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# INVESTIGATION OF THE EFFECT OF DIFFERENT COLORS OF DENTIN AND OPAQUE PORCELAIN ON THE FINAL COLOR INDICES OF METAL-CERAMIC RESTORATION

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## Abstract

**Background and Aim**: The main challenge in restorative dentistry is to match the color of metal-ceramic restorations with adjacent teeth. This study aimed to investigate the final color of metal-ceramic restorations by combining two different colors of opaque porcelain and dentin.

**Materials and Method**: An experimental study was conducted using 160 samples of base metal alloys covered with opaque and dentin (Noritake) in four different colors (A1, B2, D3,C4). The “L*”, “a*”, and “b*” values of the samples were evaluated using a spectrophotometer, and the color difference (ΔE) between the samples, Vitapan 3D Master, and Vitapan shade guide was obtained. The data were analyzed using one-way analysis of variance(ANOVA) and the Tukey post hoc test.

**Results**: The lightness of the samples varied depending on the combination of opaque and dentin. The samples with different opaque’s covered with dentin C4 had the least lightness, while the samples with different opaque’s covered with dentin A1 had the highest lightness, except for the C4A1 group. The “a” value was the least in groups with different opaques covered with dentin A1, except for the opaque D3 group, and the most was in groups with different opaques covered with dentin C4. The “b” value was the least in different opaques covered with dentin A1 and the most in different opaques covered with dentin C4.

**Conclusion**: The final color of metal-ceramic restorations made with opaques A1, C4, and B2 was significantly influenced by the dentin color, except for the C4B2 group, while the opaque color was the main determinant of the final color in the groups with opaque D3, except for the D3B2 group. The colors achieved in this study had clinically acceptable differences with the Vita 3D Master shade guide compared to the Vitapan shade guide. These findings provide valuable insights for clinicians in achieving optimal color matching in metal-ceramic restorations.

**Keywords:** Color, Dental porcelains, Metal-ceramic restorations

## Introduction

When restoring teeth, it is essential to match the size, shape, surface properties, translucency, and color of the natural teeth (1, 2). Color is the most noticeable of these characteristics and is a complex phenomenon that involves physics, chemistry, and psychology (3). The metal substructure in metal-ceramic restorations is critical for providing strength and durability, but it can also affect the restoration's appearance (4, 5). The superior physical properties, ease of oxidation, suitable bonding characteristics with ceramics, and cost-effectiveness of base metal alloy compared to high noble alloy have resulted in its increased usage in metal-ceramic restoration frameworks in clinical applications (6, 7). The final color of a metal-ceramic restoration is influenced by numerous factors, including the type of metal alloy used, the composition and thickness of the metal, the structure of the dental ceramics, the thickness and color of ceramic layers, adherence to parameters related to ceramic firing in the furnace, and the frequency of porcelain firing (8, 9, 10). Previous research findings suggest that noble and high-noble alloys are more effective in producing metal-ceramic restorations that meet clinical acceptability standards than base metal alloys (9). The color matching process for metalceramic restorations is challenging due to the limited range of available ceramics and the varying compositions of ceramic materials (11). The disparity in the structures of natural teeth and metal-ceramic restorations results in differences in the absorption and reflection of light wavelengths, making color matching between the two a difficult task.(12) The accurate description of color requires consideration of different color dimensions, including chroma, value, and hue (13).

Visual assessment with a shade guide is the primary method for tooth color evaluation, but its reliability is questioned due to differences between fired porcelain color and shade guide.(14) Spectrophotometers are the most widely used, accurate, and flexible tools for general and dental color determination. They measure the amount of light energy reflected from an object within distances of 1-25 nm from the visible spectrum (15). The most common system used for color evaluation is CIELAB, which estimates the light transmitted or reflected by an object. Within this system, the parameter "L*" signifies lightness, "a*" represents the green-red color, and "b*" represents the blue-yellow color (16).

