EVALUATION OF COLOR DUPLICATION IN A PARTIALLY STABILIZED ZIRCONIA MATERIAL (IN VITRO STUDY)

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ABSTRACT

BACKGROUND: The shade duplication procedure is essential in fabricating ceramic dental restorations, yet there is limited information on color duplication for high translucent zirconia.
AIM: To evaluate the color differences between intended and fabricated shades of high translucent zirconia.
MATERIALS AND METHODS: Sixteen square high translucent zirconia specimens were cut in the pre-sintered state and immersed in coloring agents representing the 16 shades of the Vita Classical Shade Guide. After sintering and glazing per the manufacturer's guidelines, visual and instrumental assessments were conducted to determine the corresponding shade of each specimen. These specimens served as master references for the fabrication of experimental specimens based on their respective master shades. Color differences (ΔE00) between the master and experimental specimens were analyzed.
RESULTS: there was no statistically significant difference in delta E00 between visual and instrumental methods of shade selection. The color difference between intended and fabricated specimens was found to surpass the acceptability threshold.
CONCLUSIONS: zirconia material colored using dipping technique showed un-acceptable color duplication regardless of the shade selection method used.
KEYWORDS: Shade selection, color duplication, zirconia, esthetics, dental ceramics.
RUNNING TITLE: Color duplication in high translucent zirconia: an invitro study.

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INTRODUCTION

Color is one of the integral parts of esthetic dentistry, which affects patients' satisfaction. Color reproduction is one of the most challenging tasks encountered by clinicians due to the complexity of the optical properties of natural teeth(1). The apparent color of natural teeth is a result of the reflectance from dentin modified by absorption, scattering, and thickness of enamel (2). Therefore, understanding the optical properties of teeth is imperative for accurate and consistent color reproduction (2). Color and its elements such as hue, chroma, value, opacity, translucency, light transmission, scattering, metamerism, and fluorescence influence the esthetics of a dental restoration (3). The eye can distinguish between artificial and natural teeth based on minute differences in color and translucency (2, 3).

Shade selection can be accomplished through either visual assessment or instrumental color analysis. Visual color determination using shade guides is the most frequently followed method of shade selection; however, color duplication using this process is unreliable and produces inconsistent results (4, 5). Some variables affect color perception, such as external light condition, previous eye exposure, object illuminant position, and metamerism. Other uncontrolled factors such as fatigue, aging, and emotions influence the observer's interpretation of color stimulus (5, 6). Commercially manufactured shade guides are commonly used as the color standard to which the color of the tooth is matched. Nevertheless, studies have reported that up to 80% of patients express dissatisfaction with perceptible shade differences (7). Consequently, instrumental colorimetric techniques have been introduced. However, intraoral colorimetry suffers from edge loss and an inability to assume a repeatable position on the same tooth (8). Accordingly, fabricating a restoration that matches the target shade is extremely challenging.

Zirconia ceramic has a white color and is optically classified as a semitranslucent material. Two types of zirconia restorations are available, including monolithic (or full-contour zirconia restorations) and layered zirconia restorations. Monolithic zirconia restorations are fabricated by computer-aided design/computer-aided manufacturing (CAD-CAM) systems, while in layered zirconia restorations, a CAD-CAM fabricated zirconia substructure (core) is layered with a veneering ceramic (9, 10).

Zirconia-based restorations possess optical advantages over metal-ceramic restorations, but shade reproduction with zirconia-based restorations is still challenging. This may be caused by the multifactorial nature of shade reproduction in these restorations. In comparison to full-contour zirconia, the esthetic outcome is better when veneering porcelain is applied to a zirconia substructure due to the large range of shades, translucencies, and color modifiers of the veneering ceramic. On the other hand, the laboratory process is complicated by multiple firing cycles and different layering arrangements to produce the final color, which is mainly dependent on the laboratory technician's experience (10).

Layered zirconia restorations have been found to be vulnerable to chipping and delamination, exacerbated by thermally induced residual stresses. To eliminate chipping of the veneering porcelain, full-contour zirconia restorations were introduced. Recent advances have led to monolithic zirconia material with a high level of translucency that can replace veneered restorations (11).

