

RESEARCH ARTICLE

Effects of substrate, ceramic thickness, translucency, and cement shade on the color of CAD/CAM lithium-disilicate crowns

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Abstract

Objective: The aim of this in vitro study was to evaluate the effects of substrate colors, different levels of ceramic thickness and translucency, and cement shades on the color difference from a reference color of lithium-disilicate crowns.

Materials and Methods: A premolar tooth preparation was made on a study model for 1.0 and 1.5 mm thick full-ceramic crowns. Digital impressions were taken (3Shape TRIOS) and crowns designed in a CAD program (DentalDesigner). Shade A1 crowns were milled (Everest, Kavo) from high-translucency (HT) and low-translucency IPS e.max (Ivoclar Vivadent) blocks. Twelve substrates were made of different colors and materials (Natural Die Material, Co-Cr, zirconia, and gold-colored alloy). Three different shades of try-in pastes were used to simulate the effect of cements (Variolink Esthetic try-in paste; Ivoclar). Shade measurement was done three times for each crown by a spectrophotometer (VITA Easyshade Advance); averages were compared to a reference crown (A1, HT, 1.5 mm, ND2 abutment, neutral try-in paste) with ΔE_{00} (CIEDE2000, according to the CIE latest standard) calculated.

Results: All the examined parameters influenced the ΔE_{00} of the crowns. The weakest effect was exerted by the try-in paste.

Conclusions: All examined parameters influenced the final color of e.max CAD lithium-disilicate ceramic crowns.

Clinical Significance

Matching the shade of ceramic crowns to the natural tooth color is a great challenge in dentistry. To meet patients' increasing esthetical expectations, CAD/CAM methods are very popular for full-ceramic crowns. However, several factors such as the shade of the abutment, luting cement color, ceramic thickness, and translucency may influence the final color. Our objective was to measure the optical effect of these factors on the final shade of CAD/CAM lithium-disilicate ceramic crowns.

KEYWORDS

CAD/CAM, ceramic, colorimetry, crown, optical phenomena

1 | INTRODUCTION

New CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) technologies are being introduced in the dental marketplace, and most companies investing into restorative dentistry are also on the market to develop materials for digital systems. CAD/CAM systems are

based on three factors: data collection, data processing, and manufacturing. Nowadays, open systems make it possible to use the constituent parts separately.¹

Based on a 2015 AACD (American Academy of Cosmetic Dentistry) survey, 1/3 of dentists currently use a CAD/CAM system in their practice, while another 1/3 are considering to invest into such technology.²

The abundance of new systems facilitates the use of superior dental ceramics besides conventional techniques. This strictly controlled industrial ceramic processing means increased microstructural uniformity, higher density, lower porosity, and decreased residual stress. CAD/CAM systems have the potential to improve clinical predictability. These ceramic materials are perfect for manufacturing all types of all-ceramic restorations, such as inlays, onlays, crowns, and bridges.³ The final goal is a quick, reliable, and predictable esthetic result.

Together with the development of CAD/CAM systems, intraoral scanners are also available on the dental market. With laboratory scanners, it is possible to create a 3D model of the oral cavity without taking an impression and digitizing a model. Technicians can use these intraoral scan based digital models to design the restorations.⁴ Digital impressions offer speed, efficiency, storability of captured information, and an easier way of communication between the dental office and the laboratory through digital images.⁵

Newer generations of all-ceramic systems and adhesive cements allow dentists to use a minimally invasive approach and make thinner restorations (1.0–1.5 mm). It is a great task to preserve as much tooth structure as we can and obtain a superior esthetic result. The goal is to achieve the desired color, especially the VITA Classical A1 shade, which is the most commonly selected shade tab for ceramic restorations.⁶

By allowing greater light transmission, all-ceramic materials improve the translucency of the restoration; however, a perfect natural-like color cannot be ensured.⁷ Lithium disilicate-reinforced glass-ceramic restorations are in the focus of interest due to their low refractive index, which makes the material very translucent despite its high crystalline content. This characteristic makes them suitable for full contour restorations and the highest of esthetic demands.^{8,9} In the 2015 AACD survey, when the question “which restoration material would you use in your own mouth?” was asked, the majority (84%) of responding dentists chose lithium-disilicate (eg, IPS e.max) with zirconia trailing.²

Natural tooth color is defined by the optical properties of enamel and dentin. It is a great challenge in dentistry to match the color of natural teeth with ceramic restorations.

