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The metameric effect of monolithic zirconias with varying yttrium ratios

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PURPOSE. To evaluate the metameric disparities among monolithic zirconia materials with differing yttrium compositions across various lighting conditions. **MATERIALS AND METHODS.** Thirty-six square-shaped zirconia samples measuring 10 × 10 × 0.5 mm were prepared from monolithic zirconia materials with three different yttrium contents. A 0.2 mm thick layer of polymerized dual-polymerizable self-adhesive resin cement was created using a silicone mold with the same dimensions as the prepared zirconia specimens. To evaluate metamerism, color measurements were conducted using a spectrophotometer device on a neutral gray background in a color measurement cabinet that offers four different illumination environments. All samples underwent aging by subjecting them to 10000 thermal cycles using a thermal cycle tester. Following thermal aging, color measurements were taken once more, and the data were recorded using the CIE L*, a*, b* color system. Two-way ANOVA and Post-hoc Bonferroni tests were employed to analyze the data. **RESULTS.** It was observed that there was no statistical difference among the color measurements made in different illumination environments of the monolithic zirconia ceramics used to evaluate metamerism ($P > .05$). This observation remained consistent both before and after thermal aging. After thermal aging, the color of monolithic zirconia materials exhibited a tendency towards red and yellow hues, accompanied by a decrease in brightness levels. **CONCLUSION.** It can be stated that different illumination conditions did not affect the metamerism of monolithic zirconia materials, but there was a color change in monolithic zirconia materials after a thermal aging period equivalent to one year. [J Adv Prosthodont 2024;16:48-56]

KEYWORDS
Monolithic zirconia; Metamerism; Thermal aging; Yttrium

INTRODUCTION

Today's esthetics perception and the increase in the esthetic demands of patients directly affect the materials, techniques, and treatment procedures in dentistry.[1] Ensuring a good color match between restorations and natural

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teeth is a critical step in achieving dental esthetics.[2] The most commonly used method for color selection in dentistry involves comparing the tooth color with color scales based on ceramic or acrylic resin.[3,4] However, this method is subjective; it can be affected by many factors such as age, gender, eye strain, experience, and environmental conditions.[2,5,6] Additionally, the illumination conditions of the environment are other major factors that affect color selection. The illuminator can be a natural or an artificial light source and may alter the perceived color of an object based on its origin. This phenomenon, known as metamerism, occurs because of the energy differences among various illuminants.[7,8] When the illumination conditions change, objects with metameric properties do not appear in the same color. To deal with the issue of metamerism, the chosen color should be verified by checking it under different light sources, such as daylight and fluorescent lighting.[3] The CIE has proposed a specific metamerism index to offer a suitable metric for evaluating metamerism. This index is essentially the color difference between the measured CIE Lab values of two objects under the reference and test illuminants, assessed using an appropriate color difference equation such as CIEDE2000.[9]

In addition to the illumination environment and conditions, the material used for restorative purposes holds significant importance in color selection. Today, various materials are utilized for restorative purposes. Monolithic zirconia restorations have been developed to eliminate the risk of chipping or breakage, making them increasingly popular. They offer several advantages, including enhanced mechanical strength, reduced material thickness, acceptable esthetic results, and reduced production time and cost.[10] One of the key factors influencing the esthetic success of monolithic zirconia restorations is achieving a color that matches the adjacent natural teeth.[11] There are various methods to enhance the optical performance of zirconia, including increasing the yttrium concentration, reducing the alumina content, optimizing the sintering parameters, minimizing porosity, and forming a nanometric structure.[4] In recent years, several studies have been carried out to enhance the optical properties of zirconia, leading to the introduction of various new zirconia blocks with different yttrium contents. The objective of increasing the yttrium content is to increase grain size of the material and promote the presence of the cubic phase, which exhibits reduced light refraction and increased translucency.[12,13] Monolithic zirconia restorations with enhanced translucency values have gained popularity in recent years, but they lack *in vivo* and *in vitro* studies.

