Influence of thickness and background on the color changes of CAD/CAM dental ceramic restorative materials

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Abstract
This study aimed to compare the effect of thickness and background on the color changes of CAD/CAM materials (zirconia-reinforced lithium silicate (Suprinity), lithium disilicate (IPS E-max CAD), and hybrid ceramic (Enamic)). Twelve specimens for each thickness (0.4 mm, 0.5 mm, 1 mm, 1.5 mm, and 2 mm) were obtained by sectioning three CAD/CAM materials. A spectrophotometer was used to measure the color change of the specimens against different backgrounds (A2 enamel, A4 dentin, gray, and metal) using the CIELab color space system. Analysis of variance, sample t-test, and posthoc multiple comparison tests were used to evaluate and compare the color changes for different material types, thicknesses, and background colors, with a significance level of $P \leq 0.05$. The result demonstrated that material type, the thickness of the material, and the color of the background had a significant effect on $\Delta E$ ($P = 0.000$). Regardless of the material thickness, Suprinity had the highest mean $\Delta E$ values ($5.4 \pm 1.9$), and E-max had the lowest mean $\Delta E$ values ($1.1 \pm 0.6$). At 2 mm thickness, Enamic presented the lowest $\Delta E$ values ($0.5 \pm 0.5$) against the A2 background. The 0.5 and 1 mm specimens corresponded to the highest $\Delta E$ values, whereas the 1.5 and 2 mm thickness specimens predominantly gave the lowest $\Delta E$ values. All the independent factors, including the type and thickness of the material, and color of the background, contributed significantly to $\Delta E$ of the tested materials ($P \leq 0.05$). The study confirms the high masking ability of the lithium disilicate (E-max) material. In clinical situations where the color of the core needs to be masked, it is recommended to use lithium disilicate (E-max).

Introduction

Esthetics is a topic of considerable interest in the dental field due to an increased demand for esthetic restorations by the patients. This has led to the expanded use of dental ceramics for restorative purposes, mainly because of their superior optical and mechanical properties [1–4]. The optical properties of the ceramic restorations, however, is determined by the combination of the factors such as the color of the underlying tooth structure, thickness of the ceramic covering, and the color of the luting cement. Among all, the primary factor to influence the color is the underlying dark tooth structure as in endodontically treated or discolored tooth. This could result in the darkening of the restoration, thus emphasizing the importance of factors such as ceramic shade and thickness, and color of the luting cement [5–8].
Zirconia ceramic has excellent mechanical properties, acceptable shade, and appearance with exceptional color masking ability. They were once considered an opaque material, although, in recent years, certain zirconia copings allow some amount of light to pass through [9]. On the contrary, lithium disilicate crowns have demonstrated enhanced translucency relative to zirconia crowns, making them one of the most common materials used for anterior indirect restoration [10, 11]. However, their esthetic result is influenced by the color of the underlying core. Consequently, their use in indirect restorations of extremely discolored dentin or a cast metal post and core may limit the esthetic outcome [11].

In overcoming the drawbacks of the lithium disilicate, zirconia-reinforced lithium silicate glass-ceramic (Vita Suprinity™) was introduced in 2015. According to the manufacturer, this new glass-ceramic is enhanced with zirconia, thereby combining the mechanical properties of zirconia with the esthetic characteristic of glass-ceramic [12, 13]. This restorative material is reported to mask the background color of the core material relative to zirconia and lithium disilicate ceramics. Furthermore, they possess numerous advantages, such as long-term reliability, high load-bearing capacity, ease of milling and polishing, and excellent translucency, fluorescence, and opalescence [13].

In recent years, hybrid ceramic or polymer infiltrated ceramic network (PICN) material (Vita Enamic®) has been introduced to the market. This material combines the color stability and strength of ceramics with low abrasiveness and improved flexural strength of composites. The advantages of this material are the rapid milling, increased tolerance to milling damage, elasticity similar to that of natural dentin, and high fracture resistance. Furthermore, the materials are easily polishable, finished, and repairable [13].

It is always a great challenge for the clinician to match the ceramic restoration with that of natural tooth color, which is defined by the optical properties of enamel and dentin [14]. In recent years, high-translucency (HT) zirconia ceramic materials have been marketed by dental manufacturers and laboratories due to their excellent esthetics and strength properties [15]. In the final esthetic outcome, color shade plays a major role; therefore, knowledge of the scientific principles of color is essential for this field. Color is known to be completely dependent on light that can be absorbed, reflected or transmitted depending on the material type: transparent materials allow the passage of light through it, translucent materials will transmit and absorb light, and opaque materials will reflect and absorb the light without transmission [16, 17]. The human eye’s perception of color differs from person to person. It is influenced by several factors, such as the intensity of light, the color of the external environment, the type of material, and the color of the dental core [17].