It has been described that the shade of the restorations is highly influenced by the prepared die. If a ceramic restoration is placed on a dark underlying tooth structure, for example, an endodontically treated tooth, the color beneath the crown might result in discoloration and shadowing of the restoration, particularly in the cervical areas.⁹

In addition to the prepared die, luting cements can also be a modifying factor. Composite resin cements are produced in different shades by manufacturers to influence the final appearance of full-ceramic restorations. Their aim is to enhance the final appearance of the crowns or veneers. It has been demonstrated that controlling the thickness of the ceramic might allow clinicians to manage the overall translucency of the restoration, while the choice of cement color has less of an effect.⁹ In another study, using different shaded try-in pastes did not bring the crowns a perceptible color change from their original crown color.¹⁰

The purpose of this study therefore was to evaluate the color difference of different substrate colors, different levels of ceramic thickness and translucency, and different cement shades of lithium-disilicate crowns (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) produced by CAD/CAM technology based on intraoral scans (3shape TRIOS, Copenhagen, Denmark) from a reference color.

2 | MATERIALS AND METHODS

An upper right first premolar tooth #14 on a study model was prepared with a chamfer finishing line for 1.0 and 1.5 mm thick full-ceramic crowns. A silicone index was made of the upper right quadrant to control the depth of the preparation.

Digital impression was taken using a 3Shape TRIOS intraoral scanner (Figure 1). Pre-preparation scan¹¹ was made in intercuspal position of the jaws for occlusion. The digital impression of the original tooth shape was used to design the ceramic crowns.

Crowns were designed for the prepared tooth #14 and for the adjacent teeth #13 and 15 with the DentalDesigner (3Shape, Copenhagen, Denmark) CAD program in the Dental Laboratory of the University. The CAD/CAM method ensured that all crowns were identical in shape and size.

Even thicknesses of 1.0 and 1.5 mm were secured on the buccal sides of the ceramic crowns (Figure 2), taking into consideration a 5-mm diameter of the Easysshade probe (VITA Easysshade Advance 4.0).

The influence of different cement shades on the final color was also investigated. The marginal gap for the cement was set to 0.01 mm; a uniform layer of 0.04 mm gap (3Shape DentalDesigner program original set up) was used on the inner surface (Figure 3).

Test crowns were milled from polymethyl-methacrylate material to check the design.

When satisfied with all settings and parameters, the CAD files were sent to an Everest KaVo CAM unit (KaVo, Biberach, Germany). The crowns were milled from IPS e.max CAD (Ivoclar Vivadent) lithium-disilicate ceramic blocks.

Maxillary right first premolar (14): 10 copies of 1.0 mm and 10 copies of 1.5 mm thick A1 crowns were milled from low-translucency (LT) and high-translucency (HT) blocks.

Adjacent teeth #13 and 15 crowns were also milled to secure the approximal contact points. Figure 4 shows the crowns before crystallization.



