

The Effect of Core and Veneering Design on the Optical Properties of Polyether Ether Ketone

Keywords

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ABSTRACT

This study aimed to evaluate the effect of core shade and core and veneering thickness on color parameters and translucency of polyether ether ketone (PEEK). Sixty PEEK discs (0.5 and 1 mm in thickness) with white and dentine shades were veneered with A2 shade indirect composite resin with 0.5, 1 and 1.5 mm thickness (n=5). Cores without the veneering material served as controls for translucency evaluation. Color parameters were measured by a spectroradiometer. Color difference (ΔE_{00}) and translucency parameters (TP) were computed. Data were analyzed using one-way ANOVA and Tukey's test (for veneering thickness) and independent t-test (for core shade and thickness) via SPSS 20.0 ($p < 0.05$). Regarding the veneering thickness, white cores of 0.5 mm thickness showed significant differences in all color parameters. In white cores of 1 mm thickness and dentine cores of 0.5 and 1 mm thickness, there were statistically significant differences only in L^ , a^* and h^* . The mean TP was significantly higher in all white cores of 1 mm thickness than dentine cores of 1 mm. Considering $\Delta E_{00} = 3.7$ as clinically unacceptable, only three groups had higher mean ΔE_{00} values. Core shade, core thickness, and the veneering thickness affected the color and translucency of PEEK restorations.*

INTRODUCTION

Cosmetics plays an important role in success of restorations.¹ Therefore, restorations should be able to mimic the color and translucency of the adjacent natural teeth while possessing favorable physical and chemical properties.² Polyether ether ketone (PEEK) is a new generation of composites in dentistry which may serve as a suitable alternative substrate in prosthodontics. It is a high-performance semi-crystalline thermoplastic polymer with linear aromatic structure.^{3,4} The main applications of PEEK in dentistry include dental implants, implant abutments, fixed dental prostheses, and removable dentures and components.^{5,6} PEEK has some advantages including the potential for improved biocompatibility, being devoid of metal, tooth-colored appearance, shaping ability with dental burs, and optimal physical properties.^{3,4} However, the grayish color and low translucency are among its main drawbacks. Therefore, it requires a veneering particularly in the esthetic zone.⁷

Adequate knowledge about all aspects of color of restorative materials and tooth is imperative for dental clinicians.⁸ The Munsell and the International Commission on Illumination (CIE) $L^*a^*b^*$ color coordinate systems are the most commonly used systems for color description.⁹ The CIELAB

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values are related to subjective observations, since they describe the color quantitatively in a three-dimensional and uniform color space.¹⁰⁻¹² The L* parameter represents lightness. The a* and b* parameters represent greenness-redness and blueness-yellowness, respectively.¹² The CIELCh is another color space using polar coordinates while CIELAB uses Cartesian coordinates. The L* value in this system is the same as that in CIELAB. The C*^{ab} is an open ended scale, which represents chroma. The h*^{ab} represents hue angle ranging from 0 to 360° and the arrangement of colors is similar to a rainbow. The 0° represents red, then continuing to 90, 180, and 270° indicating yellow, green and blue, respectively.¹³ Perception of color difference by the human eye can be described using a color difference equation value (ΔE)¹⁴ and it is highly useful for dental shade matching.¹⁵ However, it is difficult to determine the clinically perceptible threshold. Nevertheless, several thresholds have been described for easier evaluation. ΔE values of 0 to 1 units indicate a normally invisible difference, and values between 1 to 2.5 units indicate a very small difference which is only obvious to a trained eye and described as good color match.¹⁶ Johnston and Kao¹⁷ suggested $\Delta E=3.7$ for perception threshold of color mismatch in the oral cavity.

Translucency is another essential property for natural appearance of teeth and restorative materials.¹⁷ It plays an important role in achieving a perfect color match with natural teeth.¹⁸ The translucency parameter (TP) and contrast ratio are used to measure the translucency of dental restorative materials. TP is the color difference between uniform thickness of materials against a black and a white background. It is directly correlated to common visual evaluation of translucency.¹⁹ Paravina *et al.*²⁰ who evaluated translucency of bleaching-shade composites, offered a classification based on TP: 2.0 to 3.7 as low translucency, 3.8 to 5.4 as medium translucency, and 5.5 to 7.1 as high translucency.

