a*, and b*. Calibration of the device was completed prior to each measurement session.

In order to simulate extrinsic staining, sections were immersed in coffee solution (2 g Nescafe Classic dissolved in 200 ml distilled water) and incubated at 37 °C for seven days - corresponding to approximately seven months of in vivo exposure [20]. To prevent bacterial and yeast contamination, the prepared solution was replaced daily. Prior to re-immersion, samples were rinsed for 1 minute under an air-water spray. After staining, color measurements were repeated according to the initial measurement principles.

After staining, each material was divided into two subgroups (n=16) based on the bleaching protocol applied:

CSH: Cerasmart bleached with 16% CP
CDH: Celtra Duo bleached with 16% CP
CSO: Cerasmart bleached with 40% HP
CDO: Celtra Duo bleached with 40% HP

The CSH and CDH groups were exposed with carbamide peroxide-based home bleaching agents. A thin layer of bleach was coated to the surface of the samples with an applicator and kept at 37 °C for the duration of the bleaching process. The agent was left on the specimens for 4 hours a day for 10 days, as recommended by the manufacturer. After each application, samples were washed for 60 seconds with water and stored in kept in distilled water at 37 °C between treatments.

The CSO and CDO groups were treated with hydrogen

Table 1. Type and composition of materials

Product	Type	Composition	Manufacturer
Cerasmart	Hybrid ceramic	80% nanoceramic fillers (SiO_2 and barium glass), 20% Acrylate polymer (Bis-MEPP, UDMA, DMA)	GC Dental Tokio, Japan
Celtra Duo	Zirconia-reinforced lithium silicate	58% SiO_2, 18% LiO, 10.1% ZrO_2, 5% Phosphorus pentoxide, 1.9% Al_2O_3, etc.	Dentsply Sirona, Bensheim, Germany
Carbamide peroxide	Home bleaching gel	Carbamide Peroxide (16%), Potassium Nitrate, Sodium Fluoride	FGM Whiteness Perfect %16, Brasil
Hydrogen peroxide	Office bleaching gel	Hydrogen Peroxide (40%), Potassium Nitrate, Fluoride	Ultradent Opalescence Boost %40, USA

peroxide-based office bleaches. The agent was applied using an applicator 0.5-1.0 mm thick and performed as three consecutive applications of 20 minutes each in a single session [21]. After each application, all samples were rinsed with distilled water and dried with air. Color measurements were then repeated and recorded.

Color change (ΔE) between different timepoints was obtained using the following formula:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

The calculated ΔE values represent the amount of color change between two different measurement points.

According to this formula:

ΔE1: Difference between baseline and post-staining
ΔE2: Difference between staining and post-bleaching
ΔE3: Difference between baseline and post-bleaching

IBM SPSS v23.0 was used for statistical analysis. Descriptive statistics were reported as mean, minimum and maximum values. A three-way repeated measures ANOVA was used to assess the effects of material type and bleaching method over time. Bonferroni post-hoc test was used for pairwise comparisons. A significance threshold of p<0.05 was set for all analyses.

Results and Discussion

Descriptive statistics for different materials and ΔE color change values are presented in Table 2 and Fig. 1.

Table 2. Descriptive statistics

	ΔE1 Mean±SD (Min-max)	ΔE2 Mean±SD (Min-max)	ΔE3 Mean±SD (Min-max)
CSH	5,29±0,85 (3,58-6,59)	4,89±0,88 (3,73-7,08)	1,14±0,67 (0,41-2,40)
CSO	4,90±0,97 (2,96-6,37)	4,05±0,60 (3,11-5,28)	2,29±0,95 (0,75-4,12)
CDH	2,89±1,12 (1,01-4,75)	3,56±1,05 (1,63-4,78)	2,09±0,91 (0,77-3,61)
CDO	2,52±1,01 (1,19-4,34)	2,58±0,64 (1,35-4,17)	1,97±1,39 (0,41-5,69)