The minimum thickness of porcelain required is 0.7 mm, with a desired amount of 1 to 1.5 mm. Studies have demonstrated that variations in the thicknesses of opaque porcelain, dentin, and enamel can result in the final restoration appearing darker or lighter (12, 17). In less translucent porcelains, such as Noritake, the parameter "b*" displays greater variability than in more translucent porcelains (18). An investigation into the color difference between the Vita Classic color guide and metal-ceramic restorations revealed a significant discrepancy between the samples and the color guide solely in the "a*" parameter (19).

Previous studies have indicated that varying thicknesses of opaque porcelain can lead to differences in the final color of metal-ceramic restorations. Specifically, the maximum value of "L*" has been observed at thicknesses of 0.2 and 0.3 mm.

Previous investigations have demonstrated that varying thicknesses of opaque porcelain can lead to differences in the final color of metal-ceramic restorations. Specifically, the maximum values of "L*" were observed with 0.2 and 0.3 mm thicknesses, while the lowest value of "a*" was associated with 0.1 mm thickness, and no notable difference was observed in the value of "b*". Opaque porcelain with a thickness of 0.1 mm exhibited a higher $\Delta E$ compared to other thicknesses (16). As color selection kits typically encompass a range of 16 to 29 colors, it can be challenging to select an appropriate color when the available tooth color does not match any of the kit colors and appears to be a combination of colors. To address this issue, this study aims to investigate the final color of metal-ceramic restorations created using a combination of opaque porcelain and dentin porcelain of two different colors and offer practical solutions.

**Method and Material**

In the present investigation, a base metal alloy with a nickel-chromium-bromine structure (Thermo-bond, Burlington) SUPERCAST was utilized,(figure 1-3) which was subsequently covered with opaque porcelain layers and dentin porcelain (Super Porcelain EX-3, Tokyo, Japan) Noritake of four different colors and standard thickness.(figure 4)

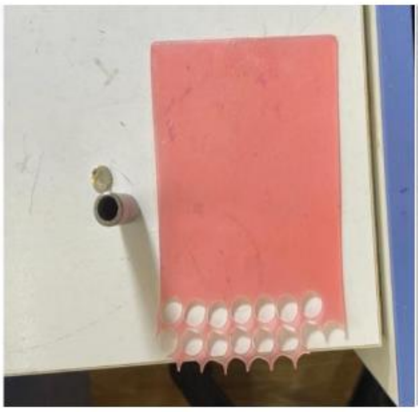


Figure 1. A wax model for base metal alloy casting structure

Figure 2. A base metal alloy with a nickel-chromium-bromine structure (Thermo-bond, Burlington) SUPERCAST

Figure 3. A base metal model structure from lateral view

To prepare 160 metal substructures for this study, a disc-shaped generator made of stainless steel with a diameter of 10 mm and a thickness of 1 mm, equipped with two 1.2 mm appendages on both sides of the disc (Figure 5), was utilized to maintain the packed porcelain's thickness. Molten Inlay wax (Azarteb, Tehran, Iran) was then poured into the prepared generator, and the resulting wax discs were subjected to the casting process according to the manufacturer's instructions. Afterward, the porcelain acceptor surface was cast onto the metal discs, which were subsequently polished with diamond polishing mills (JotaBern, Switzerland) until a smooth surface was obtained (12). To enhance bonding between the metal and porcelain, the discs were sandblasted with very soft 50 µm aluminum oxide particles (SU-Alustral, Berlin, Germany) at a pressure of 2 times and an angle of 45 degrees from a distance of 2 cm for 10 seconds (20). The discs were then cleaned using an ultrasonic device (Sonitec, Milan, Italy). Following this, the oxidation process was conducted at a temperature of 980°C with the presence of vacuum in an Auto Therm-300 porcelain furnace (Koushafan Pars, Tehran, Iran) to produce metal oxides on the alloy surface for porcelain bonding. Opaque porcelain of four different colors (A1, D3, B2, and C4)based on the Vita classic color selection kit (Vitapan, Berlin, Germany) was applied to the alloy surface in two layers with a thickness of 0.2 ± 0.05 mm (Figure 6). The samples were completely smoothed using green silicone sandpaper (Jota, Bern, Switzerland) (21). The thickness of the samples was subsequently measured using digital calipers (Guanglu, Guangdong, China) to ensure that the porcelain layer's final thickness was 1.2 mm.