There are different devices to measure the translucency and color of dental materials including spectrophotometers, spectroradiometers and colorimeters. One of the most important advantages of spectrophotometers over spectroradiometers is that color measurements by spectrophotometers are closer to the human visual perception.²¹

Several studies assessed the effect of factors such as core shade, core material, and core and veneering thickness on the final shade or translucency of metal-ceramic and all-ceramic restorations.^{11,14,15,22-25} Sinmazisik *et al.*¹⁵ evaluated the effect of core and dentine porcelain thickness on zirconia restorations. They found that color parameters are significantly influenced by core and dentine porcelain thickness. Ozturk *et al.*¹⁴ in their study on lithium disilicate glass-ceramic and zirconium-oxide demonstrated that dentine ceramic thickness is an important factor in achieving the desired color. Jacobs *et al.*²⁶ stated that color of metal ceramic restorations is affected by alloy type and porcelain thickness. To the best of authors' knowledge, there is only one study regarding the optical properties of

bi-layered PEEK restorations. Stawarczyk *et al.* evaluated the effect of core and veneering material and the veneering thickness on color and demonstrated that colorimetric properties of PEEK cores are comparable to those of ZrO₂ and CoCrMo.²⁷ However, they did not provide any information about the effect of core thickness and translucency of such materials; instead, they focused on the type of materials. The manufacturers state that PEEK can be used even in limited restorative space without any concern about strength. Nevertheless, obtaining acceptable shade match in such situations and selecting the best combination of core and the veneering thickness need further investigations. The aim of present study was to evaluate the effect of core shade and core and veneering thickness on color parameters and translucency of PEEK restorations. The null hypothesis was that the translucency and final shade of PEEK restorations would not be affected by core shade, core thickness or the veneering thickness.

MATERIALS AND METHODS

CORE PREPARATION

In this experimental study, a total of 60 discs 10 mm in diameter with 0.5±0.05 mm and 1±0.05 mm thickness were fabricated to serve as core material (*Figures 1a and 1b*). The discs were milled out of PEEK blanks in open CAD/CAM system (breCAM BioHPP) with different shades (white and dentine) (n=15) using a milling machine (Arum). Each group of core specimens was divided into three subgroups based on the veneering thickness (0.5, 1, and 1.5 mm). Totally, there were 12 groups (n=5) that were coded based on core shade (D: dentine and W: white) and two numbers. The first number represented the core thickness and the second number indicated the veneering thickness (0.5W0.5, 0.5W1, 0.5W1.5, 1W0.5, 1W1, 1W1.5, 0.5D0.5, 0.5D1, 0.5D1.5, 1D0.5, 1D1 and 1D1.5).

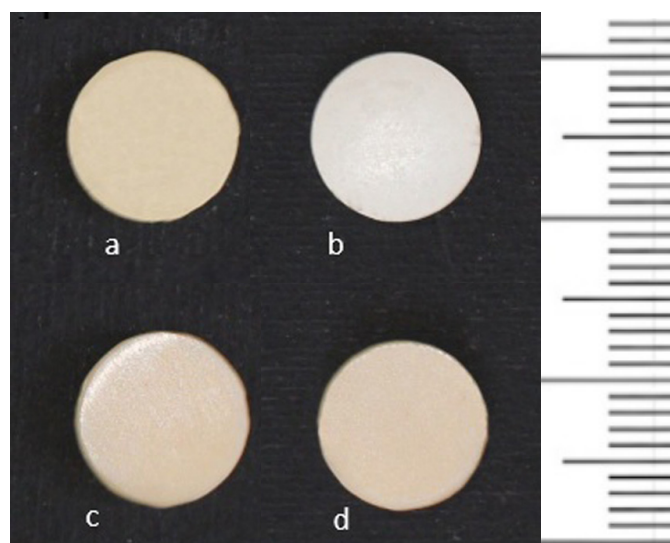


Figure 1: a) Dentine PEEK with 1 mm thickness before veneering, b) White PEEK with 1mm thickness before veneering, c) Dentine PEEK + veneering (1D1.5), d) White PEEK + veneering (1W1.5).