To achieve esthetics comparable with those of veneering porcelain, monolithic zirconia material is shaded by two different methods. The first method is to use pre-shaded blanks with metallic pigments added to the initial zirconia powder, before or after pressing the milling blocks. While the second approach is the application of coloring liquids to white zirconia restoration before sintering (12). The application of coloring liquids is done by either dipping or painting with brushes. The application of coloring liquids to zirconia provides restorations with higher translucency and provides the ability of additional characterization of the final restoration (12). The method of applying coloring liquids to color the zirconia restorations is subjected to various factors that predispose to errors in the final shade, including immersion time/number of brushing strokes, concentration of acidic dyes, and contamination of the liquid dyes (11). Therefore, it is more technique-sensitive and might not produce the same results as the proposed shade, and hence, the color may not be the same as the intended shade (5).

This study is designed to evaluate color differences between intended and fabricated shades of high translucent zirconia material colored by coloring liquids using visual and instrumental shade matching systems. The null hypothesis of this study was that there are no differences between intended and fabricated shades of high translucent zirconia materials colored by coloring liquids using visual and instrumental shade matching systems.

MATERIALS AND METHOD

Fabrication of specimens

High translucent zirconia blocks (XTCERA - Shenzhen Xiangtong Co., Ltd) were cut under continuous water irrigation using diamond-impregnated slicing wheels mounted on a slow-speed saw microtome (Isomet; Buehler) to yield 16 cuboid specimens measuring (14.5 x 14.5x 5 mm) **(Figure 1)**. Each one of the specimens was dipped into one of the coloring liquids (XTCERA COLORS - Shenzhen Xiangtong Co. Ltd) from A1 to D4 shades for 20 seconds then placed on a tissue paper to remove excess coloring liquid for 5 minutes **(Figure2)**. The specimens were then placed under infrared light for 45 minutes to ensure complete drying. The specimens were sintered in a zirconia sintering furnace as recommended by the manufacturer **(Table 1)**.

The thickness of the specimens was then confirmed using a digital caliper (TOTAL). **(Figure 3)**

For glazing, glaze paste (IPS Emax ceram glaze paste; ivoclar vivadent AG) was applied onto one surface of the specimens using a brush. The glazing cycle took place in a porcelain firing furnace (Programat® P310; ivoclar vivadent AG) according to manufacturer firing parameters **(Table 2)**. All specimens were left out of furnace to cool down to room temperature and became ready for visual and instrumental analysis. The specimens were randomized so that the investigator was blinded and didn’t know which specimen represented which original shade.

Visual analysis:

Visual shade matching procedures were performed under controlled lighting conditions using a custom light box. the background and walls of the box were lined with a neutral grey lining to reduce the possibility of errors resulting from contrast (successive or simultaneous) and after image (positive or negative) (13). At the top of the box a uniform artificial light source (Philips 6500k cool daylight) was used and at the bottom of the box the specimens and the shade guide were placed next to each other. The distance between the light source and the specimens was approximately 2 feet away to reduce lumen diminution and the influence of ambient light **(Figure 4)**.

Visual shade selection was performed by10 female dentists examiners of the same age group (25-35 years) and educational background. To eliminate possible errors resulting from defects in color vision among observers, each clinician was tested for color blindness by the Ishihara color blindness test. A time limit of 10 seconds was imposed for shade assessment to reduce the possibility of retinal fatigue. The clinicians were asked to select shades by looking at each specimen from both sides (right and left) to subdue any possibility of binocular difference in color perception.

The selection was based on an agreement between 6 or more of the 10 dentists. The readings were collected, and each specimen was assigned as a specific shade based on the agreement to serve.

As a master specimen yielding only 10 master visual specimens. 6 shades (A1, B4,C2,D2,D3,D4) were not selected during visual analysis.