**Figure 4** A base metal model covered with opaque porcelain layers and dentin porcelain Super Porcelain EX -3, Tokyo, Japan) Noritake

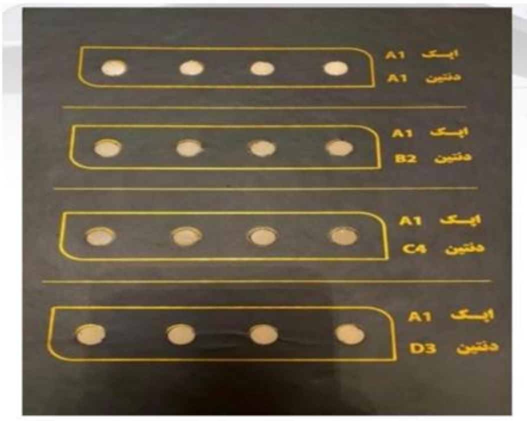
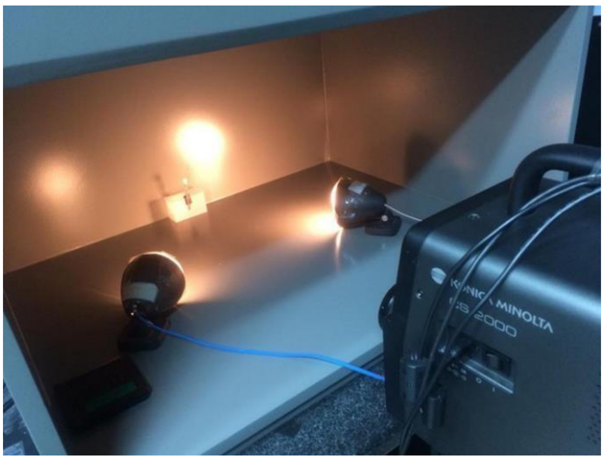



**Figure 5.** Models with same opaque and different dentin color

In each group, control subgroups were identified where the opaque and dentin colors were the same. The samples' color was then recorded at three points of each sample on a white background using a spectrophotometer (Spectroradiometer Cs-20000-Konica Minolta, Berlin, Germany) at a temperature of 25.4°C and 45% humidity, with a 2-degree angle in accordance with the CIELAB system (Figure 3) (22). To investigate individual error, 10 samples were re-examined by the researcher after an interval of 10 days. The values of "a*", "L*", and "b*" were determined and recorded for each group, and the mean data and ΔE of the samples in the study groups were calculated. $\Delta$ Eab (L*a*b) = $[(\Delta L)2 + (\Delta a)2 + (\Delta b)2]^{1/2}$ These groups were also evaluated using the color samples of the Vitapan 3D Master kit (Vitapan, Berlin, Germany) and Vita Classic to further analyze the results.




The samples' color was recorded on a white background using a spectrophotometer (Spectroradiometer Cs-20000-Konica Minolta, Berlin, Germany)

**Results**

The examination of the mean and standard deviation of color components (L, a, b) in the groups studied with opaque in different colors showed that the lowest and highest "L*" parameters were respectively related to the color combinations of C4B2 (66.63±0.60) and A1A1 (79.97±0.59). Regarding the parameter "a*", the lowest and highest were related to the color combinations of C4A1 (0.12 ± 0.84) and B2C4 (0.61 ± 3.59), respectively. In the parameter "b*", the lowest and highest were related to the color combinations of C4A1 (13.03±0.12) and A1C4 (25.16±0.12), respectively (Table 1).

The results of the paired comparison of the two groups showed that in the group with A1 porcelain color, all "L*", "a*", and "b*" groups were significantly different in pairs, except for A1A1 and A1B2 in component "a*" (P = 0.710). In the group with opaque porcelain B2 in the B2B2 and B2A1 groups in component "a*" (P = 1.000), B2B2, B2A1 (P = 0.580), B2C4, and B2D3 in component "b*" had no statistically significant difference (P = 932). Regarding the groups with opaque porcelain C4, C4C4, and C4D3 in component "L*" (P = 0.149), C4A1 and C4B2 in component "a*" (P = 0.182), and C4C4 and C4D3 in component " b*" (P = 932), no statistically significant difference was observed. Regarding the groups with opaque porcelain D3, D3A1, and D3B2 in component "L" (P = 0.118), D3A1 and D3B2 in component "a" (P = 0.219), and D3C4 and D3D3 in component "b", no statistically significant difference was observed (P = 5480).