VENEERING OF SPECIMENS

Free-hand veneering was performed for each group based on the manufacturer's instructions to achieve A2 shade (Vita Classical Shade Guide). The core specimens were sandblasted according to the manufacturer's instructions by 110 μm Al₂O₃ particles (angle of approximately 45°, distance of 3 cm, and 2.5 bar pressure). A thin layer of bonding agent (Visio.link) was applied and cured (Labolight LV-III) for 90 seconds. One uniform layer of Crea.lign opaquer (indirect composite based opaque) was added and cured for 180 seconds. The required amount of opaque material was applied on the entire surface of specimens using a single stroke of brush to reach a uniform thickness. Next, A2 shade Crea.lign dentine paste (Micro-filled indirect resin composite) was applied and the curing was performed for 5 minutes. In order to control the veneering thickness, four custom mold with the height of 1, 1.5, 2 and 2.5 mm and the internal width of 10 mm were constructed by auto-polymerizing acrylic resin. The veneering thickness of each sample was specified using one of the molds and a glass slab pressed on top of the mold before polymerization. Since surface texture could also affect the results, in order to control for the surface texture and achieve the desired thickness, all specimens were manually polished with 600, 800, 1000 and 1200-grit silicon carbide papers for 10 seconds (Figures 1c and 1d). Due to the importance of thickness, final thickness of specimens was controlled by a digital caliper with an accuracy of 0.01 mm. All specimens were fabricated by an expert technician.

MEASURING THE CIE L*A*B* COLOR PARAMETERS

All specimens were cleaned in an ultrasonic bath for 180 seconds and dried prior to measuring the color parameters. Steam cleaning was not performed according to the manufacturer's recommendations. The core specimens were marked at their periphery to allow their reproducible positioning for measurements. The spectral reflectance values were measured by a spectroradiometer (CS-2000). The color parameters in CIELAB and CIELCH color systems were measured using the standard illuminant D65 and 10-degree observer. The specimens were placed at the center against a standard white and black background (Sealed Paper Charts) and color parameters were measured. Measurements were repeated three times for each specimen at the center against the respective background and the mean of the three values was calculated. In order to ensure the reliability of the instrument, it was calibrated using a standard white calibration plate prior to each series of color measurements. The L*, a*, b*, C* and h° values were measured. The color parameters of A2 shade guide were measured as well.

COMPUTING THE COLOR DIFFERENCE

The color difference between each subgroup and A2 Vita Classical Shade Guide was calculated using CIEDE2000 (ΔE^*_{00}) formula²⁸ which is seen in equation 1:

$$\Delta E_{00} = [(\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + R_T(\Delta C'/K_C S_C)(\Delta H'/K_H S_H)]^{1/2}$$

(Equation 1)

Where $\Delta L'$, $\Delta C'$, and $\Delta H'$ represent lightness, chroma, and hue difference, respectively; R_T is a hue rotation term to deal with the problematic blue region (interaction between chroma and hue difference); S_L , S_C , and S_H are compensations for lightness, chroma, and hue known as weighting functions; and correction terms, k_L , k_C , k_H , are for the experimental situations.

In the present study, the clinically unacceptable threshold was considered to be 3.7 based on a study by Johnston and Kao.¹⁷

ASSESSMENT OF TRANSLUCENCY

To measure the translucency, TP was used. The TP values were calculated by the color difference of the specimens against black and white backgrounds according to the equation 2.²⁹

$$TP = [(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2]^{1/2}$$

(Equation 2)

Where "B" refers to color coordinates against the black background, and "W" refers to color coordinates against the white background. Therefore, ΔL^* , Δa^* , and Δb^* were the difference in lightness, the green-red coordinate, and the blue-yellow coordinate against black and white backgrounds, respectively. The TP values of the core specimens without the veneering were used as controls.

STATISTICAL ANALYSIS

The statistical analyses were performed using SPSS version 20.0 (SPSS Inc., Chicago). To analyze the effect of core shade, core thickness, and the veneering thickness on quantitative variables, three-way ANOVA was applied. Since significant interactions were found between the factors in some conditions by two-way ANOVA, the effect of each factor was assessed individually. Independent t-test was used to assess the effect of core shade and core thickness on color parameters and TP, and one-way ANOVA was used to assess the effect of the veneering thickness on color parameters and TP. In order to determine significant differences, Tukey's multiple-comparison test was performed. The statistical analyses were performed with a significance level of 0.05 and 95% confidence interval.