Instrumental analysis

The shade of the specimens was evaluated using a clinical spectrophotometer (VITA Easy shade Compact). Calibration was performed by placing the probe tip on the calibration port aperture before each color measurement. All Specimens were measured by holding the probe tip at 90° to the surface of each specimen at the center of the specimens **(Figure 5)**. All measurements were performed inside the light box used previously and were repeated three times for each specimen. According to the readings each specimen was assigned a specific shade to act as a master specimen yielding 7 master instrumental specimens. 9 shades (A3,B1,B4,C1,C2,C3,D2,D3,D4) were not detected during instrumental analysis.

Fabricated specimens

Seventeen specimens were fabricated corresponding to visual (n=10) and instrumental (n=7) master specimens using the same method of coloring, sintering and glazing of the zirconia specimens to test the color duplication accuracy.

Spectrophotometer analysis:

color measurement of the 17 master and 17 fabricated discs were performed using a desktop spectrophotometer (UV. Shimadzu 3101 PC). Color coordinates (CIE L* a* b*) were measured for each specimen. Color differences (ΔE_{00}) between the master and the fabricated discs were determined with the use of the equation.

$$\Delta \boldsymbol{E}_{\mathbf{00}} = [(\frac{\Delta L'}{K_L S_L})^{\mathbf{2}} + |(\frac{\Delta C'}{K_C S_C})^{\mathbf{2}} + (\frac{\Delta H'}{K_H S_H})^{\mathbf{2}} + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)]$$

The ΔE_{2000} (ΔE_{00}, dE2000, CIEDE2000 or dE00) formula considers several factors to better align with human visual perception. These factors include differences in lightness (L), chroma (C), and hue (H). The formula also incorporates corrections for the specific sensitivities of the human eye to different colors, addressing the non-uniformity of color perception (14).

- **Lightness Difference (ΔL):** Represents the difference in brightness between two colors.
- **Chroma Difference (ΔC):** Measures the difference in color intensity or saturation between two colors.
- **Hue Difference (Δh):** Describes the difference in hue angle between two colors.
- **Chroma and Hue Weighting Functions (S_L, S_C, S_H, R_T):** These functions adjust the chroma and hue differences based on the lightness and chroma of the colors being compared, accounting for the non-uniformity of human color perception.
- **parametric factors (K_L, K_C and K_H):** As corrections accounting for the influence of experimental viewing conditions.
- **The DeltaE (ΔE) Value:** The final color difference value obtained by combining the calculated differences in lightness, chroma, and hue, along with the weighting functions.

Statistical Analysis

Descriptive statistics were calculated as means, standard deviation (SD), and range (Minimum – Maximum). Normality of the study variable was tested using descriptive statistics, Q-Q plot, histogram, and Shapiro Wilk normality test. The comparison between visual and instrumental specimens was performed using independent samples t-test. Significance was set at p-value <0.05. Data was analyzed using SOSstat, Statistical software.