The aim of this study is to investigate the metamerism of new-generation monolithic zirconias with different yttrium content in different illumination environments before and after thermal aging.

The null hypothesis states that there will be no color change in the material in different illumination environments with or without thermal aging.

MATERIALS AND METHODS

As a result of the power analysis, the required number of samples was found to be 12 in each subgroup (n = 12). To ensure standardization, square-shaped specimens measuring 10 × 10 × 0.5 mm were extracted from presintered monolithic zirconia blocks (Table 1) of high translucency (HT), super translucency (ST), and extra translucency (XT). These zirconia blocks had been color treated during the production process and were subsequently designed in the AutoCAD program before being engraved using a CAD-CAM milling device (CORiTEC 550i, GmbH, Eiterfeld, Germany). The sintering procedure was performed on the monolithic zirconia samples using a sintering furnace (Programat P300, Ivoclar Vivadent, Bendererstrasse, Liechtenstein), following the manufacturer's instructions. The presintered samples were prepared to be 20 - 25% larger than their actual size, considering the anticipated shrinkage during the sintering process. After the procedure, the sample sizes were measured and verified using a digital caliper (ALPHA TOOLS 150 mm, Gammertingen, Germany). Prior to testing, the sample surfaces were cleaned by immersing them in distilled water in an ultrasonic cleaner (HYDRA Ultrasonic, Istanbul, Türkiye) for 10 minutes, followed by air-drying.

Various lighting environments (Table 2) were categorized as experimental groups, while the D65 light source was designated as the standard control light. The initial measurements (L_1^*, a_1^*, b_1^*) were conduct-

Table 1. Brand and content information of zirconia samples used in the study

Brand	Code	Lot Number	Color	Generation	Manufacturer	Contents
VITA YZ HT	HT	77433	2M3	3Y-TZP (2.Generation)	VITA-Zahnfabrik, Germany	ZrO_2 %90-95, Y_2O_3 %4-6, Al_2O_3 %0.03
VITA YZ ST	ST	59220	A3	4Y-TZP (4.Generation)	VITA-Zahnfabrik, Germany	ZrO_2 %88-93, Y_2O_3 %6-8, Al_2O_3 %0.03
VITA YZ XT	XT	61960	A3	5Y-TZP (3.Generation)	VITA-Zahnfabrik, Germany	ZrO_2 %86-91, Y_2O_3 %8-10, Al_2O_3 %0.03

Table 2. İllumination environments used in the study

Artificial illumination environment	Operating temperature (°K)	Bulb type	Usage area
D65	6500°K	Phosphorus 7, Midnoon Daylight.	International artificial standard Daylight.
D50	5000°K	Phosphorus 7, Midnoon Daylight.	Noon Sunlight.
TL84	4000°K	European commercial fluorescent	Represents shop/office light. The most widely used artificial lighting medium.
INCA-A	2400°K	Tungsten Halogen	The incandescent light was generally used for home lighting.

Color measurements were made under illumination conditions of D65, D50, TL84 and INCA-A. ΔE00 color differences were evaluated to determine metamerism.
Study groups
Group 1: D65/TL84, Group 2: D65/INCA-A, Group 3: D65/D50

ed under D65 lighting conditions using spectrophotometry. Subsequently, the ΔE_{00} value was computed based on the subsequent measurements (L_2^*, a_2^*, b_2^*) taken under TL84, INCA-A, and D50 illumination conditions. Comparative analyses were performed among the different groups for each type of monolithic zirconia material.

Dual-polymerized resin cement (Bifix QM, VOCO GmbH, Cuxhaven, Germany) was used in the study. For the resin cement sample, a silicone mold was prepared with a square-shaped cavity measuring 10 × 10 × 0.2 mm. The resin cement was carefully placed in the mold, ensuring that it filled the cavity without any air gaps. The base and catalyst components of the dual-polymerized resin cement were mixed and applied according to the manufacturer's instructions. The resin cement was polymerized by exposing it to light for 20 seconds from the upper surface of a curing device (VALO Cordless LED, South Jordan, UT, USA) in contact with a 2 mm glass spacer. To smoothen the surface of the cement sample, silicon carbide sandpapers with grit sizes of 200, 400, and 600 were sequentially used on a polishing machine (MINITECH 233 REF 66300, Grenoble, France).