FIGURE 1 Scan of prepared dies in the DentalDesigner CAD program

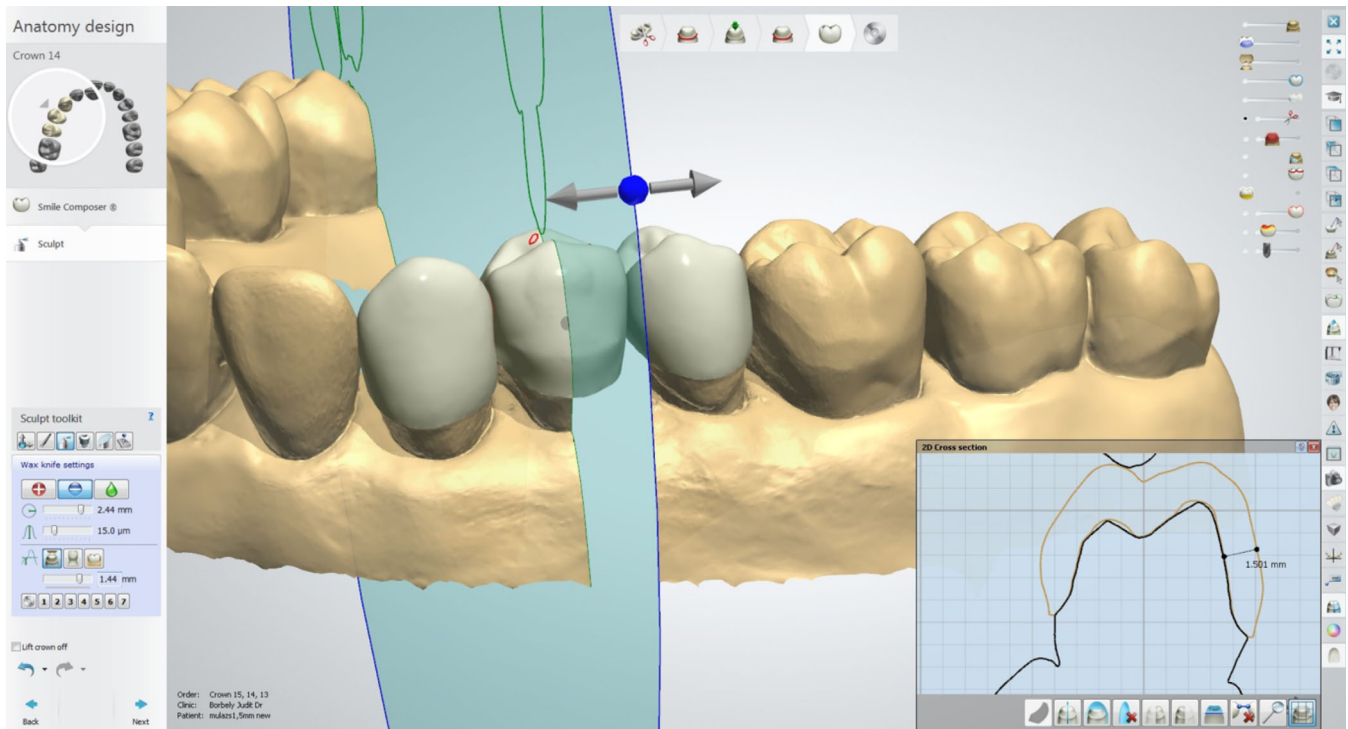


FIGURE 2 The buccal surface designed and controlled for equal thicknesses (1.0 mm and 1.5 mm)

Crystallization firing and glazing of the crowns was done according to the manufacturers' instructions.

IPS Natural Die (Ivoclar Vivadent) composite material of nine different shades was used to create the core part of the substrates fused together with replaceable plastic posts of the study model. CAD/CAM method was used to mill Co-Cr alloy, gold painted alloy, and superwhite zirconia substrate cores. Substrates were made in 12 different colors (Figure 5).

Variolink Esthetic (Ivoclar Vivadent) try-in cement was used for cementation. The advantage of the try-in paste is that it can be easily wiped off crowns. Opaque light plus, yellowish warm, and translucent neutral shades were used.

VITA Easyshade Advance 4.0 device was used for shade measurement. To measure the color, spectrophotometers can be used. The VITA company's first spectrophotometer was the Easyshade in 2004. Dozic et al found that Easyshade was the most reliable instrument of