Four A1B1, B2A1, C4D3, and D3C4 groups had clinically acceptable ΔE with control groups.

**Discussion**

The present study demonstrates the feasibility of employing a systematic classification method to accurately determine hue, chroma, and value in three dimensions using a device. The formula ΔE was used to measure the color components of "L*", "a*", and "b*" for different colors, revealing that "a*" has the least impact on the accuracy of the measurements (p>0.5). This finding indicates that red and green colors do not significantly affect the final result. The results further indicate that a decrease in the "L*" value corresponds to a darker color, which is consistent with a reduction in the amount of value. Moreover, as the "L*" value decreases, the measurement accuracy of the device also diminishes. Given that the primary color of human teeth is yellow, "b*" plays a crucial role in determining tooth color perception. Analysis of the measurements obtained from the Vitapan color guide revealed that the highest ΔE measured values are within the clinically unacceptable range. In contrast, such issues were not observed during Munsell color guide measurements conducted under similar conditions. The gradual color change observed in the Vitapan color guide and the instability in its fabrication and production were identified as factors that influenced the research results (23, 24). Johnston and Kao conducted research on the perceived appearance of dental materials and concluded that it is a highly complex phenomenon that cannot be fully defined by the three color parameters alone. As a result, they proposed an acceptable range of ΔE = 3.7, which has been widely adopted as a reference criterion in numerous studies, including the present study (25). Douglas et al. conducted a clinical study in which they predicted that 50% of operators can perceive a color difference of 2.6 ΔE*ab, whereas 50% of dentists perform restorations due to color mismatch when the value of 5.5 ΔE*ab is reached (26). Li et al. investigated the impact of the three color parameters, namely "L", "a", and "b", on color difference and found that ΔL*, which reflects light, had the greatest contribution to the color difference. Additionally, this parameter was found to be influenced by the thickness of the material, with a more pronounced effect observed in metal-ceramic restorations compared to non-metal restorations due to the greater reflectivity of metal surfaces than porcelain (28). Cari M. Pieper et al. conducted a study to evaluate the impact of the thickness of two types of opaque porcelain on the final color of metal-ceramic restorations. They found that the opaque powder resulted in higher "L" values and lower "a" and "b" values as compared to opaque paste. The authors identified that the parameter "a" had the least impact on color changes observed in both powder and paste opaques, followed by "b," and "L" had the greatest effect (16).

In a study by Fazi et al., it was observed that there were fewer color differences between A2 porcelain colors and the corresponding VITA color guide (average delta 2.50) in comparison to A3 with an average delta of 3.84 and A3.5 with an average ΔE of 3.49 (29). In the present study, the ΔE of color combination of A1A1 with the color guide A1 was found to be 2.84, which is consistent with Fazi et al.'s findings, suggesting relative similarity between the measurement methods employed in both studies.

In another study, Ozcelik reported that opaque porcelain on nickel-chrome alloy was inadequate in accurately reproducing the color of opaque porcelain. However, the color difference of the base metal alloys, as determined by the control group, fell within the clinically acceptable range (ΔE less than 3.5) (11). Bargi et al. conducted a research study in which they observed significant color variations between three types of porcelain from the same brand. Additionally, they found that the porcelain fired in the laboratory did not match the manufacturer's shade guide (6).