The aim of this study was, therefore, to compare the color changes between zirconia-reinforced silicate lithium, lithium disilicate, and hybrid ceramic against different background materials with different thicknesses. The null hypothesis stated that the color change against different background materials would not vary for different thicknesses of zirconia-reinforced silicate lithium, lithium disilicate, and hybrid ceramics.

Materials and methods

Preparation of specimens

Twelve specimens for each thickness (0.4 mm, 0.5 mm, 1 mm, 1.5 mm, and 2 mm) was obtained from three different ceramic CAD/CAM materials namely; zirconia-reinforced lithium silicate (Suprinity, VITA Zahnfabrik, Bad Sackingen, Germany), lithium disilicate (IPS E-max CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein), and hybrid ceramic (Enamic, VITA Zahnfabrik, Bad Sackingen, Germany), were prepared. All the study materials were pre-shaded (A2) highly translucent (HT) for the standardization process.

A preformed silicon mold (Deguform plus, DeguDent GmbH, Germany) was used to invest the ceramic blocks using clear self-curing orthodontic resin (Orthoresin, DENTSPLY Limited, Surrey, England) (figure 1(a)) to prepare the specimens for the cutting process. The invested blocks were then cut to the determined thickness using a precision diamond cutter (Isomet 2000 precision saw, Buehler, Lake Bluff, IL) equipped with a 0.6 mm blade rotating at a speed of 1000 rpm. The stability of the specimens during the cutting was maintained using a positioning jig fabricated using clear self-curing orthodontic resin (Orthoresin, DENTSPLY Limited, Surrey, England) (figure 1(b)).

The size of the specimens was predetermined by marking using a caliper with consideration for the amount of material removed during cutting and shrinkage during crystallization. Zirconia-reinforced lithium silicate and lithium disilicate ceramics were subjected to the crystallization process as per the manufacturer’s recommendations (figure 1(c)). For the same purpose, the thickness of these specimens was increased by 20% to compensate for the shrinkage during the crystallization. The thickness of all the specimens was maintained using a dual-design grinder/polisher machine (LECO Spectrum System 1000, USA) with the sequential use of P400-P1200 grit silicon carbide abrasive papers paper (Water Proof SiC paper; Struers, OH, USA) at 300 rpm under running water. This was followed by sequential lap polishing (Meta Di Supreme, Buehler Co, IL, USA) of the specimen surfaces with diamond paste. The final thickness of each specimen was confirmed with a digital...
electronic measuring gauge, and any specimen exceeding 0.05 mm of the desired thickness was discarded. All the specimens were cleaned with distilled water in the ultrasonic bath for 10 min and then dried with compressed air before color measurements.

**Preparation of background substrate**

Four different background substrate measuring 37 mm in diameter and 2 mm in thickness was fabricated. All the substrates were prepared with a silicon mold (Speedex, Coltene, Altstatten, Switzerland). Resin composites (IPS Empress Direct, Ivoclar Vivadent, Schaan, Liechtenstein) in A2 and A4 shades were used to simulate the enamel and dentine color, respectively. The resin composites were filled into the silicone mold and then pressed using a microscopic glass slide to extrude excessive material. The composite discs were polymerized using a handheld visible-light polymerization unit (Elipar Free Light 2, 3 M ESPE, St. Paul, MN) for 40 s. The resin disc was removed from the mold and polymerized for an additional 40 s on the other side to ensure optimal polymerization.

The gray substrate background was prepared by mixing auto polymerizing acrylic resin (Dentsply Ltd Weybridge, Surrey, KT, England) with amalgam powder and poured into a silicone mold [18]. Following polymerization, the composite and acrylic resin discs were polished with 600-grit silicon carbide abrasive papers for 10 min. The background discs were stored in de-ionized water at 37 °C ± 1 °C for 24 h before color measurement.

A metal substrate was cast from non-precious metal (Talladium, Inc., OH, USA) as per the required dimension and later shot-blasted using 110-μm aluminum oxide particles with 2 bar psi for 10 s to eliminate gloss and mimic a metal post in endodontically treated teeth.