RESULTS

EVALUATION OF TRANSLUCENCY BASED ON CORE SHADE, CORE THICKNESS, AND THE VENEERING THICKNESS

Table 1 shows the mean and standard deviation values (SD) for TP. Statistically significant differences were found with regard to core shade ($P < 0.05$). White cores of 1 mm thickness with the veneering thickness of 0 ($p = 0.001$), 0.5 ($p = 0.009$), 1 ($p = 0.016$) and 1.5 mm ($p = 0.001$) had significantly higher TP values than dentine cores with 1 mm thickness.

With regard to core thickness, there were significant differences between the two different thicknesses of dentine cores in all groups. The control group ($p < 0.001$), 0.5D0.5 ($p = 0.002$), 0.5D1 ($p = 0.013$) and 0.5D1.5 ($p = 0.002$) had significantly higher TP values.

One-way ANOVA showed significant differences between some groups for the veneering thickness. The control group had a significantly lower TP value than group 0.5D1.5 ($p = 0.03$). The control group with white core of 0.5 mm thickness had the greatest mean TP value while group 1D1.5 had the lowest value.

EVALUATION OF COLOR PARAMETERS BASED ON CORE SHADE, CORE THICKNESS, AND THE VENEERING THICKNESS

Table 2 shows the mean and SD values of L^* , a^* , b^* , C^* , and h^* parameters and color difference (ΔE) in each group. With regard to core shade, significant differences were observed in color parameters ($P < 0.05$). Group 0.5W0.5 had a significantly higher mean L^* value than group 0.5D0.5 ($p < 0.001$) and the mean L^* value was significantly higher in group 1W0.5 than group 1D0.5 ($p = 0.008$).

With regard to core thickness, there were significant differences in L^* value. Group 0.5W0.5 had a significantly higher mean L^* value than group 1W0.5 ($p = 0.004$), and group 0.5D0.5 had a significantly higher mean L^* value than group 1D0.5 ($p = 0.042$). The mean values of a^* ($p = 0.016$), b^* ($p = 0.01$), and C^* ($p = 0.009$) were significantly higher in group 0.5W1 than group 1W1. The mean h^* value in group 0.5W1 was significantly lower than that in group 1W1.

One-way ANOVA showed significant differences in color parameters according to the veneering thickness. The mean b^* and C^* values were significantly influenced by the different veneering thicknesses only in presence of white cores with 0.5 mm thickness ($p = 0.005$). Group 0.5W1 had a significantly higher value than groups 0.5W0.5 and 0.5W1.5. The mean L^* and a^* values were not significantly different between the groups 0.5W1 and 0.5W1.5, 0.5D1 and 0.5D1.5, and 1D1 and 1D1.5. The mean values of hue angle were not significantly

Table 1. Mean and standard deviation of translucency parameter (TP) in each group.

| Core shade | Core thickness (mm) | Veneering thickness (mm) | TP Mean (SD) |
|------------|---------------------|--------------------------|--------------|
| White | 0.5 | 0 | 0.95 (0.17) |
| White | 0.5 | 0.5 | 0.81 (0.26) |
| White | 0.5 | 1 | 0.73 (0.17) |
| White | 0.5 | 1. | 0.69 (0.18) |
| White | 1 | 0 | 0.77 (0.10) |
| White | 1 | 0.5 | 0.69 (0.17) |
| White | 1 | 1 | 0.64 (0.17) |
| White | 1 | 1.5 | 0.61 (0.07) |
| Dentine | 0.5 | 0 | 0.94 (0.14) |
| Dentine | 0.5 | 0.5 | 0.81 (0.19) |
| Dentine | 0.5 | 1 | 0.67 (0.19) |
| Dentine | 0.5 | 1.5 | 0.62 (0.13) |
| Dentine | 1 | 0 | 0.64 (0.11) |
| Dentine | 1 | 0.5 | 0.81 (0.08) |
| Dentine | 1 | 1 | 0.67 (0.1) |
| Dentine | 1 | 1.5 | 0.82 (0.1) |

different between the groups 0.5w1 and 0.5w1.5 and between the group 1D1 and 1D1.5. Other comparisons were statistically significant ($p < 0.001$).