ΔE_1: Stained-Baseline, ΔE_2: Bleaching-Stained, ΔE_3: Bleaching-Baseline

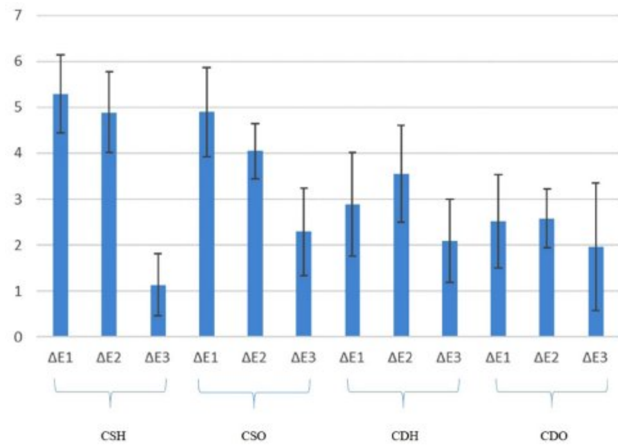

Fig. 1. Descriptive statistics (CSH: carbamide peroxide bleached Cerasmart, CDH: carbamide peroxide bleached Celtra Duo, CSO: hydrogen peroxide bleached Cerasmart, CDO: hydrogen peroxide bleached Celtra Duo. ΔE1: Stained-Baseline, ΔE2: Bleaching-Stained, ΔE3: Bleaching-Baseline)

A statistically significant difference in color change was observed between the tested materials ($p < 0.001$). The mean ΔE value for the CS was 3.76±1.74, while the mean ΔE value was 2.60±1.15 for the CD. Additionally, color change varied significantly across the three measurement timepoints ($p < 0.001$). The mean ΔE1 value (baseline - stained) was 3.90±1.56. The mean ΔE2 value (stained - bleached) was 3.77±1.16. The mean ΔE3 value (baseline - bleached) was 1.87±1.08.

The three-way repeated measures ANOVA revealed statistically significant interactions for material × time and bleaching × time ($p<0.001$ for both), indicating that the pattern of color change over time varied depending on the type of material and bleaching method, respectively. However, the three-way interaction (material × bleaching × time) was not significant ($p=0.083$), suggesting that the combined effect of material and bleaching protocol did not significantly impact the temporal pattern of color change (Table 3).

The findings of the combined effect of time and material are shown in Table 4. According to the ΔE1 and ΔE2 values, there were significant differences between the CS and CD ($p<0.05$). The color change values of the CS showed significant differences at all time intervals

Table 3. Three-way ANOVA results of difference in color changes

Source	Sum of squares	df	Mean square	F	*p*
Material	64,332	1	64,332	55,176	**<0,001**
Bleaching	3,185	1	3,185	2,732	0,104
Time	164,651	2	82,325	108,806	**<0,001**
Material×Bleaching	2,620	1	2,620	2,247	0,139
Material×Time	60,127	2	30,063	39,734	**<0,001**
Bleaching×Time	16,537	2	8,269	10,928	**<0,001**
Material×Bleaching×Time	3,838	2	1,919	2,536	0,083

Table 4. Results of Bonferroni Multiple Comparison Test Regarding the Combined Effect of Time and Material

Time	Material	
	CS (Mean ± Sd)	CD (Mean ± Sd)
ΔE1	5,10±0,92^{a,A}	2,71±1,07^{ab,B}
ΔE2	4,47±0,85^{b,A}	3,07±0,99^{b,B}
ΔE3	1,71±1,00^{c,A}	2,03±1,16^{a,A}

ΔE1: Stained-Baseline, ΔE2: Bleaching-Stained, ΔE3: Bleaching-Baseline
Mean: Average, Sd: Standart deviation
*Within the same material group, there is no statistically significant difference between the same lowercase letter (p>0.05).
**Within the same time points, there is no statistically significant difference between the same uppercase letter (p>0.05).

($p<0.05$). After staining with coffee solution, the CS exhibited significantly higher discoloration compared to the CD. Although the ΔE3 value of the CD (2.03) was higher than the CS (1.71), no difference was observed between the color change of materials after the bleaching process compared to the baseline.