The prepared monolithic zirconia samples were numbered and placed in a closed box to protect them from any contamination that could potentially affect the color measurements. Color measurements of the zirconia specimens were conducted using cement samples that had been prepared within a color cabinet (Prowhite Light box 4.0, Istanbul, Turkey) featuring a neutral gray background, offering lighting conditions corresponding to D65 (artificial standard daylight), TL84 (storage/office light), INCA-A (incandescent light), and D50 (sunlight at noon), respectively. When combining the square-shaped samples, a drop of distilled water was placed between them to ensure better contact during measurement and reduce the chance of light loss from the tips of the samples. Color measurements were performed using a spectrophotometer device (VITA Easyshade Advance 4.0, VITA Zahnfabrik, Bad Säckingen, Germany). Before measuring each sample, the device was calibrated following the manufacturer's instructions.

Measurements were repeated three times from the same point in the center of the sample. The obtained CIE Lab* color system coordinates from the measurements were recorded. The first set of values (L_1*, a_1*, b_1*) were obtained using D65 as the illumination environment. The second set of values (L_2*, a_2*, b_2*) were obtained using TL84, INCA-A, and D50 as the illumination environments, and the ΔE_{00} value was calculated based on these values. The color difference (ΔE_{00}) was assessed in accordance with the CIEDE2000 standard. The calculation is derived from the following equation:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{KLSL}\right)^2 + \left(\frac{\Delta C'}{KCSC}\right)^2 + \left(\frac{\Delta H'}{KHSH}\right)^2 + R_T\left(\frac{\Delta C'}{KCSC}\right)^2 + \left(\frac{\Delta H'}{KHSH}\right)\right]^{1/2}$$

DL*, DC*, and DH* represent the differences in lightness (L), chroma (C), and hue (H) between a pair of specimens in ΔE_{00}. The function RT, commonly referred to as the rotation function, addresses the interaction between chroma and hue differences, specifically in the blue region. Weighting functions SL, SC, and SH are employed to adjust the total color difference, considering variations in the location of the color difference pair in L0, a0, b0 coordinates. Additionally, parametric factors KL, KC, and KH serve as correction terms for experimental conditions. In the context of the CIEDE2000 color difference formula, these parametric factors were uniformly set to 1.[14]

Thermal aging was applied to all samples to simulate the clinical use of the material. Following the recommendation in ISO 11405, a total of 10000 thermal cycles were carried out. Each cycle consisted of immersing the samples in baths of distilled water at 5°C and 55°C (± 3.5°C) with a 25-second dwelling time between the baths and a 10-second waiting time. It is assumed that 10000 thermal cycles are equivalent to 1 year of clinical use.[15]

The color measurement of all samples was conducted after thermal aging by the same operator as before, and the recorded values were obtained. ΔE_{00} values were calculated according to the CIE Lab* system. Paravina *et al*.[16] explored the relationship between color difference (ΔE_{00}) and perceptibility and acceptability thresholds in their study. The perceptibility threshold denotes the smallest color difference discernible by an observer (when ΔE_{00} is 0.81 (0.34-1.28)). The acceptability threshold represents the color difference that observers would find unacceptable, requiring color correction (when ΔE_{00} is 1.77 (1.23-2.37)). These thresholds were initially established when 50% of observers perceived the color difference or found it unacceptable. In our study, we adopted the clinically unacceptable threshold value of $\Delta E_{00} < 1.8$, as determined by Paravina *et al*.[16] for ΔE_{00}.

