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# Color Variation Between Matched and Fabricated Shades of Different Ceramics

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## Abstract

**Purpose:** The aim of this study was to evaluate and compare the total color difference (ΔE) between natural teeth and fabricated crowns from three ceramic systems with different thicknesses.
**Materials and Methods:** The color of ninety maxillary central incisors was measured from the middle third of the labial surface with a Vita Easyshade spectrophotometer. All-ceramic crown preparations with different thicknesses (0.8, 1.2, 1.5 mm) were done on selected teeth (n = 30). Prepared teeth were randomly divided into three equal groups to fabricate ceramic crowns from three ceramic systems, Duceram LFC (DLFC), In-Ceram SPINELL (ICS), and IPS Empress (IPSE). Colors of cemented crowns were measured and compared with their corresponding measurements before preparations. Data were statistically analyzed using two-way ANOVA at 5% significance level.
**Results:** A significant difference of ΔE was detected between natural teeth and different thicknesses of crowns constructed from the all-ceramic materials investigated. Comparing the three materials at 0.8 mm thickness revealed that the lowest ΔE was recorded for DLFC, which was significantly different from the other ceramic systems while IPSE showed the highest ΔE. At higher thicknesses there was no difference between natural tooth shade and crowns constructed from different ceramic materials.
**Conclusions:** Reinforcement of ceramics by alumina for In-Ceram and leucite for Empress decreases color production. Level of acceptance between the different ceramic materials and thicknesses varied. DLFC showed the highest color matching at all thicknesses followed by ICS and IPSE in descending order. In general, increasing the thickness of fabricated crowns enhances color match.

Correctly recording color dimensions is complex and represents a challenge for achieving esthetically acceptable restorations. The degree of opalescence, translucency, fluorescence, surface texture and shape properties, ceramic brand, and batches are some of the confounding aspects for this procedure.[1-3]

Color measurements can be classified and specified in several ways. The most common systems for describing color are the Munsell system and the International Commission on Illumination (CIE) $L^*a^*b^*$ color system.[4] In the latter system, $L^*$ represents the darkness-lightness coordinate (or value), $a^*$ represents the chromaticity between green (negative $a^*$) and red (positive $a^*$), and $b^*$ represents the chromaticity between blue (negative $b^*$) and yellow (positive $b^*$). The CIE $L^*a^*b^*$ color system is commonly used in perceptual studies for dental color assessment because of its approximate visually uniform coverage of the color space. In this color space, color difference between two objects ($L^*_1, a^*_1, b^*_1$ and $L^*_2, a^*_2, b^*_2$) can be calculated using the following CIE 1976 $L^*a^*b^*$ color difference formula:[5]

$$\Delta E = \left[(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2\right]^{1/2}.$$

Among the color difference values expressed as ΔE, values greater than 1 unit are visually detectable by 50% of human observers in controlled conditions.[6] Color differences between 2.0 and 3.7 are visually detectable under clinical conditions.[7]

Studies assessing color observation by humans repeatedly showed differences in recording the color of samples.[8-10] A multitude of factors were found to underline this inconsistency. Possible color vision deficiency[11] and variations in the degree of dental experience and professionalism[12,13] are among the factors affecting the results of color inspection. In a paper entitled "Evaluating factors that affect the shade-matching ability of dentists, dental staff members and laypeople," Çapa et al[14] found that dental technicians were able to match colors significantly better than restorative dentists, prosthodontists, and endodontists. There was no significant difference among specialists. Nevertheless, conventional shade-matching techniques using different shade guides for comparisons do not render sufficient reliability or reproducibility.[15]

On the other hand, electronic devices allow quantitative, objective assessment of dental shades. The theoretical benefits of using the spectrophotometer are that the measurements are not subject to human biases, subjectiveness, vision deficiencies, or an unsteady light source.[16-20] It also allows easier communication between individuals.[17] However, the final color matching may be affected by the combination of ceramic color and thickness, together with the luting agent and the color of the underlying dental structure.[21-26] Again, the optical behavior of ceramic materials differs from system to system.[27] Knowledge of the optical properties of different thicknesses of available ceramic systems enables the clinician to make appropriate choices when faced with various esthetic challenges.[28,29]

The aim of this study was to evaluate and compare the total color difference (ΔE) between natural teeth and fabricated crowns from three ceramic systems with different thicknesses. The null hypotheses investigated were that there would be no difference in ΔE between natural teeth and crowns fabricated from different ceramic systems used or between different ceramic thicknesses of each system or combination of both.