EVALUATION OF COLOR DIFFERENCE

Table 2 shows the mean and SD of ΔE_{00} . Considering the ΔE_{00} value of 3.7 as the clinically unacceptable threshold¹⁷ only three groups had a mean ΔE value of greater than 3.7. The mean ΔE_{00} values of groups 1W1.5, 0.5w1, and 0.5w1.5 were 3.71, 4.00 and 4.01, respectively. Group 0.5D0.5 had the lowest ΔE_{00} value (1.10) (Table 2). In general, by an increase in the veneering thickness from 0.5 to 1 mm, the ΔE_{00} changed more compared to the increase of that from 1 to 1.5 mm.

The mean and SD of thickness in each group discussed above are shown in Table 3.

Table 2. Mean and standard deviation of L*, a*, b*, C*, and h* parameters and color difference (ΔE) in each group.

| Core shade | Core thickness (mm) | Veneering thickness (mm) | L Mean (SD) | a Mean (SD) | b Mean (SD) | C Mean (SD) | h Mean (SD) | ΔE_{00} Mean (SD) |
|------------|---------------------|--------------------------|--------------|-------------|--------------|--------------|--------------|---------------------------|
| White | 0.5 | 0.5 | 78.78 (0.42) | 1.24 (0.35) | 21.61 (0.75) | 21.65 (0.76) | 86.72 (0.91) | 2.30 (0.31) |
| White | 0.5 | 1 | 74.33 (1.02) | 3.50 (0.62) | 23.17 (0.89) | 23.44 (0.94) | 81.44 (1.31) | 4.00 (0.69) |
| White | 0.5 | 1.5 | 73.10 (0.86) | 3.80 (0.51) | 21.28 (0.64) | 21.62 (0.66) | 79.89 (1.24) | 4.01 (0.37) |
| White | 1 | 0.5 | 77.45 (0.61) | 1.19 (0.44) | 21.42 (1.06) | 21.46 (1.07) | 86.83 (1.12) | 1.62 (0.39) |
| White | 1 | 1 | 74.51 (0.47) | 2.48 (0.42) | 21.40 (0.79) | 21.55 (0.79) | 83.38 (1.09) | 2.35 (0.19) |
| White | 1 | 1.5 | 72.96 (0.90) | 3.24 (0.27) | 20.85 (0.89) | 21.10 (0.85) | 81.15 (1.01) | 3.71 (0.37) |
| Dentine | 0.5 | 0.5 | 76.87 (0.45) | 1.50 (0.53) | 21.90 (0.67) | 21.95 (0.71) | 86.11 (1.24) | 1.10 (0.26) |
| Dentine | 0.5 | 1 | 74.02 (0.28) | 2.82 (0.41) | 22.23 (1.00) | 22.41 (1.04) | 82.79 (0.70) | 2.75 (0.55) |
| Dentine | 0.5 | 1.5 | 73.38 (1.10) | 3.30 (0.31) | 20.95 (1.04) | 21.21 (1.07) | 81.06 (0.49) | 3.68 (0.28) |
| Dentine | 1 | 0.5 | 75.87 (0.81) | 1.52 (0.46) | 21.52 (0.53) | 21.58 (0.57) | 85.97 (1.11) | 1.17 (0.23) |
| Dentine | 1 | 1 | 73.92 (1.17) | 2.37 (0.30) | 21.06 (0.87) | 21.20 (0.85) | 83.55 (1.00) | 2.49 (0.39) |
| Dentine | 1 | 1.5 | 72.77 (1.38) | 2.97 (0.53) | 21.34 (0.3) | 21.55 (0.98) | 82.09 (1.13) | 3.66 (0.61) |

Table 3. Mean and standard deviation of thickness in each group.