The results of the combined effect of time and bleaching method are presented in Table 5. The bleach values after coffee staining were statistically different between the two bleaching methods ($p<0.05$). However, when the relationship between baseline and post-bleaching colour values was examined, no statistical difference was found between the two methods.

The current study aimed to investigate the impact of staining and subsequent bleaching protocols on the optical properties of hybrid ceramics and zirconia-reinforced lithium disilicate ceramics. The findings partially rejected the first null hypothesis, as staining with coffee led to significant differences in color change across materials. However, no statistical difference was observed in final color recovery values (ΔE3) among the groups.

Table 5. Results of Bonferroni Multiple Comparison Test Regarding the Combined Effect of Time and Bleaching

Time	Bleaching	
	Home Bleaching (Mean ± Sd)	Office Bleaching (Mean ± Sd)
ΔE1	4,09±1,56^{ab,A}	3,71±1,56^{a,A}
ΔE2	4,22±1,17^{a,A}	3,31±0,97^{a,B}
ΔE3	1,62±0,93^{b,A}	2,13±1,18^{b,A}

ΔE1: Stained-Baseline, ΔE2: Bleaching-Stained, ΔE3: Bleaching-Baseline
Mean: Average, Sd: Standart deviation
*Within the same bleaching procedures, there is no statistically significant difference between the same lowercase letter (p>0.05).
**Within the same time points, there is no statistically significant difference between the same uppercase letter (p>0.05).

Zirconia lithium silicate and resin matrix hybrid CAD-CAM blocks are generally the preferred choice for aesthetic prosthetic restorations. These materials provide satisfactory results for aesthetic restorations. However, due to their structural differences, these two materials can exhibit different behaviors against staining agents.

Cerasmart is more vulnerable to discoloration due to its UDMA (Urethane Dimethacrylate) content. Previous reports have indicated that bleaching agents may chemically interact with the resin matrix of hybrid ceramics, particularly those containing UDMA, potentially leading to surface degradation and increased porosity over time [22]. This may influence both color stability and the long-term clinical performance of such materials. According to the literature, hybrid ceramics have a high water absorption due to their organic matrix content, which can increase external staining [2, 23]. The presence of hydrophilic resin components and filler particle morphology plays a key role in influencing water sorption, solubility, and overall dimensional stability of hybrid dental materials. Resin-modified calcium silicate-based biomaterials with similar resin matrices have demonstrated variations in porosity and leaching behavior, which may impact their optical and mechanical behavior under clinical conditions [12]. Zirconia-reinforced lithium silicate ceramics, on the other hand, have a higher glassy phase with characteristic needle-shaped crystals and a homogeneous microstructure, which increases their durability and color stability [24, 25].

As described in recent literature, the optimization of filler particle size and resin matrix compatibility is essential for enhancing polishability and reducing discoloration in nanohybrid restorative materials [9]. This is particularly relevant for materials like Cerasmart, which contain nanoscale ceramic fillers in a resin-based matrix.

In this study, ceramic-based CAD-CAM materials were stained by immersing them in a coffee solution for one week. The results showed that Cerasmart exhibited higher color change values (ΔE1) compared to Celtra Duo after immersion in coffee. Similarly, a study conducted in 2022 reported that resin-based materials exhibit more significant color changes when exposed to staining agents like coffee, but noticeable color recovery can be achieved with office bleaching agents [26]. Yıldırım et al. [25] reported that in their study, in which hybrid ceramic (Cerasmart) and zirconia-reinforced lithium silicate (Vita Suprinity) CAD-CAM blocks were immersed in tea solution, Vita Suprinity samples showed higher color stability. Also, Dejan et al. [27] evaluated the color changes of different CAD-CAM ceramics after staining with coffee, red wine, and artificial ageing and found that ZLS blocks had higher color stability than hybrid ceramics. The findings of the current study are in accordance with those reported in the literature.