## Materials and methods

### Selection of teeth

Ninety natural caries-free anterior teeth of the same size in regard to crown length and buccolingual and mesiodistal width were selected. Calculus was removed from the teeth, which were then polished and stored in distilled water. The tooth shades were selected using the digital Vita Easyshade system (Ivoclar Vivadent AG, Schaan, Liechtenstein) with its probe tip perpendicular and flush to the tooth surface. Easyshade shows the shade on the screen within 2 seconds. The teeth were thermostatically stored in normal saline solution in at 37°C.

### Tooth preparation for ceramic restorations

Standardized all-ceramic preparations with shoulder finish lines were made. Prepared teeth were randomly allocated to the type of ceramic crown (n = 30) (Table 1) as follows:

Group 1: Fabrication of crowns using Duceram LFC ceramic materials (DLFC).
Group 2: Fabrication of crowns using Vita In-Ceram SPINELL (ICS).
Group 3: Fabrication of crowns using IPS Empress (IPSE).

Within each group of ceramic crowns, teeth were randomly allocated to preparation thickness groups (n = 10). Three thicknesses of labial reduction were made (0.8, 1.2, 1.5 mm). The prepared teeth were smoothed with wet 600-grit silicone carbide paper for 1 minute according to Van Meerbeek et al.[30]

Impressions of prepared teeth were taken with poly(vinyl siloxane) impression material (Vitual, Ivoclar Vivadent) using plastic cylinders. Adhesive was painted on the inner surface of the plastic cylinders. Impressions were poured using improved stone, and individual dies were fabricated.

**Table 1** Ceramic systems used

| Ceramic materials | Manufacturer | Abbreviation |
|---|---|---|
| Duceram LFC | Dentsply, Woodbridge, Canada | DLFC |
| Vita In-Ceram SPINELL | Vita Zahnfabrik, Bad Sackingen, Germany | ICS |
| IPS Empress Esthetic | Ivoclar Vivadent, Schaan, Liechtenstein | IPSE |

### Fabrication of ceramic crowns

Ceramic crowns of each group were fabricated with different ceramic thicknesses. The average thicknesses were $0.8 \pm 0.1$, $1.2 \pm 0.1$, and $1.5 \pm 0.1$ mm.

For group 1: DLFC crowns were fabricated. Stone dies were duplicated to obtain refractory dies. DLFC powder was mixed with its special liquid, and the porcelain mix was built up on the refractory dies with the help of a counter die, and fired according to manufacturer's instructions. Each crown was adjusted on its master die and glazed.

Group 2: Fabrication of ICS crowns. Stone dies were duplicated using the special plaster. Vita ICS powder was mixed and applied to the plaster model (refractory die) to form the slip. The slip was removed, followed by firing and glass infiltration according to the manufacturer's instructions. The accuracy of fit was checked on the master die.

Group 3: Fabrication of IPSE crowns. A standardized thickness of wax patterns were fabricated, sprued, and invested in an investment cylinder. The investment cylinder was heated. The ceramic material was pressed according to the manufacturer's instructions. The ceramic crown was adjusted on the master die to verify its fitness and glazed.

### Cementation of ceramic crowns

A translucent shade of dual-cure resin cement (3M ESPE, St Paul, MN) was used to cement the crown on each corresponding tooth. The color of the cemented crowns was measured using a Vita Easyshade spectrophotometer. During color measurement, the Vita Easyshade probe touched the middle third of the labial surface of the crown perpendicular to it. The screen showed the total color difference between the shade of the manufactured crown and the previously selected shade.

### Statistical analysis

The collected data were tabulated and statistically analyzed using two-way ANOVA with two between-subject factors (type of ceramic crown, thickness). The interaction term was included in the model. Level of significance was set at 0.05. Tukey's post hoc test was performed within each thickness to compare ceramic systems and within each ceramic system to compare thicknesses. Statistical software (SPSS, v.16, SPSS Inc., Chicago, IL) was used for data analysis.

## Results

Table 2 shows means and standard deviations of ΔE between the desired shade and ceramic crowns constructed with different thicknesses from the three ceramic materials investigated, while Figure 1 represents the mean comparison. Two-way ANOVA (Table 3) showed a significant difference of ΔE between the desired shade and ceramic crowns constructed from all ceramic systems with all different thicknesses. DLFC crowns showed the lowest ΔE at all thicknesses, while IPSE esthetic crowns showed the highest color difference at 0.8 mm thickness (7.42 ± 0.17). Regarding different thicknesses, statistical analysis found a significant difference of ΔE between natural teeth and crowns constructed from different ceramic materials at 0.8 mm thickness, while no difference was found between ΔE of crowns constructed from all-ceramic materials at 1.5 mm thickness or between ICS and IPSE at 1.2 mm thickness (Table 4). Comparing the three ceramic materials, there was significant difference of ΔE between natural teeth and crowns constructed from different materials at all ceramic thicknesses investigated (Table 5).