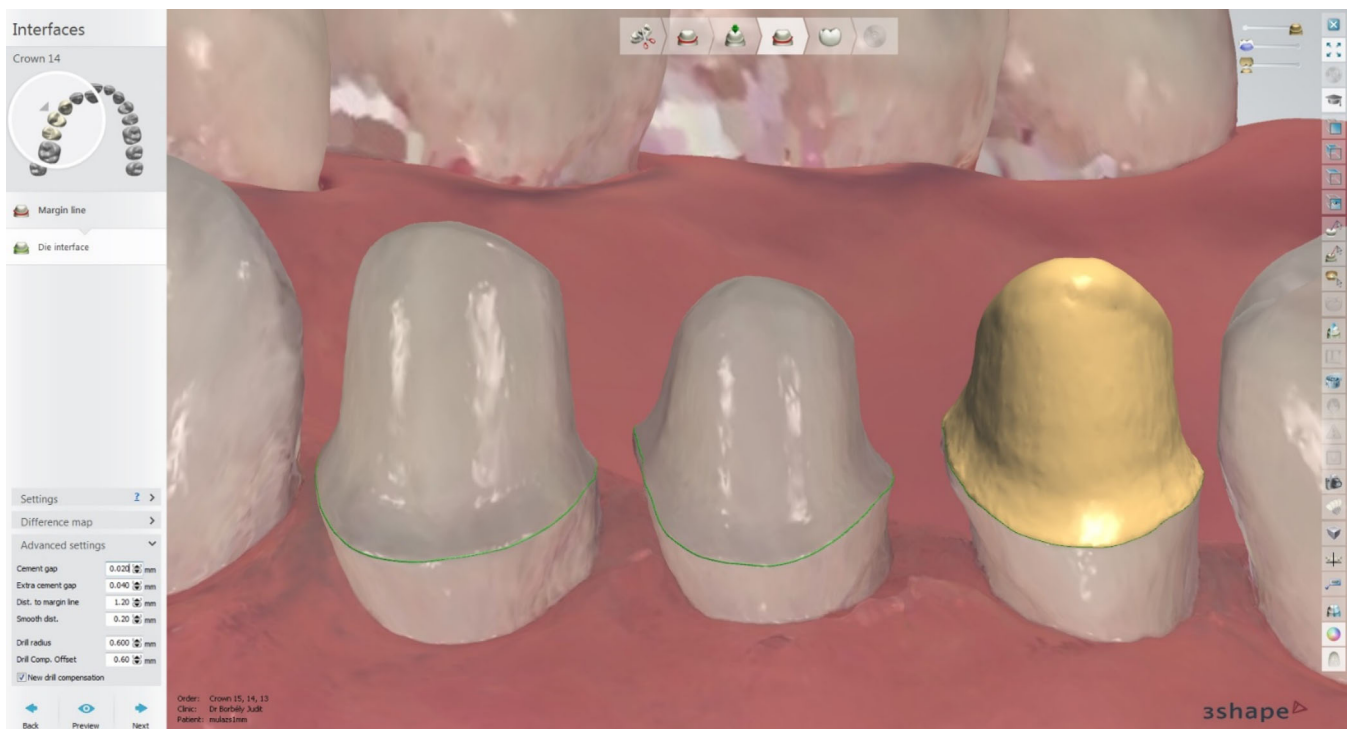


FIGURE 3 The cementation gap (40 μm)



FIGURE 4 IPS e.max CAD crowns before crystallization

shade matching in both in vitro and in vivo circumstances.¹² The position of the Easyshade probe was standardized on the buccal surface of the crowns. Each crown-shade was measured three times. CIELAB values were recorded. Easyshade measurements were performed by two trained dental students. The spectrophotometer was calibrated before each measurement. External light sources such as daylight were not excluded during all measurements and they were taken in a room with artificial lightening conditions. According to the Commission internationale de l'éclairage (CIE) standard Easyshade uses the D65 (6500 K, daylight) illuminant for shade matching.¹² As it is described by CIE in 1931 for determining the color of an object the size of tooth the 2° Observer is needed. The 2° Observer is used in the Easyshade for CIELAB color space.¹³

Easyshade advance 4.0 screen can display the $L a b$ coordinates for the measured shade. We can calculate a modified chroma C' and hue angle h' from L' , a' , and b' coordinates to define the numerical color difference (ΔE_{00}) between two pairs of samples by using CIEDE2000 equation.¹⁴

ΔE_{00} (color difference in the coordinate system according to CIEDE2000) was calculated by comparison to the reference crown: high translucent, A1, 1.5 mm thick crown placed on the ND2 substrate with neutral try-in paste. Many studies have selected shade A1 for their research, as this tooth shade is the most commonly selected for

ceramic restorations.^{6,19,22–25,28,30} For reference abutment we have chosen ND2 shade acting as a non-discolored prepared healthy dentin and neutral try-in paste, that we would not want to affect the final color of the crown by a colored luting cement.

CIEDE 2000 (ΔE_{00}) equation¹⁵ was used to calculate color difference:

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

CIELAB is classically the standard parameter for total color difference between two objects, but to improve the correction between computed and perceived color differences, it is recommended to use the CIEDE2000 color-difference formula (ΔE_{00}). CIEDE2000 (ΔE_{00}) includes specific corrections for nonuniformity of CIELAB space (so-called weighting functions S_L , S_C , and S_H) and the parametric factors for the influence of illuminating and viewing conditions in color-difference evaluation (K_L , K_C , and K_H). The values of K_L , K_C , and K_H in the CIEDE2000 formula were all set to 1.¹⁵ R_T means rotation function, the interaction between chroma and hue differences in the blue region.¹⁶

The CIEDE2000 formula is the latest international standard according to CIE.¹⁵ It provides better adjustments in color-difference evaluation.^{17,18}

For CIEDE 2000 formula, the perceptibility threshold (PT) was set at 0.8 and an acceptability threshold (AT) of $\Delta E_{00} = 1.8$ was set.¹⁹

Measurement procedure steps taken included cement application, crown positioning on the substrate, cement excess removal, spectrophotometer calibration and measurement.