In evaluating the clinical relevance of color change, perceptibility and acceptability thresholds were considered. According to the literature, a ΔE*ab value of 1.2 represents the 50:50% perceptibility threshold (PT), while 2.7 corresponds to the 50:50% acceptability threshold (AT) [28, 29]. In this study, ΔE3 values for both materials following bleaching procedures remained below the AT threshold, indicating that the color changes were within clinically acceptable limits. The bleaching process applied to the coffee-stained samples in both materials was considered successful in terms of achieving a return to the original color.

When the post-bleaching colour change values (ΔE3) were examined, the second hypothesis of the study was accepted since there was no statistical difference between the two bleaches.

In our study, both hydrogen peroxide and carbamide peroxide based bleaching agents were found to provide a significant degree of color recovery in both materials. The results showed that the ΔE3 colour change values for both materials were within clinically acceptable limits. It was observed that the stained Cerasmart group showed a greater return to the initial color values after the bleaching process compared to Celtra Duo (ΔE3). The main reason for this is that the zirconium oxide content in Celtra Duo increases the mechanical and optical stability of the material, reducing pigment penetration. Furthermore, it has been reported that materials consisting of crystalline minerals with a dense microstructure and glass matrix can prevent the penetration of stains [30]. Previous studies have also confirmed that zirconia-reinforced lithium silicate materials exhibit less colour change, as well as superior mechanical strength and resistance to subcritical crack propagation, than conventional and hybrid ceramics [26, 31]. Similarly, the study by Elsaka et al. [32] reported that nanoceramic materials exhibited more significant color change to stains, and the color stability after bleaching varied depending on the material. Lee et al. [26] stained Cerasmart and Celtra Duo samples with red wine and applied bleaching treatments using 16% and 40% hydrogen peroxide. They concluded that the color change values were dependent on the material than on the bleaching agent. As only coffee was used as the staining agent in our study, the findings may not fully reflect the effects of other dietary chromogens such as tea or red wine. Future studies including multiple staining agents are needed to broaden the clinical applicability of the results. The ANOVA results of our study indicate that differences in materials can result in different color change values after staining and bleaching procedures.

When the ΔE3 values of materials were evaluated, no statistically significant difference was found between those two bleaching methods, regardless of the material. This result is in line with the study by Öztürk et al. [16] The researchers reported that although the concentration of the at-home bleaching was lower than that of the in-office bleaching system, the longer application time was the reason for the lack of difference between the two bleaching systems. However, as noted in the current study, the effects of both bleaching methods on long-term color stability should be evaluated.

Within the limitations of our study, factors such as pH, saliva, and temperature variations were not simulated to mimic the oral environment. The use of single shade and thickness samples is another limiting factor of this study. Additionally as no polishing or glazing was performed, surface roughness resulting from standardized grinding may have contributed to increased stain uptake, particularly in the hybrid ceramic group. Future studies may benefit from comparing surface treatments to better simulate clinical outcomes. Another limitation of this study is the lack of evaluation of surface roughness or gloss following bleaching. As surface texture may influence long-term stain susceptibility, especially in hybrid ceramics, future studies should investigate the topographical changes induced by bleaching agents. Investigation of the mechanical and physical properties of materials using different staining agents and application times should be considered in future studies.

Conclusion

Based on the results of this study, clinicians should be aware that hybrid ceramic restorations are more prone to discoloration than lithium silicates. Home and office bleaching agents are effective in removing this stain, and neither method shows clinical superiority over the other in achieving color change values close to the initial. Although both bleaching protocols demonstrated similar efficacy in color recovery, clinicians may consider the patient's compliance and the surface sensitivity of the restorative material when choosing between in-office and at-home bleaching.

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Author's contributions: ŞEG: Conceptualization, Investigation, Validation, Methodology, Project administration, Writing – review & editing. GS: Investigation, Validation, Methodology, Project administration, Writing – review & editing. MA: Data curation, Formal Analysis, Writing – original draft. EE: Investigation, Data curation, Writing – original draft. All authors read and approved the final manuscript.

Abbreviations

The following abbreviations are used in this manuscript:

CAD-CAM Computer-aided design and manufacturing

ZLS zirconia-reinforced lithium silicate ceramic

HP hydrogen peroxide
CP carbamide peroxide

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