The data obtained from the measurements were recorded using the CIE Lab* color system. The recorded data were analyzed using the Instant Statistical Package Program (Instant Graphad Software 6.0, San Diego, CA, USA). The Shapiro-Wilk test was employed to assess the normal distribution of the data. For normally distributed data, a two-way analysis of variance was performed, followed by post-hoc Bonferroni Multiple Comparison tests to evaluate the differences among and within groups. The values were reported as mean and standard deviation. A significance level of $P < .05$ was considered statistically significant for all analyses.

RESULTS

In our study, which investigates the metamerism of monolithic zirconia materials with different yttrium content in various illumination environments before and after thermal aging, the evaluations were conducted by examining the ΔE_{00} values.

The ΔE_{00} values of 0.5 mm thick HT zirconia samples under D65/TL84 illumination before thermal aging ranged from 0.26-1.87 (Mean: 0.82). ΔE_{00} values after thermal aging ranged from 0.04-2.26 (Mean: 0.90). The ΔE_{00} value of the HT monolithic zirconia material increased after thermal aging in the D65/TL84 illumination environment, but the difference was not statistically significant ($P > .05$) (Table 3). The ΔE_{00} values of HT zirconia samples under D65/INCA-A lighting before thermal aging is in the range of 0.07-2.96. (Mean: 1.02). ΔE_{00} values after thermal aging ranged from 0.11-1.83 (Mean: 0.67). The ΔE_{00} value of the HT monolithic zirconia material decreased after thermal aging in the D65/INCA-A illumination environment, but the difference was not statistically significant ($P > .05$) (Table 3). The ΔE_{00} values of HT zirconia samples under D65/D50 illumination before thermal aging are

Table 3. Mean and standard deviation values of the groups before and after thermal aging with two-way ANOVA and post-hoc bonferroni test

	İllumination environments	Pre-aging	Post-aging
VITA YZ HT (0.5 mm)	D65/TL84	0.829 ± 0.56^{aA}	0.909 ± 0.85^{aA}
	D65/INCA-A	1.027 ± 0.88^{aA}	0.675 ± 0.59^{aA}
	D65/D50	0.342 ± 0.43^{aA}	0.700 ± 0.70^{aA}

$P > .05$
Same letters indicate that there is no significant difference between the groups. Capital letters are used for vertical comparisons, lower case letters are for horizontal comparisons.

in the range of 0.06-1.64 (Mean: 0.34). ΔE_{00} values after thermal aging ranged from 0.07-2.11 (Mean: 0.69). The ΔE_{00} value increased after thermal aging of the HT monolithic zirconia material in a D65/D50 illumination environment, but the difference was not statistically significant ($P > .05$) (Table 3). The ΔE_{00} values of 0.5 mm thick HT zirconia samples before thermal aging showed the highest value in the D65/INCA-A group, followed by the D65/TL84 group, and the lowest value was observed in the D65/D50 group. The difference among these groups was not statistically significant ($P > .05$) (Table 3). The mean ΔE_{00} values after thermal aging were as follows: D65/TL84 > D65/D50 > D65/INCA-A. The difference among these groups was also not statistically significant ($P > .05$) (Table 3).