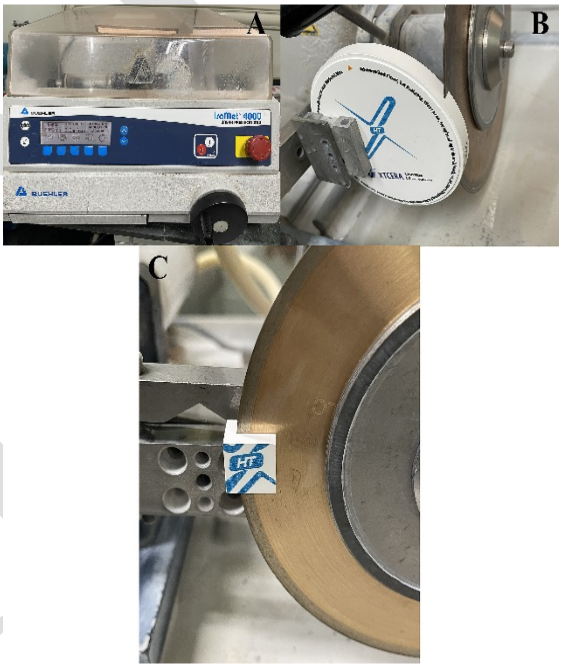

Figure (1): Cutting of zirconia specimens using slow speed saw microtome

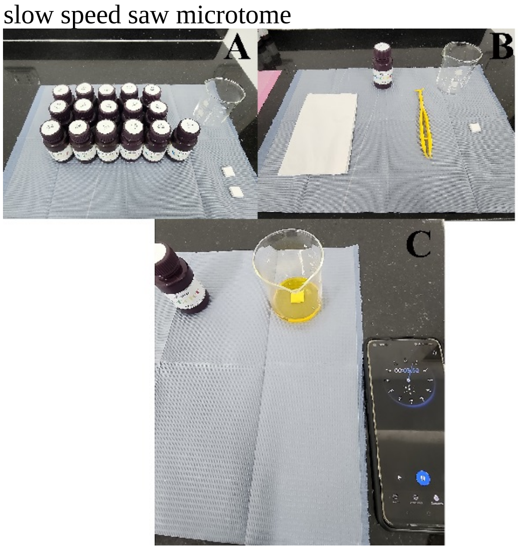

Figure (2): Dipping of zirconia specimens into the coloring liquids for 20 seconds

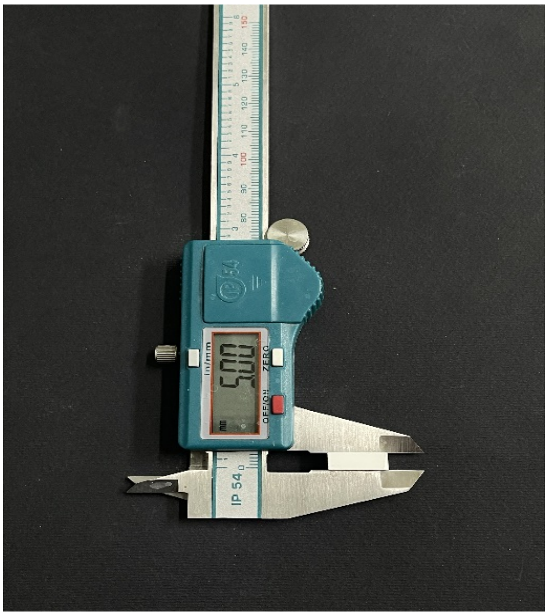

Figure (3): Confirmation of the thickness of each zirconia specimen

Figure (4): Visual analysis using a custom light box

Figure (5): Instrumental analysis using vita easyshade, All Specimens were measured by holding the probe tip at 90° to the surface of each specimen at the center of the specimens and the reading was repeated 3 times for each specimen

RESULTS

Table (3) compares visual and instrumental specimens, showing no statistically significant difference between the groups (p= 0.86). The mean ±SD for master visual specimens was 6.27 ±3.99, and for master instrumental specimens, it was 7.90 ± 5.48 (p = 0.86). When compared to the clinically perceptible threshold (≤1.30) and the clinically acceptable threshold (≤2.25), both groups exceeded these values, indicating that neither the visual nor the instrumental specimens meet the criteria for clinical acceptability or perceptibility.

Table 1: Sintering of zirconia specimens.

Sintering steps	Temperature(*c)	Time(h)
Phase 1	20-900	1.5
Phase2	900-900	0.5
Phase 3	900-1530	3.0
Phase 4	1530-1530	2.0
Phase 5	1530-800	1.0
Phase 6	800-natural cooling 100	-

Table 2: Glazing of zirconia specimens.

Stand-by temperature [°C]	Heating rate [°C/min]	Firing temperature [°C]	Holding time [min]	Vacuum 1[°C]	Vacuum 2[°C]
403	60	710	1	450	709

Table 3: Comparison of results of master visual and master instrumental specimens.

	Master visual specimens (n=10)	Master instrumental specimens (n=7)
Min. – Max.	1.31 – 11.82	1.21 – 12.10
Mean ± SD.	6.27 ±3.99	7.90 ±5.48
Test value P value	.79 .86	

DISCUSSION

This study aimed to evaluate the color differences between intended and fabricated shades of high translucent zirconia materials, colored using coloring liquids, through visual and instrumental shade matching systems. Color differences (ΔE_{00} values) between intended and fabricated specimens were found to be exceeding the acceptability threshold and are considered clinically unacceptable regardless of the shade matching method used (visual or instrumental) therefore the null hypothesis was rejected.