**Color measurements**

The color measurements were performed using a reflecting spectrophotometer (Color-Eye 7000 A spectrophotometer, Michigan, USA) equipped with color measurement software (EasyMatch 4.90, Hunterlab, VA, USA). The spectrophotometer device was calibrated against a standard white background (CIE L* = 94.3, a* = −0.4, and b* = 1.4) and a black background (CIE L* = 0.2, a* = 0.4, and b* = −0.6). The aperture size of the device was 25.4 mm in diameter, and illuminating and viewing configuration was CIE diffuse/8° geometry [18].
The substrate materials were positioned on the specimen holder against a white background to prevent any absorption effects. The initial color measurements of the background substrate were performed using a CIELab color coordinates \(L^*, a^*,\) and \(b^*\) under a standard D65 light source illuminant, which corresponds to average daylight.

Once the measurement for background materials was recorded, the CAD/CAM specimens were then positioned on the backgrounds without an underlying medium, and the CIELab values of the specimens were recorded. Three measurements were made for each specimen against each background. The color difference \(\Delta E^*\) of the CAD/CAM specimen with that of the background substrate was calculated using the equation:

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

\(\Delta L^*\) - difference in lightness and darkness; \(\Delta a^*\) - difference in red and green axis; and \(\Delta b^*\) - difference in yellow and blue axis.

Statistical analysis
Data were analyzed using SPSS v. 21 (IBM SPSS Inc., Chicago, IL, USA). One-way ANOVA was used to evaluate the difference in the color change among the ceramic CAD/CAM materials for each thickness and the different thicknesses for the same material. Three-way ANOVA was used to analyze the influence of material type, thickness, and background color on \(\Delta E\). A one-sample t-test was used to evaluate the background’s \(\Delta E\) when different thicknesses of the different materials were used. A P value of \(\leq 0.05\) was considered statistically significant for all the tests.

Results
The impact of the material type and thickness on \(\Delta E\) revealed that each independent factor, including the type of material, the thickness of the material and color of the background, had a significant effect on \(\Delta E\) \((P < 0.000)\) for all factors (table 1).

**Effect of the background color on \(\Delta E\) for different CAD/CAM materials with different thicknesses**
The mean and standard deviations of \(\Delta E\) for each material type, thickness against four different backgrounds are presented in table 2. Regardless of the material thickness, Suprinity ceramic material had the highest mean \(\Delta E\) values among all the specimens. The E-max specimens had the lowest mean \(\Delta E\) values at all thickness except for the 2 mm thick specimens.

A one-sample t-test used to evaluate the differences between the \(\Delta E\) against different backgrounds and the \(\Delta E\) of different materials for each material thickness revealed that all the differences were statistically significant \((P \leq 0.05)\) (table 3).

**Effect of the background color on \(\Delta E\) for different thicknesses with different CAD/CAM material types**
The mean and standard deviations of \(\Delta E\) for each material thickness against four different backgrounds are presented in table 4. Regardless of the material type, the 0.5 and 1 mm thickness specimens corresponded to the highest \(\Delta E\) values, whereas the 1.5 and 2 mm thickness specimens predominantly demonstrated the lowest \(\Delta E\) values. Furthermore, the 1 mm thick specimens of Suprinity material against the A2 background presented the highest \(\Delta E\) value.

The difference between the \(\Delta E\) values of different background colors and the \(\Delta E\) of different material types for each material thickness was evaluated. The highest mean difference (5.35) was found at a thickness of 1 mm with the Suprinity material; all these differences were found to be statistically significant \((P \leq 0.000)\) (table 5).
Discussion

The outcome of the present study recommends the rejection of the null hypothesis since the color change (ΔE) against different backgrounds varied significantly for different thicknesses of zirconia-reinforced silicate lithium, lithium disilicate, and hybrid ceramics.

Currently, dental appearance and esthetics constitute a significant concern for the practitioner and a requirement for the patient. This has encouraged the researchers worldwide to focus on multiple esthetic parameters and factors that affect optical properties such as translucency, the color of the core, and thickness of the restorative material [3, 4, 9, 11, 19, 20]. Although the effect of thickness on the color changes of ceramic restorative materials has been evaluated previously [12], there is a lack in the literature regarding the color changes of zirconia-reinforced lithium silicate and hybrid ceramics. Hence the present study was an attempt to compare the color difference of different thicknesses of conventional ceramics and hybrid ceramic against different backgrounds. All the evaluated CAD/CAM ceramic materials were of A2 shade as it is commonly