**Table 2** Mean ± standard deviation of ΔE at different ceramic thicknesses for the materials investigated

| Ceramic materials | 0.8 mm | 1.2 mm | 1.5 mm |
|---|---|---|---|
| DLFC | 4.51 ± 0.07 | 3.97 ± 0.21 | 3.41 ± 0.20 |
| ICS | 6.52 ± 0.15 | 5.64 ± 0.16 | 3.71 ± 0.28 |
| IPSE | 7.42 ± 0.17 | 5.52 ± 0.39 | 3.65 ± 0.24 |

**Table 3** *p*-values of two-way ANOVA for ΔE on the effect of ceramic materials, thickness, and their interaction

| Source | Sum of squares | df | Mean square | *F*-value | *p*-value |
|---|---|---|---|---|---|
| Model | 161.095 | 8 | 20.137 | 393.321 | <0.001 |
| Ceramic materials | 42.682 | 2 | 21.341 | 416.844 | <0.001 |
| Thickness | 98.851 | 2 | 49.426 | 965.401 | <0.001 |
| Material × thickness | 19.561 | 4 | 4.890 | 95.519 | <0.001 |
| Error | 4.147 | 81 | 0.051 | | |
| Total | 2350.908 | 90 | | | |
| Corrected total | 165.242 | 89 | | | |

**Table 4** *p*-values of Tukey's post hoc test comparing significant difference of ΔE between the ceramic systems investigated for each thickness

| Thickness (mm) | Material | DLFC | ICS |
|---|---|---|---|
| 0.8 | ICS | <0.001* | |
| | IPSE | <0.001* | <0.001* |
| 1.2 | ICS | <0.001* | |
| | IPSE | <0.001* | 0.595 |
| 1.5 | ICS | 0.049* | |
| | IPSE | 0.094 | 0.848 |

*$p < 0.05$ (significant).

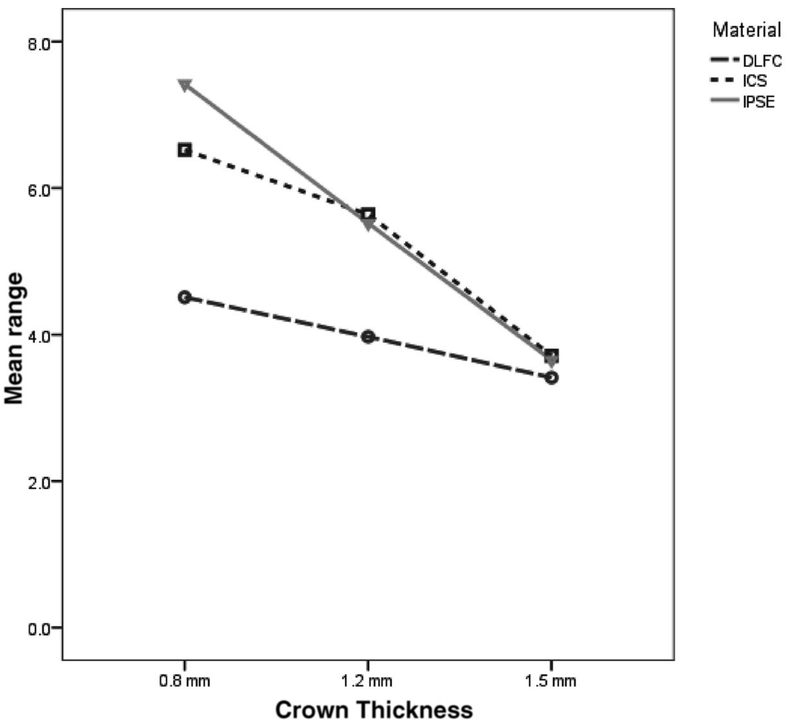


**Figure 1** Comparison between mean color differences (ΔE) of different thicknesses of crowns constructed from ceramic systems investigated in this study.

**Table 5** *p*-values of Tukey's post hoc test comparing significant difference of ΔE between different thicknesses for each ceramic system

| Material | Thickness | 0.8 mm | 1.2 mm |
|---|---|---|---|
| DLFC | 1.2 mm | <0.001* | |
| | 1.5 mm | <0.001* | <0.001* |
| ICS | 1.2 mm | <0.001* | |
| | 1.5 mm | <0.001* | <0.001* |
| IPSE | 1.2 mm | <0.001* | |
| | 1.5 mm | <0.001* | <0.001* |

*$p < 0.05$ (significant).