3 | STATISTICAL ANALYSIS

We used the four-way interaction model for statistical analysis. We estimated the goodness of the model's fit by subtracting the ratio of the residual sum of squares and the total sum of squares from one (ie, calculating the coefficient of determination, R^2), and also looked at the proportion of residuals under the perceptibility and ATs. The model's fit was remarkably good at $R^2 = 0.9798$ for ΔE_{00} (with $R^2 = 0.9860$ achievable in a complete four-way interaction structure). Residuals were under the PT/ATs in 91.5%/99.7% of observations. The parameter



FIGURE 5 The 12 different substrates

values of C and h for each observation were calculated from L , a , and b following published formulae. L , a , b , C , and h were then averaged across each measurement triplet. This averaged dataset was then used to calculate ΔE_{00} . A crown identifier was generated to group observations of identical crown thickness and translucency (but varying substrate and cement material). Multilevel mixed-effects linear regression was used to evaluate the effects of technical parameters on color match. The outcome variable was ΔE_{00} based on the CIEDE2000 formula. Fixed-effect explanatory variables included crown translucency, crown thickness, substrate type, and cement type (all categorical), plus interaction terms between: thickness and translucency; thickness and substrate; translucency and substrate; cement and substrate; translucency and thickness and substrate (three-way). Interactions between cement and thickness, and between cement and translucency, were not used because they were observed to be negligible size compared to other interactions. The model included the random effect of crown identifier and allowed heteroskedastic variability across different substrates. Modeling results were expressed as adjusted predictions with 95% confidence intervals (CI) or adjusted effects with 95% CI. The significance criterion was set at $\alpha = 0.05$. The statistical package Stata²⁰ was used for data handling and analysis.

4 | RESULTS

Working with the recent CIEDE 2000 equation (Figure 6) 41 of the 144 measured combinations were within the acceptable range (under AT); however, only 13 of these were below the PT.

The smallest ΔE_{00} values were measured on 1.5 mm thick LT crowns. With Co-Cr and gold alloy substrates, there was no combination under the PT. The greatest color difference compared to the

reference crown could be detected on 1 mm HT crowns on Co-Cr substrates.

Negative range data presented in Figure 7 indicate that the respective ΔE_{00} values (ie, shade discrepancy) were lower for 1.5 mm than for 1.0 mm crowns. It can be concluded that thicker crowns provide better coverage, as expected, unless the material is highly translucent, in which case thickness seems to play a less accentuated role. It is interesting to note that thickness has no effect when applying HT crowns with zirconium dioxide substrates. However, in case of LT crowns, inferior results were obtained with the thicker formulation.

As it is represented in Figure 8, crowns with greater translucency have higher ΔE_{00} values resulting in a lower quality shade match. Nonetheless, the results of HT crowns on yellowish substrates show decreasing ΔE —despite the decreasing lightness of the shade (ND1-ND6)—though ΔE_{00} increase was expected since HT crowns are more translucent. This phenomenon demonstrates the complexity of the optical properties of these materials.

In Figure 9, the Values in the negative range indicate better results having been achieved with a type of cement different from the neutral. ΔE_{00} differences greater in absolute value than 1 can be considered clinically significant; such effects are exclusive to the ND9 and Co-Cr substrates when applying light plus cement, and to the zirconia substrates when applying warm cement.