| Table 2. Descriptive analysis of ΔE for the different material thickness against all backgrounds. |
|-----------------------------------------------|
| Thickness (mm) | Material | Gray Mean ΔE | Metal Mean ΔE | A2 Mean ΔE | A4 Mean ΔE |
|----------------|---------|--------------|---------------|------------|------------|
| 0.4            | E-max   | 1.5          | 1.0           | 1.4        | 1.3        |
|                | Enamic  | 1.1          | 0.8           | 2.0        | 1.8        |
|                | Suprinity | 2.0       | 1.5           | 2.9        | 1.4        |
| 0.5            | E-max   | 1.7          | 0.9           | 1.3        | 0.99       |
|                | Enamic  | 0.6          | 0.7           | 2.4        | 1.3        |
|                | Suprinity | 2.4       | 1.8           | 2.7        | 1.98       |
| 1              | E-max   | 1.2          | 0.6           | 0.9        | 0.7        |
|                | Enamic  | 3.4          | 1.2           | 3.9        | 1.5        |
|                | Suprinity | 3.0       | 1.3           | 2.3        | 1.3        |
| 1.5            | E-max   | 0.5          | 0.3           | 0.7        | 0.5        |
|                | Enamic  | 0.9          | 0.7           | 1.1        | 0.6        |
|                | Suprinity | 1.0       | 0.5           | 1.9        | 1.0        |
| 2              | E-max   | 1.1          | 0.6           | 1.6        | 0.8        |
|                | Enamic  | 0.8          | 0.5           | 0.8        | 0.5        |
|                | Suprinity | 1.7       | 0.9           | 1.8        | 1.9        |

| Table 3. Comparison between the background and ΔE of different material types with different material thicknesses. |
|-----------------------------------------------|
| Thickness (mm) | Material | Gray ΔE = 0.029 | Metal ΔE = 0.034 | A2 ΔE = 0.011 | A4 ΔE = 0.015 |
|----------------|---------|-----------------|-----------------|-------------|-------------|
| 0.4            | E-max   | 1.5             | <.000           | 1.4         | <.000       |
|                | Enamic  | 1.0             | <.000           | 2.0         | <.000       |
|                | Suprinity | 2.3         | <.000           | 2.8         | <.000       |
| 0.5            | E-max   | 1.7             | <.000           | 1.3         | <.000       |
|                | Enamic  | 0.6             | <.000           | 2.3         | <.000       |
|                | Suprinity | 2.4         | <.000           | 2.7         | <.000       |
| 1              | E-max   | 1.2             | <.000           | 0.9         | <.000       |
|                | Enamic  | 3.4             | <.000           | 3.9         | <.000       |
|                | Suprinity | 3.0         | <.000           | 2.3         | <.000       |
| 1.5            | E-max   | 0.5             | <.000           | 0.7         | <.000       |
|                | Enamic  | 0.9             | <.000           | 1.1         | <.000       |
|                | Suprinity | 0.99         | <.000           | 1.8         | <.000       |
| 2              | E-max   | 1.0             | <.000           | 1.5         | <.000       |
|                | Enamic  | 0.8             | <.000           | 0.8         | <.000       |
|                | Suprinity | 1.7         | <.000           | 1.7         | <.000       |

Mean dif. = Mean difference; Sig. = Significant
favored by researchers to evaluate and compare the dental restorative materials [2, 21]. However, the comparison to the previous studies should be avoided due to the difference in laboratory investigation, materials used, and simulation conditions.

Most ceramic materials developed with the CAD/CAM technique can withstand a 0.4 mm thick load for minimally invasive veneers in the anterior region and a thickness of 2 mm for posterior crowns [5]. The thickness of the material for restorative purposes is determined by several factors such as the type of tooth to be restored, the choice of restorative treatment, the extent of coverage (full or partial), the color of the core, and the physical and mechanical properties of the material. It is also well established that the thickness of the restoration has a significant impact on the translucency and color outcome of the final prosthesis [19, 22].