| Group | Mean \pm SD (mm) |
|----------|--------------------|
| 0.5W0.5 | 1.01 \pm 0.03 |
| 0.5W1 | 1.51 \pm 0.02 |
| 0.5 W1.5 | 2.02 \pm 0.03 |
| 1W0.5 | 1.51 \pm 0.02 |
| 1W1 | 2.01 \pm 0.03 |
| 1W1.5 | 2.5 \pm 0.01 |
| 0.5D0.5 | 1.01 \pm 0.02 |
| 0.5D1 | 1.51 \pm 0.03 |
| 0.5 D1.5 | 2.02 \pm 0.03 |
| 1D0.5 | 1.52 \pm 0.03 |
| 1D1 | 2.01 \pm 0.01 |
| 1D1.5 | 2.52 \pm 0.04 |

DISCUSSION

This study evaluated the effect of core and the veneering thickness and core shade on final shade and TP of PEEK restorations. The null hypothesis that the translucency and final shade of PEEK restorations would not be affected by core shade, core thickness or the veneering thickness was rejected.

Comparison of L*, C* and h^o values is possibly easier to comprehend since they share several features. Furthermore, these values simply correspond to earlier systems, which were based on physical samples i.e. the Munsell Color Scale.³⁰ On the other hand, the previous studies used L*, a*, and b* values for color analysis. Therefore, in order to be able to compare our results with those of previous studies, the statistical analyses were performed for both the CIELAB and CIELCh color systems.

According to the results of the present study, the TP and L* values were influenced by the core shade. With regard to TP, the white cores had higher mean values, which could be explained by their lower C* value (chroma).³¹ Jacobs *et al.*²⁶ assessed the effect of porcelain thickness and type of framework alloy on color of metal-ceramic restorations. They found that type of alloy affected the porcelain hue both visually and spectrophotometrically. However, no significant differences were noted in chroma or value. In a study by Barizon *et al.*³² different shades of lithium disilicate porcelain significantly affected the TP.

Our statistical analyses showed that color parameters were significantly influenced by the core thickness. Shokry *et al.*²² evaluated the effect of core and the veneering thickness on color of two all-ceramic restorations. For leucite-reinforced ceramics, increasing the core thickness significantly increased the mean a^* and b^* values but not the L^* value; for the Spinel ceramic, the L^* value significantly decreased while the b^* value significantly increased. Sinmazisik *et al.*¹⁵ conducted a study on zirconia ceramic restorations. They demonstrated that with an increase in zirconia core thickness, the L^* value increased while the a^* and b^* values decreased. These differences in the results may derive from different structural and optical properties of materials Such as effect of relative amounts, shapes, and sizes of the glassy and crystalline phases on the optical properties of the dental ceramic or effect of filler loading, type and size on the composite resin materials.

With regard to TP, thicker core specimens showed lower mean TP values; Heffernan *et al.*³³ demonstrated that core thickness and the total thickness (core + veneering) affect the translucency of all ceramic restorations. They stated that opacity increases by increasing the thickness. The majority of TP values in our study were below 1.0, which can be considered relatively opaque.²⁰ Therefore, these differences may not be significant in clinical practice and it may be concluded that PEEK cores are relatively opaque and can mask the underlying substrate. Therefore, there should not be any concern about the discoloration of underlying tooth or shade of core build-up.

Based on our results, the veneering thickness affected the color parameters. The mean L^* values decreased as the veneering thickness increased. In fact, increasing the thickness increases the absorption and scattering of the incident light, and therefore, decreases the amount of reflected light from the opaque layer and subsequently the lightness.²² This is consistent with the results of previous studies.^{14,15,22-25,34,35}

Chromatically, with an increase in thickness, the mean a^* value increased significantly and consequently the color shifted toward red. With regard to the b^* parameter, no particular pattern was observed, and a^* value was more sensitive to change of thickness in these restorations. Several studies evaluated the effect of different thicknesses of materials in all-ceramic (other than zirconia) and metal-ceramic restorations. Based on their findings, increasing the thickness resulted in an increase in a^* and b^* values.^{11,14,15,22-25} However, in studies by Sithiamnuai *et al.*³⁵ and Uludag *et al.*²³ (for IPS Empress) no significant effects were noted regarding the b^* value, similar to our study. Some studies were conducted on bi-layered zirconia restorations. Sinmazisik *et al.*¹⁵ found that with an increase in the veneering thickness, the a^* and b^* values decreased while in the study by Ozturk *et al.*¹⁴ the a^* value increased without any significant effect on the b^* value, which is consistent with our results. In a study on monolithic zirconia restorations, It was demonstrated that the b^* value increased while the a^* value decreased by an increase in thickness.³⁶