The ΔE_{00} values of 0.5 mm thick ST zirconia samples under D65/TL84 lighting before thermal aging ranged from 0.18-1.89 (Mean: 0.81). ΔE_{00} values after thermal aging ranged from 0.15-0.80 (Mean: 0.36). The ΔE_{00} value of the ST monolithic zirconia material decreased after thermal aging in the D65/TL84 illumination environment, but the difference was not statistically significant ($P > .05$) (Table 4). The ΔE_{00} values of ST zirconia samples under D65/INCA-A illumination before thermal aging were in the range of 0.29-2.57 (Mean: 0.99). ΔE_{00} values after thermal aging are in the ranged from (Mean: 0.54). The ΔE_{00} value of ST monolithic zirconia material decreased after thermal aging in D65/INCA-A illumination environment, but the difference was not statistically significant ($P > .05$) (Table 4). The ΔE_{00} values of ST zirconia samples under D65/D50 illumination before thermal aging were in the range of 0.24-1.61 (Mean: 0.79). ΔE_{00} values after thermal aging are in the ranged from 0.12-2.55 (Mean: 0.56). ΔE_{00} value of ST monolithic zirconia material decreased after thermal aging in D65/D50 illumination environment, but the difference was not statistically significant ($P >.05$) (Table 4). ΔE_{00} values of 0.5 mm thick ST zirconia block samples before aging showed the highest value in the D65/INCA-A group, followed by the D65/TL84 group, and the lowest value was observed in the D65/D50 group. The difference among these groups was not statistically significant ($P > .05$) (Table 4). The mean ΔE_{00} values after thermal aging were as follows: D65/D50 > D65/INCA-A > D65/TL84. Similarly, the difference among these groups was not statistically significant ($P >.05$) (Table 4).

The ΔE_{00} values of 0.5 mm thick XT zirconia samples under D65/TL84 lighting before thermal aging are in the range of 0.22-2.28 (Mean: 0.92). ΔE_{00} values after

Table 4. Mean and standard deviation values of the groups before and after thermal aging with two-way ANOVA and post-hoc Bonferroni test

	İllumination environments	Pre-aging	Post-aging
VITA YZ ST (0.5 mm)	D65/TL84	0.813 ± 0.63^{aA}	0.365 ± 0.22^{aA}
	D65/INCA-A	0.994 ± 0.79^{aA}	0.543 ± 0.59^{aA}
	D65/D50	0.792 ± 0.43^{aA}	0.562 ± 0.73^{aA}

$P > .05$
Same letters indicate that there is no significant difference between the groups. Capital letters are used for vertical comparisons, lower case letters are for horizontal comparisons.

thermal aging ranged from 0.10-2.31 (Mean: 0.64). The ΔE_{00} value of XT monolithic zirconia material decreased after thermal aging in D65/TL84 illumination environment, but the difference was not statistically significant ($P > .05$) (Table 5). The ΔE_{00} values of XT zirconia samples under D65/INCA-A illumination before thermal aging is in the range of 0.44-2.14 (Mean: 1.29). ΔE_{00} values after thermal aging ranged from 0.31-1.23 (Mean: 0.69). The ΔE_{00} value of XT monolithic zirconia material decreased in D65/INCA-A illumination environment after thermal aging and the difference was found to be significant ($P < .01$) (Table 5). The ΔE_{00} values of XT zirconia samples under D65/D50 illumination before thermal aging are in the range of 0.10-1.82 (Mean: 0.82). ΔE_{00} values after thermal aging are in the range of 0.21-1.34 (Mean: 0.65). ΔE_{00} value of XT monolithic zirconia material decreased after thermal aging in D65/D50 illumination environment, but the difference was not statistically significant ($P > .05$) (Table 5). ΔE_{00} values of 0.5 mm thick XT zirconia samples before thermal aging showed the highest value in the D65/INCA-A group, followed by the D65/TL84 group, and the lowest value was observed in the D65/D50 group. The difference among these groups was not statistically significant ($P > .05$) (Table 5). The ΔE_{00} values after thermal aging are as follows: D65/INCA-A>D65/D50>D65/TL84. The difference among these groups was also not statistically significant ($P > .05$) (Table 5).

DISCUSSION

In these studies, the metamerism of monolithic zirconia ceramics with different yttrium content was evaluated in various illumination environments before and after thermal aging. The results of the study revealed that there were no statistically significant differences in the color measurements of the monolithic zirconia ceramics with a thickness of 0.5 mm under different illumination environments ($P > .05$). This finding was consistent both before and after thermal aging. Therefore, our null hypothesis was accepted.