The A1C4 group had the highest ΔE value compared to A1A1 and C4C4 color averages, while the A1B2 color had the lowest ΔE value compared to A1A1 and B2B2 color averages. The significant difference in ΔE values may be attributed to the vast color difference between A1 and C4, where one is the lightest and the other is the darkest color in the Vita color sample. The paired comparison of combined color samples revealed that the A1B2, A1D3, A1C4, and A1B2 exhibited the largest ΔE differences, with opaque A1 being the lightest color in the selection kit, indicating that altering dentin may significantly impact the overall color difference. The present study revealed that the dentin color played a more significant role in determining the final color in groups that utilized opaques A1, B2, and C4, except for C4B2, where the opaque color had a more profound effect. Conversely, in groups with opaque D3, the final color was more influenced by the opaque, except for the D3B2 color. Overall, it can be concluded that the dentin color was a significant determinant in most groups of combined colors since light passes through the dentin twice, first passing through the dentin and reaching the opaque, and then passing through the opaque, reflecting from the dentin, and reaching the viewer's eye. All combined groups of the control group with the same color number in the Vita color selection kit had acceptable ΔE, except for C4C4. Changes in "L" were statistically significant in all groups. A1A1, A1B2, and A1C4 were lighter than 2M3 and darker than 1M1, while B2B2 and B2A1 were both yellower than 4L1.5 and less yellow than 3M2. B2A1 was darker than 3M2, while B2B2 was redder than 3M2. D3A1 and D3B2 were both yellower than 4M1, but D3A1 was lighter and D3B2 was darker than 2M2. C4A1 had the least redness and yellowness, and C4C3 and C4D4 were both darker than 4R1.5.

## Conclusion

The present study aimed to investigate the effect of combining different colors of opaque porcelain and dentin on the final color indices of metal-ceramic restorations. The results showed that the lowest lightness was associated with the combination of different opaques with dentin C4, while in the group with opaque C4, the lowest lightness was observed in dentin B2 and D3. The highest lightness was observed in combinations of different opaques with A1 dentin, except for the C4A1 group. The lowest amount of "a" was observed in groups with different opaques with dentin A1, except for opaque D3, which had the lowest amount of "a" in dentin B2. The highest amount of "a" was observed in groups with different opaques with dentin C4. The lowest amount of "b" was observed in different opaques with dentin A1, while the highest amount of "b" was observed in different opaques with dentin C4. In comparison to the Vitapan color sample, the present study identified a greater number of combined colors with clinically acceptable differences with the Vita 3D Master color sample.

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**Table 1:** Mean and standard deviation of color component ( a ,L ,b ) in tested groups

| SIG | Standard deviation | Mean | Group | Color component | Group | Mean | Standard deviation | SIG |
|---|---|---|---|---|---|---|---|---|
| .<0.001 | 0.59 | 79.97 | A1A1 | L | C4C4 | 73.67 | 1.90 | .<0.001 |
| | 0.22 | 78.59 | A1B2 | | C4A1 | 72.32 | 1.06 | |
| | 0.65 | 71.22 | A1C4 | | C4B2 | 66.63 | 0.60 | |
| | 0.22 | 74.83 | A1D3 | | C4D3 | 67.76 | 0.41 | |
| | 3.48 | 76.15 | Total | | Total | 70.10 | 3.20 | |
| .<0.001 | 0.19 | 0.88 | A1A1 | a | C4C4 | 1.20 | 0.12 | .<0.001 |
| | 0.11 | 0.96 | A1B2 | | C4A1 | -0.84 | 0.12 | |
| | 0.21 | 3.56 | A1C4 | | C4B2 | -0.19 | 0.09 | |
| | 0.12 | 2.17 | A1D3 | | C4D3 | 0.70 | 0.14 | |
| | 1.11 | 1.89 | Total | | Total | 0.40 | 0.59 | |
| .<0.001 | 0.23 | 17.73 | A1A1 | b | C4C4 | 18.07 | 0.29 | .<0.001 |
| | 0.26 | 20.81 | A1B2 | | C4A1 | 13.03 | 0.15 | |
| | 0.29 | 25.16 | A1C4 | | C4B2 | 14.42 | 1.00 | |
| | 0.28 | 22.87 | A1D3 | | C4D3 | 17.92 | 0.44 | |
| | 2.78 | 21.64 | Total | | Total | 15.86 | 2.29 | |
| .<0.001 | 0.59 | 78.23 | B2B2 | L | D3D3 | 71.34 | 0.64 | .<0.001 |
| | 0.45 | 79.97 | B2A1 | | D3B2 | 76.12 | 0.73 | |
| | 1.04 | 70.71 | B2C4 | | D3A1 | 75.28 | 1.30 | |
| | 0.51 | 72.25 | B2D3 | | D3C4 | 69.43 | 0.17 | |
| | 4.00 | 75.29 | Total | | Total | 73.04 | 2.90 | |
| .<0.001 | 0.10 | 1.42 | B2B2 | a | D3D3 | 2.11 | 0.29 | .<0.001 |
| | 0.06 | 1.42 | B2A1 | | D3B2 | 1.23 | 0.16 | |
| | 0.61 | 3.59 | B2C4 | | D3A1 | 1.04 | 0.06 | |
| | 0.52 | 3.07 | B2D3 | | D3C4 | 2.39 | 0.28 | |
| | 1.06 | 2.37 | Total | | Total | 1.69 | 0.61 | |
| .<0.001 | 1.54 | 20.66 | B2B2 | | D3D3 | 20.68 | 0.83 | .<0.001 |
| | 0.33 | 20.06 | B2A1 | | D3B2 | 16.78 | 0.30 | |
| | 1.02 | 24.35 | B2C4 | | D3A1 | 18.26 | 0.77 | |
| | 0.94 | 24.67 | B2D3 | b | D3C4 | 21.07 | 0.50 | |
| | 2.34 | 22.43 | Total | | | 19.20 | 1.88 | |