According to the CIE LCh, the mean value of C^* (chroma) was significantly affected by thickness. No particular pattern was found with change of thickness. It can be concluded that chroma alterations are not predictable by change of thickness. The mean h° value (hue) showed a reduction with an increase of the veneering thickness. This descending trend shows that color shifted from yellow towards red, confirming the results of CIE Lab system in which the a^* value increased (redness). Nevertheless, the alterations in hue angle were small (less than 7°).

Based on the results of the present study, it was observed that the mean TP values decreased with an increase in thickness. All values were below 1.0, which indicate the trivial translucency of this type of material as previously stated for core thickness. In studies conducted on bi-layered ceramics^{32,33,37-39} and monolithic zirconia restorations,^{36,40} increase in thickness inversely affected the TP. Also, in a study on composite resins, translucency was assessed in different thicknesses (0.5, 1, 2, 3, 4 mm) and it was found that translucency increased exponentially with a reduction in thickness.⁴¹ Based on the Lambert's law, light absorption decreases by reducing the thickness and thereby allowing more light transmission. In addition to the thickness, absorption and scattering features of the specimen affect the fraction of incident light.³⁶

The present study showed that color differences were influenced by difference in thickness similar to previous studies.^{12,14,22,24,25,38,42} Considering ΔE_{00} value of 3.7 as the clinically unacceptable threshold, only three groups had greater mean ΔE_{00} value (1W1.5, 0.5W1, and 0.5W1.5). It means that very good shade match can be achievable in limited restorative space with minimal thickness of restoration. It was found that core specimens with 1 mm thickness provided a better shade match in identical total thickness. When the effect of core shade was evaluated, it was observed that dentine core resulted in relatively better shade match. However, it seems that additional characterization is often needed to achieve a good shade match ($\Delta E_{00} < 2.5$) particularly in cases with larger restorative space ($> 1.5\text{mm}$). Therefore, it may be tentatively suggested that in cases with limited restorative space, PEEK restorations with higher core/veneering thickness ratio and dentine shade of core can provide a good shade match in addition to adequately high strength according to the manufacturer's claims.

These findings can help the clinicians achieve the desired esthetic appearance in PEEK restorations by choosing the correct core shade and the right combination of the core and the veneering thickness. In the present study, we tried to control for the effect of thickness of opaque layer. However, more investigations are required to assess the effect of opaque thickness on the results. Furthermore, this study was conducted on only A2 shade to evaluate the color difference. Therefore, further studies need to be conducted on other shades.

CONCLUSIONS

Within the limitations of this *in vitro* study, it may be concluded that:

1. The effects of core shade, core thickness and the veneering thickness on L* values were statistically significant while other color parameters were influenced by the core and veneering thickness but not the core shade.
2. Increasing the veneering thickness resulted in a significant decrease in the mean L* and h° values and a significant increase in the mean a* value.
3. Increasing the veneering thickness resulted in an increase in ΔE_{00} values. However, most groups had clinically acceptable mean ΔE_{00} value.
4. The TP value was significantly affected by the core shade, core thickness and the veneering thickness. In other words, translucency decreased with an increase in the veneering thickness.

MANUFACTURERS' DETAILS

1. breCAM BioHPP, Bredent, Senden, Germany
2. Arum, Dowoom, Daejeon, Korea
3. Vita Classical Shade Guide, Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg
4. Visio.link, Bredent, Senden, Germany
5. Labolight LV-III, GC, Tokyo, Japan
6. Crea.lign opaquer, Bredent, Senden, Germany
7. Crea.lign dentine paste, Bredent, Senden, Germany
8. Autopolymerizing acrylic resin, Technovits 4000; Heraeus Kulzer GmbH & Co., Wehrheim, Germany
9. CS-2000 spectroradiometer, Konica Minolta, Chiyoda, Tokyo
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