5 | DISCUSSION

Results of the present study showed that the color difference (ΔE_{00}) of a CAD/CAM glass-ceramic lithium-disilicate full-ceramic crown is influenced by ceramic thickness and translucency, substrate color, and cement color. Data of this investigation are in agreement with previous studies in the literature.^{9,10,21–31}

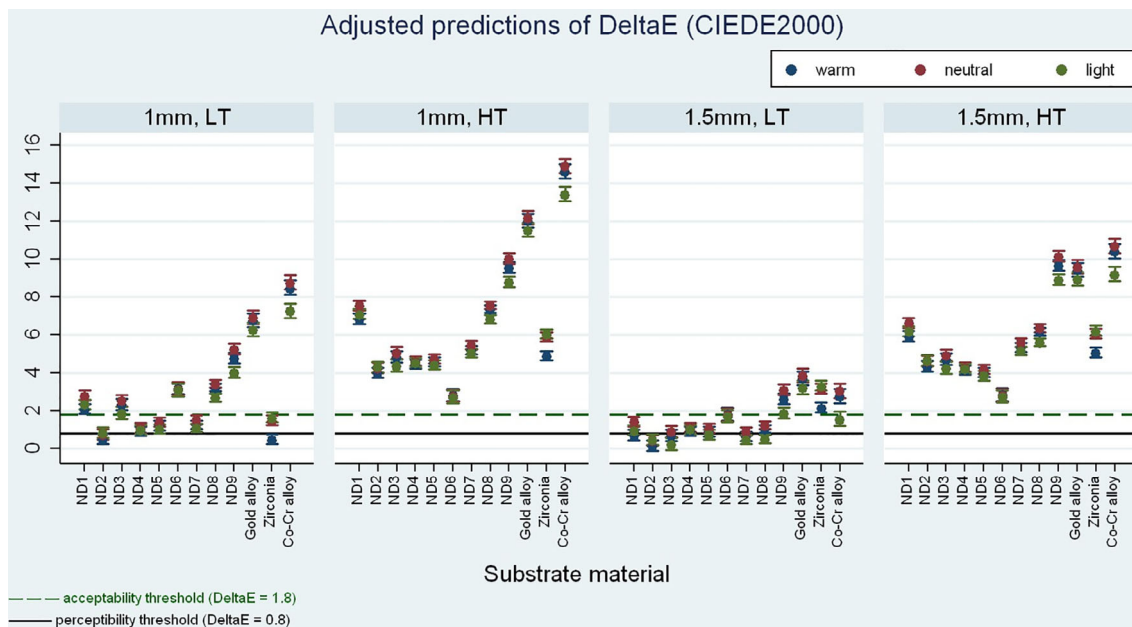


FIGURE 6 Model predictions as a function of restoration technical parameters (ΔE_{00} based on CIEDE2000 formula). The y-axis represents ΔE shade of substrate. Markers indicate point estimate and 95% confidence interval. The green and black lines are the acceptability threshold and the perceptibility threshold, respectively. The reference crown (A1 crown/low translucency/1.5 mm thick/neutral cement/ND2 substrate) is also represented here