**Table 2:** The clinically acceptable ΔE of combined colors with Vita pan color guide

| color Vita pan | **E**Δ Between combined colors |
|---|---|
| A1 | D3A1) 1.891( |
| | A1B2) 2.84( |
| | B2A1) 3.36( |
| | A1A1) 2.84( |
| B2 | D3B2) 3.31( |
| | A1B2) 1.69( |
| | B2B2) 1.82( |
| D3 | D3B2) 2.80( |
| | D3D3) 2.414( |

**Table 3:** The amount of matching of combination samples with 3D Master color guide

| Combined colors ( **E)** Δ | | | | **3DMASTER** |
|---|---|---|---|---|
| | | **A1A1 2/77** | **B2A1 2/52** | 1M-2 |
| | | **C4B2 1/94** | C4A1 3/18 | 2L-1.5 |
| | | | **A1D3 2/41** | 2L-2.5 |
| | | **C4B2 1/18** | C4A1 **1/81** | 2M-1 |
| | **D3D3 46/3** | **D3B2 1/55** | D3A1 **3/17** | 2M-2 |
| | | | **A1D3 2/26** | 2M-3 |
| C4B2 **1/45** | C4A1 **3/08** | D3B2 **3/12** | D3A1 **2/49** | 2R-1.5 |
| | A1D3 **2/68** | **D3D3 2/58** | **D3B2 2/95** | 2R-2.5 |
| | **C4D3 3/13** | **D3D3 2/19** | **D3C4 2/86** | 3L-1.5 |
| | A1C4 **2/22** | **B2D3 1/97** | B2C4 **2/88** | 3L-2.5 |
| | | C4B2 **1/52** | C4A1 **2/16** | 3M-1 |
| | | A1D3 **2/91** | **D3B2 3/13** | 3M-2 |
| | **C4D3 3/21** | D3D3 **2/55** | **D3C4 2/98** | 3R-1.5 |
| | A1C4 **1/25** | B2D3 **1/61** | B2C4 **2/20** | 3R-2.5 |
| **C4D3 2/53** | **C4C4 3/03** | **D3D3 2/49** | D3C4 **1/43** | 4L-1.5 |
| | | **C4D3 2/69** | **C4C4 1/83** | 4M-1 |
| | B2C4 3/00 | D3D3 **2/75** | D3C4 **1/11** | 4M-2 |
| | C4D3 **3/36** | C4C4 **3/01** | D3C4 **2/47** | 4R-1.5 |
| | | A1C4 **1/25** | B2C4 **2/84** | 4R-2.5 |