Enamic, the first hybrid dental ceramic, is known to combine the properties of composites and ceramics mimicking the properties of natural dentin. The strength of these materials is comparable to that of dentin due to the interpenetrating polymer within its network, which advocates their use in thin sections [23, 24]. On the other hand, zirconia-reinforced lithium silicate (Suprinity) are machinable materials produced with the CAD/

Table 4. Descriptive analysis of ΔE for different CAD/CAM materials against all backgrounds.

| Material | Thickness (mm) | Background | A2 | A4 | Metal | Gray |
|----------|----------------|------------|----|----|-------|------|
|          |                |            | Mean ΔE | SD  | Mean ΔE | SD  | Mean ΔE | SD  | Mean ΔE | SD  |
| Suprinity| 0.4            |            | 2.68   | 1.68| 2.8     | 1.56| 2.86    | 1.43| 2.35    | 1.48|
|          | 0.5            |            | 2.77   | 2.20| 2.59    | 1.83| 2.7     | 1.98| 2.42    | 1.79|
| E-max    | 0.4            |            | 5.36   | 1.88| 2.47    | 1.35| 2.34    | 1.32| 3.03    | 1.35|
|          | 0.5            |            | 1.22   | 0.87| 1.66    | 0.80| 1.84    | 1.01| 1.02    | 0.54|
|          | 1              |            | 1.63   | 1.32| 1.02    | 0.60| 1.77    | 1.88| 1.72    | 0.91|
|          | 1.5            |            | 1.29   | 1.01| 1.69    | 0.87| 1.3     | 0.999| 1.71    | 0.93|
| E-max    | 2              |            | 0.69   | 0.46| 0.94    | 0.69| 0.89    | 0.66| 1.22    | 0.61|
|          | 1.5            |            | 0.60   | 0.36| 0.59    | 0.4 | 0.73    | 0.53| 0.52    | 0.33|
| E-max    | 0.4            |            | 0.92   | 0.53| 1.04    | 0.54| 1.58    | 0.76| 1.11    | 0.61|
|          | 0.5            |            | 2.68   | 1.35| 1.83    | 1.90| 2.08    | 1.84| 1.11    | 0.79|
| E-max    | 1              |            | 3.45   | 1.24| 2.78    | 1.36| 3.89    | 1.48| 3.43    | 1.22|
|          | 1.5            |            | 1.40   | 0.94| 0.97    | 0.64| 1.13    | 0.62| 0.88    | 0.73|
|          | 2              |            | 0.80   | 0.53| 0.55    | 0.48| 0.80    | 0.51| 0.83    | 0.50|

Table 5. Comparison between the background and ΔE at different material thicknesses for the different material types.

| Material | Thickness (mm) | Background | A2 | A4 | Metal | Gray |
|----------|----------------|------------|----|----|-------|------|
|          |                |            | ΔE = 0.011 | ΔE = 0.015 | ΔE = 0.034 | ΔE = 0.029 |
|          |                |            | Mean dif. | Sig.  | Mean dif. | Sig.  | Mean dif. | Sig.  | Mean dif. | Sig.  |
| Suprinity| 0.4            |            | 2.67     | <.000  | 2.78     | <.000  | 2.83     | <.000  | 2.32     | <.000  |
|          | 0.5            |            | 2.76     | <.000  | 2.57     | <.000  | 2.66     | <.000  | 2.39     | <.000  |
| E-max    | 0.4            |            | 5.35     | <.000  | 2.45     | <.000  | 2.30     | <.000  | 3.00     | <.000  |
|          | 0.5            |            | 1.84     | <.000  | 1.65     | <.000  | 1.80     | <.000  | .99      | <.000  |
|          | 1              |            | 1.63     | <.000  | 1.01     | <.000  | 1.74     | <.000  | 1.69     | <.000  |
| E-max    | 0.4            |            | 1.21     | <.000  | 1.44     | <.000  | 1.38     | <.000  | 1.52     | <.000  |
|          | 0.5            |            | 1.28     | <.000  | 1.68     | <.000  | 1.27     | <.000  | 1.68     | <.000  |
|          | 1              |            | .68      | <.000  | .93      | <.000  | .85      | <.000  | 1.19     | <.000  |
|          | 1.5            |            | .59      | <.000  | .57      | <.000  | .69      | <.000  | .49      | <.000  |
|          | 2              |            | .90      | <.000  | 1.03     | <.000  | 1.54     | <.000  | 1.08     | <.000  |
| E-max    | 0.4            |            | 2.67     | <.000  | 1.82     | <.000  | 2.04     | <.000  | 1.08     | <.000  |
|          | 0.5            |            | 3.28     | <.000  | 3.22     | <.000  | 2.3      | <.000  | .64      | <.000  |
|          | 1              |            | 3.44     | <.000  | 2.76     | <.000  | 3.86     | <.000  | 3.4      | <.000  |
|          | 1.5            |            | 1.39     | <.000  | .96      | <.000  | 1.1      | <.000  | .85      | <.000  |
|          | 2              |            | .79      | <.000  | .53      | <.000  | .77      | <.000  | .81      | <.000  |

Mean dif. = Mean difference, Sig. = Significant.
CAM technique with zirconia in its structure to enhance the physical properties and the color masking ability of the ceramics [25]. This was supported in a study by Elsaka and Elnaghy, who reported that Suprinity exhibited superior mechanical properties than E-max [26].