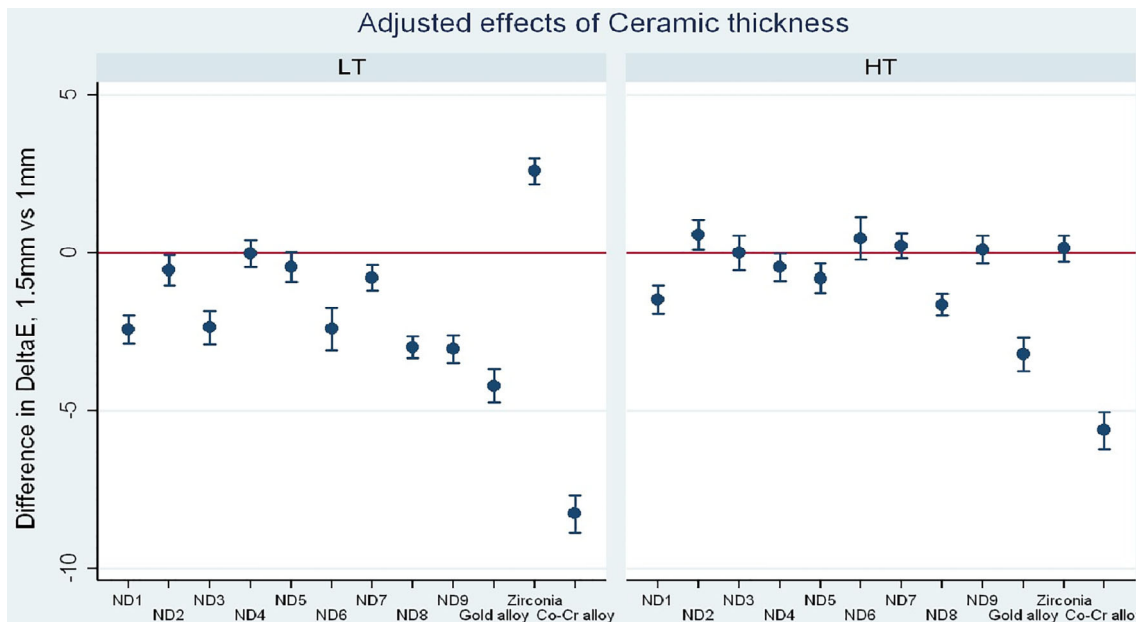


FIGURE 7 Comparison of 1.0 and 1.5 mm ceramic thickness. The x-axis represents substrate shades while y represents ΔE_{00} differences of 1.5 mm crowns in relation to their 1.0 mm counterparts. The red reference line represents mean values for 1.0 mm crowns

If a ΔE_{00} value less than 0.8 (with the recent CIEDE2000 formula) is regarded a clinically imperceptible color change, only 13 of the measured combinations of LT crowns were below this visibility threshold. None of the HT crowns was in this range. The reason might be the material's optical properties: LT blocks have more lithium-disilicate crystals than HT blocks. Crystals reduce the internal scattering of light as it passes through the material. That means when the substrate has a dark color or the underlying tooth is highly discolored, the application of a CAD/CAM glass-ceramic lithium disilicate with a HT ceramic block may result in limited success.^{9,24,28,29}

However, translucent ceramics have been more frequently used to fabricate anterior restorations than opaque ones, for example, medium-opacity and low-opacity (LO) blocks. Pires et al compared HO (high-opacity) and LO ceramics and found ΔE_{00} values of ceramic HO to be lower than those of ceramic LT. Clinicians should consider increasing the thickness and opacity of the ceramic to mask the underlying color.³⁰ In many studies, increasing ceramic thickness is accompanied by better color results.^{9,21,22,28} We found that ceramic thickness has less of an effect if the material is highly translucent (HT crowns, Figure 7).

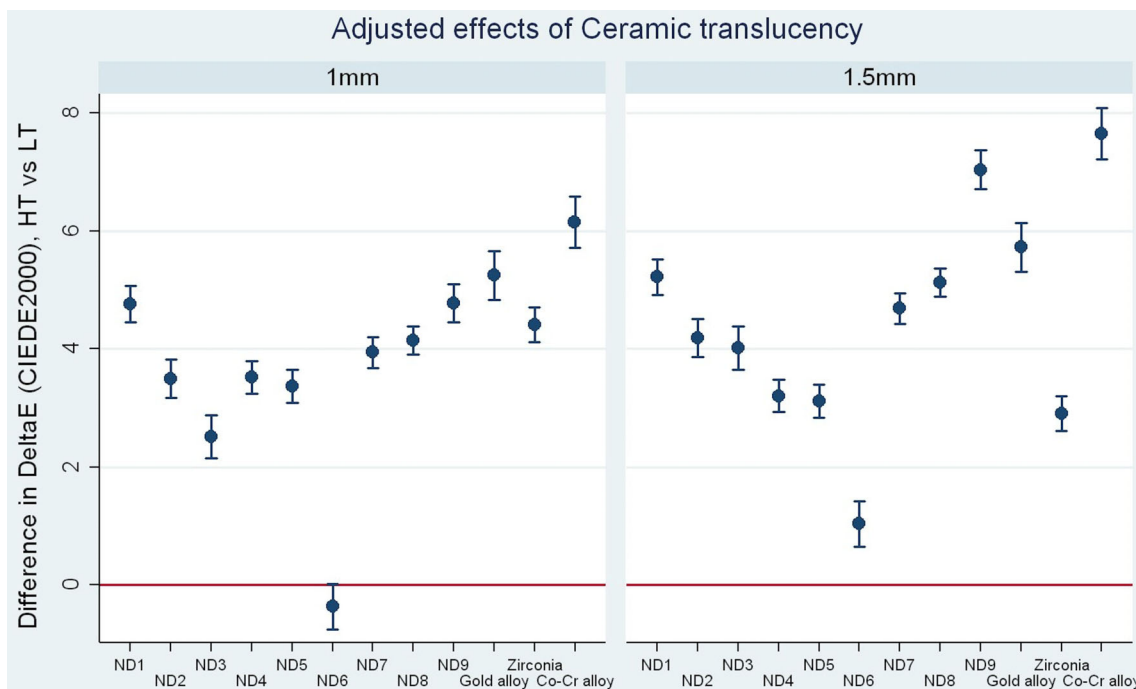


FIGURE 8 Low-translucency (LT) crowns' ceramic translucency compared to high-translucency (HT) crowns. The red line demonstrates the values of the LT crowns