Color is a critical factor in dental restorations, significantly impacting both patient satisfaction and the overall esthetic outcome of the treatment. Previous studies have noted that even minor differences in color and translucency can lead to a noticeable contrast between natural teeth and restorations, which underscores the importance of precision in color selection and fabrication. This issue is particularly prominent in zirconia restorations, given the material's inherent optical properties and the challenges posed by its semitranslucent nature. The difficulty in color matching with zirconia is exacerbated by the multifactorial nature of shade reproduction, which involves variables such as translucency, opacity, and the type of staining technique used (2, 3, 12).

The application of coloring liquids is highly technique-sensitive, as previously indicated in the literature (13). The factors influencing the outcome, such as immersion time, brushing techniques, and concentration of the dyes, are difficult to standardize and may lead to variations in the final color (15).

Visual shade matching was carried out in a controlled lighting environment using custom made light box. To eliminate possible errors resulting from defects in color vision among observers, each clinician was tested for color blindness by the Ishihara color blindness test (16). A time limit of 10 seconds was imposed for shade assessment to reduce the possibility of retinal fatigue. The clinicians were asked to select shades by looking at each specimen from both sides (right and left) to subdue any possibility of binocular difference in color perception (17).

For instrumental shade matching Calibration was performed before each color measurement to ensure standardization. All Specimens were measured by holding the probe tip at 90° to the surface of each specimen at the center of the specimens. All measurements were repeated three times for each specimen.

The use of color difference (ΔE_{00}) analysis provides a quantitative method to assess the accuracy of color duplication. A ΔE_{00} value below 1.8 generally indicates that the color difference is imperceptible to the human eye, while values greater than 1.8 are typically noticeable (18). In this study, a comparison of ΔE00 values between the master and fabricated specimens would allow for a more detailed evaluation of how closely the fabricated specimens matched the original shades (master specimens), providing a quantitative measure of the accuracy of the fabrication process.

The use of un-shaded zirconia blanks and the application of coloring liquids offer practical solutions to improve shade matching especially in uncommonly used shades that may be unavailable in pre-shaded form, however the complexity introduced by manual application methods or dipping may lead to inconsistencies in color duplication. Furthermore, factors such as liquid concentration, the environmental conditions during the sintering process and the potential contamination of the coloring liquids could also influence the final shade. These findings reinforce the importance of establishing standardized protocols and ensuring precise control over the dyeing process to minimize errors and produce predictable, reliable results.

Similar results were found in previous studies evaluating color duplication in metal ceramic complexes and Lithium Disilicate Restorations. the results showed significant color differences between intended and fabricated specimens and are considered clinically unacceptable (3, 4). Moreover, the shade selection method used in the aforementioned studies didn’t improve color duplication of the tested materials (3,4).

Recommendations:

The limitations of this study include several key points. Firstly, the potential long-term effects of the coloring process on the stability of the shade were not accounted for, which could impact the clinical longevity of the restoration. Additionally, the study did not compare results between pre-shaded zirconia blocks and white zirconia blocks colored by dipping in coloring liquids, which could provide a more comprehensive understanding of the impact of different coloring methods. Furthermore, the study relied solely on the Vita Classical shade guide for visual assessment, limiting the breadth of shade comparison. Future research should address the effects of aging and wear on the color stability of these restorations and assess the effectiveness of various coloring methods over extended periods. Additionally, the use of different shade guides, such as the Vita 3D Master, should be incorporated to provide more detailed and accurate color evaluations.

CONCLUSION

Within the limitations of this study, reliable color duplication of high-translucent zirconia restorations could not be achieved. zirconia material colored using dipping technique showed un-acceptable color duplication regardless of the shade selection method used.

The authors declare that they have no conflicts of interest.

FUNDING STATEMENT

The authors received no specific funding for this work.

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