In the current study, different thicknesses of CAD/CAM materials were used simulating the clinical situations where the different thicknesses of a ceramic layer need to be used. The 0.4 mm thickness of the material followed the manufacturer’s recommendation of minimum thickness for both Suprinity and E-max that can produce good esthetics on teeth with minimal discoloration. It is also considered the thickness of choice for veneers with an acceptable color of the core [5, 27, 28]. A 0.5 mm thick material is indicated in cases with minimum veneer preparation and acceptable color of the underlying structure. A 1 mm thick specimens are the recommended thickness for cervical preparations of anterior full coverage restorations for all the evaluated materials [5, 28]. Thicknesses of 1.5 and 2 mm are indicated for full-coverage restoration on either posterior or anterior tooth, and it is also the recommended thickness in cases of severe discoloration.

Different backgrounds for determining the color changes in this study simulated the clinical environment of the oral cavity. The shades A2 and A4 background simulated the dental hard tissues, enamel, and dentin. The gray background mimicked an endodontically discolored tooth, and a metal background was used to replicate the clinical situations of a metal post and core [28].

The outcome of this study demonstrated that all three variables (thickness, background, and material type) (table 1) have a significant effect on the color change (ΔE) of each material. The form of material and thickness for ceramic materials is considered essential criteria for optical properties, and variations in color and translucency of the materials can be predicted as the thickness of the porcelain layer varies [12]. This is also considered a limitation of ceramics because different materials have different microstructures, and secondly, thicker materials tend to mask the background better than thinner ceramic. Furthermore, the substrate color affects the final esthetic outcome [29]. This is consistent with the findings of the previous studies, which have demonstrated that material type, thickness, and background color affect the shade of the final prosthesis [3, 20, 24, 30]. Background color had a significant effect on the color of all the three selected materials at each thickness. Suprinity had the highest mean difference in ΔE with all backgrounds and for all thicknesses except 1 mm, whereas Enamic showed a higher mean difference with all backgrounds except A2 enamel. Lithium disilicate (E-max) had the lowest mean difference among the materials except with gray background at the 0.4, 0.5, and 2 mm thicknesses; however, at a thickness of 2 mm, it showed a higher mean difference than Enamic.

The high ΔE of Suprinity could be related to the incorporation of zirconia into its composition. Furthermore, the two types of crystals in its composition and inhomogeneity of the crystalline structure contribute to the high color difference values, which could result in low masking ability [3, 20, 30]. On the contrary, the high masking ability of lithium disilicate (IPS e.max) could be attributed to enhanced crystal structure and high translucency of a single type of crystal in its composition. It has also been demonstrated that the difference in color and translucency between IPS and Suprinity is caused by the discrepancies between the crystalline structures and is interpreted as a difference in the structure and volume of the crystals [12].

The thickness of the material contributed significantly to the ΔE of the materials. In general, a positive linear correlation between the thicknesses and ΔE was observed; the thicker the material, the higher is the masking ability and less color change. The increased thickness will result in diminished diffused reflection effects of the underlying or background color, and most of the diffused reflection occurs in the overlying material. Thus, clinicians should consider increasing the ceramic’s thickness to mask the underlying color [20, 22, 30].

The current in-vitro study evaluating the color changes of CAD/CAM materials was made possible to simulate the oral environment. However, the results may not be directly correlated with in-vivo conditions because of the factors affecting the color changes such as diet, patient preferences, and color of the luting cement. Future studies should be directed towards evaluating the effect of other parameters such as the luting cement shade and the finishing technique on the color change of dental CAD/CAM ceramics.

**Conclusion**

Within the limitations of the study, the following conclusions are made:

(a) All the independent factors, including the type and thickness of the material, and color of the background, contributed significantly to ΔE of the tested materials.

(b) Zirconia-reinforced lithium silicate (Suprinity) demonstrated the highest ΔE values among the three types of materials, and the lowest ΔE values were observed with lithium disilicate (E-max).

(c) The ΔE values of Vita Enamic were in between lithium disilicate (E-max) and lithium silicate (Suprinity) CAD/CAM materials.
(d) In clinical situations where the color of the core needs to be masked, it is recommended to use lithium disilicate (E-max).

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Conflict of interest

None to declare.

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