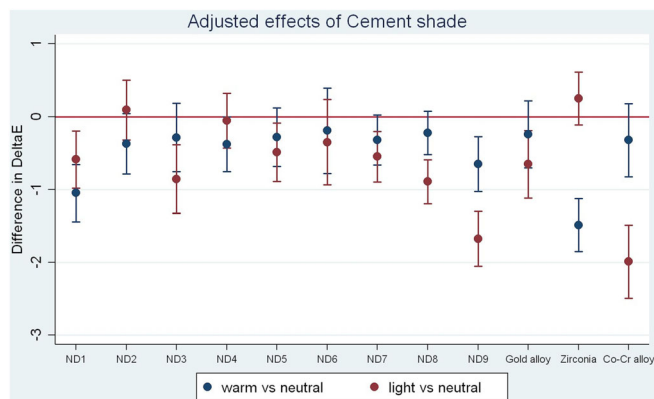


FIGURE 9 Cement shade effect compared to the reference neutral shade. The x-axis represents substrate shades while the y-axis represents the estimated ΔE_{00} of test cements in comparison to the neutral cement, with the red line (zero) representing mean ΔE_{00} values obtained with neutral cements

Besides translucency, crown chromacity also plays an important role in final color. A limitation of our study therefore is that we measured A1 shaded crowns only. Al Ben Ali et al confirmed that increasing chromacity (high-opacity ceramics) can reduce the color effect of the underlying tooth structure.²²

Previous studies agreed that the underlying substructure affects the final color of the restoration.^{9,10,21–23,28} Chaiyabutr et al found that dark-colored abutment teeth had the greatest ΔE values compared to other configurations.⁹ Changing the underlying color from a lighter to a darker background resulted in increased color differences.^{9,22} Ge et al found that using gold shaded posts and cores did not influence the color of 1.5 mm thick full-ceramic crowns (Empress 2), with all measurements being under the patients' average perception level ($\Delta E = 1.8$). The greatest color change was caused by the Ni-Cr post core.¹⁰ The present study found that there was no combination under the AT ($\Delta E_{00} = 1.8$) with gold alloy substrates, and only one measured combination was below the AT ($\Delta E_{00} = 1.8$) with Co-Cr substrates (1.5 mm LT crown, light plus try-in paste). As we expected, the lowest ΔE values were found with LT 1.5 mm thick crowns (Figure 6).

Only a few studies can be found about the color modifying effect of luting cements, but they agree that the choice of cement color has less of an effect on the final color of restorations.^{9,23,28}

According to Niu, the final shade of a 1.5-mm thick lithium-disilicate crown is affected not only by the cement's shade but also by its layer thickness (300, 100, 50 μm). In this study, white opaque cements (Multilink white opaque; Nexus3 white opaque) demonstrated better masking ability than cements of other colors.³¹ When we used opaque cement (Variolink Esthetic light plus), it significantly influenced the crown-shade on ND9 and Co-Cr substrates (Figure 9).

Another parameter of interest is luting cement layer thickness. Increasing white opaque cement layer thickness from 100 to 300 μm did not affect the shade of lithium-disilicate restorations.³¹ Neither any measured ceramic layer thickness (1.0, 1.5, 2.0, 2.5 mm), nor increased cement thickness (300 vs 100 μm) had significant modifying effects.⁹

It should be plausible that the layer thickness we used (40 μm) results in no more than a minuscule color change. However,

increasing the amount of luting cement causes a loss of bond strength between the crown and the die, and increases the possibility of ceramic fractures.

6 | CONCLUSION

Within the limitations of this study, all examined parameters play an important role in changing the color of a monolithic CAD/CAM full-ceramic crown compared to the reference crown. In case of HT crowns, the crown wall thickness has limited influence. Data show that the optical properties of these ceramic materials are highly complex, but of the two examined e.max CAD block translucency levels (LT and HT), LT crowns produced better color outcomes. Cement color has less of an effect, but in some cases (ND9, Co-Cr substrates) opaque cement shades can help mask the underlying darker substrate color.

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