## Discussion

In this study, three ceramic systems were compared for ΔE using a Vita Easyshade spectrophotometer. The machine consists of a control unit with a 2.0 in × 4.0 in florescent touch screen, a 6-ft fiber optic cord, and a handpiece with a 5-mm wide probe tip. It has been the most reliable instrument in both in vitro and in vivo circumstances.[31-33]

Spectrophotometers differ from colorimeters in that in the former, color estimation is made by measuring the intensity of the reflected light in all visible wavelengths, while colorimeters measure the intensity of the reflected light filtered by red, green, and blue filters.[34] These differences in the manner that intraoral shade-matching instruments interpret the reflected light may have a direct effect on the measuring functions of the devices, which indirectly affect their matching functions. The matching function is based on the extrapolation of color measurement values into more meaningful values for a clinician, such as the shade tabs of a guide system.[35] In this respect, electronic matching outweighs visual matching by removal of human variables as a source of variation in reliability.[8-14]

Cementation procedure was standardized by using a translucent shade of dual-cure resin cement because of its previously observed influence on the final color of the restoration.[36] The baseline color for comparison was that of an extracted human tooth, so that each tooth represented its own color control.

The lowest ΔE was found with DLFC, followed by ICS, with IPSE last. This means that DLFC showed the highest color matching. IPSE showed the highest ΔE at 0.8 mm thickness crowns as compared to all other specimens investigated. This result was not in accordance with that of Fazi et al.[36] Using an Easyshade spectrophotometer, they found no significant difference between Duceram Kiss, VITA Omega, Wieland Reflex, and Ivoclar IPS d.SIGN ceramic systems. This might be because of differences in ceramic thickness. In this respect, using a colorimeter, Przybylska[37] found that at thicknesses of ≤2.0 mm of dentin porcelain, the all-ceramic systems exhibited more shade matches than the metal ceramic systems.

The average color differences for DLFC were 4.51, 3.97, and 3.41 ΔE units for 0.8, 1.2, and 1.5 mm thickness, respectively. These values remain below the 50% acceptable level of 5.5 ΔE units,[38] but exceed the 50% perception threshold for a clinical mismatch (2.6 ΔE units). Nonetheless, Duceram LFC is relatively new porcelain referred to as a "hydrothermal low-fusing ceramic" (LFC). It is composed of an amorphous glass containing hydroxyl ions. It is fabricated by powder condensation. It was reported that ceramics fabricated by this technique have a great amount of translucency and are highly esthetic,[26] and are used mainly as veneering layers.[39]

In-Ceram SPINELL was introduced in 1994 to overcome the opacity of In-Ceram Alumina. Its framework contains a mixture of magnesia and alumina ($MgAl_2O_4$) to improve material translucency.[40,41]

On the other hand, IPS Empress is a leucite-reinforced glass ceramic ($SiO_2$-$Al_2O_3$) considered a monochromatic restoration.[42] It can be surface characterized to the desired shade. The material is claimed to produce esthetics comparable to layering techniques.[43] This might confirm that reinforcement of ceramic by alumina in the case of In-Ceram, and leucite in the case of Empress, decreases color production.

The porcelain thicknesses used in this study (0.8, 1.2, 1.5 mm) were selected because they represent the most commonly used thicknesses. Exceptions can occur in cases of discolored, endodontically treated teeth. These may require a slightly deeper chamfer to hide discoloration with the prosthetic structure and intra-sulcular margins to reduce the visibility of dark cervical tooth structure.[44]

There was a significant difference of ΔE between natural teeth and crowns fabricated with different thicknesses of all the ceramic systems investigated. Our result was in accordance with those of other studies.[25,45,46] In this respect, Christensen et al[47] and Chu et al[48] commented that although deeper preparation for ceramic veneers presents some disadvantages related to the adhesion of the veneer to the underlying dental structure and more sound tissue removal jeopardizing pulpal health, it also promotes enhanced masking of the darkened tooth. Accordingly, the null hypothesis tested in the present study was rejected.

## Conclusion

Within the limitations of this study the following conclusions can be drawn:

1. There was a significant difference of ΔE between natural teeth and crowns fabricated from DLFC, ICS, and IPSE ceramic materials. Also there was a significant difference of ΔE between natural teeth and 0.8, 1.2, and 1.5 mm ceramic thicknesses or combinations of both.
2. Duceram LFC showed the highest color matching followed by In-Ceram SPINELL, while IPS Empress showed the least color match.
3. Reinforcement of ceramic by alumina in the case of In-Ceram and leucite in the case of Empress decreases the color production.
4. At the highest 1.5 mm crown thickness, there was no significant difference between natural teeth and crowns constructed from different ceramic materials.

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