To evaluate metamerism, the ΔE_{00} value was determined by using the first measurements taken in the D65 illumination environment as the control for color measurements conducted in the following illumination environments: D65, TL84, INCA-A, and D50. According to the measurement results, the ΔE_{00} values obtained before thermal aging for all zirconia blocks showed the highest value in the D65/INCA-A illumination environment, followed by the D65/TL84 illumination environment. The lowest value was observed in the D65/D50 illumination environment. All measured values consistently stayed below the clinically acceptable threshold ($\Delta E_{00} < 1.8$) across all lighting environments, yielding results deemed clinically satisfactory. No statistically significant difference was found among the groups ($P > .05$). After applying the thermal aging processes to the materials, the ΔE_{00} values of the materials varied across different illumination environments. In the VITA YZ HT material, the highest value was observed in the D65/TL84 illumination environment, while the lowest value was observed in the D65/D50 illumination environment. For the VITA YZ ST material, the highest value was observed in the D65/D50 illumination environment, while the lowest value was observed in the D65/TL84 illumination environment. In the case of the VITA YZ XT material, the results after thermal aging showed similarity compared to the pre-aging condition.

Table 5. Mean and standard deviation values of the groups before and after thermal aging with two-way ANOVA and post-hoc bonferroni test

	İllumination environments	Pre-aging	Post-aging
VITA YZ XT (0.5 mm)	D65/TL84	0.930 ± 0.63^{aA}	0.647 ± 0.71^{aA}
	D65/INCA-A	1.297 ± 0.58^{aA}	0.694 ± 0.28^{bA}
	D65/D50	0.820 ± 0.60^{aA}	0.651 ± 0.35^{aA}

$P > .05$

Same letters indicate that there is no significant difference between the groups. Capital letters are used for vertical comparisons, lower case letters are for horizontal comparisons.

Previous studies have explored various materials commonly utilized in restorative dentistry using fundamental colorimetric methods. One of the earliest studies focused on investigating the impact of metamerism on pairs of dental materials and bovine teeth with similar colors under two illuminants.[17] The spectral reflectance factors acquired were straightforwardly converted to CIE Lab values for both reference and test illuminants, with color differences assessed using the shortest Euclidean distance. This methodology has subsequently become standard in dental research. The outcomes revealed that the average ΔE^*ab color difference resulting from illuminant variation was barely perceptible. Others have proposed a metamerism index by calculating the ratio of color differences between parametric pairs of samples measured under reference and test conditions. In a comparison of human dentin samples with dental materials, it was concluded that no evidence of a metameric effect could be discerned.[18] The metamerism index was subsequently applied in various studies, including an investigation of the metameric effect between natural teeth measured *in vivo* and two shade guide brands. Hein *et al*.[9] conducted a study to assess metamerism among natural teeth, monolithic zirconia, and veneered zirconia restorations, revealing that metamerism between natural teeth and both veneered and monolithic zirconia restorations was smaller than the detectable threshold of 0.8 CIE units (except for one case) and within the bounds of clinical acceptability. This finding aligns with the outcomes of our study.

Corcodel *et al*.[19] conducted studies evaluating the relationship between *in vivo* tooth color and color scales, focusing on the dependence on the light source used. CIE Lab* values were calculated in D65, A (Incandescent light), and TL84 illumination viroments. The study identified a metamerism effect between natural teeth and color scales, leading to the recommendation of matching color scales with teeth using different lighting conditions. On the other hand, Lee and Powers[18] conducted a study in D65, A and F (Fluorescent light) lighting environments to determine the color differences between resin composites of various colors and dentin that may be due to metamerism. They observed that the color differences between resin composites and dentin changed when the illuminant was changed from daylight to incandescent or fluorescent light. Consistent with the findings of Lee *et al*., Brokos *et al*.[20] achieved similar results in their investigation of the metameric effects of composite resins. Kim *et al*.[21] evaluated the metameric effect by measuring different shades (A2, A3, and A3.5) of one brand of dental porcelain and comparing them to the color of three different brands of porcelain repair composite in three illumination environments (D65, A, and F). The study highlighted the metameric effect between the porcelain used and the repair composites, emphasizing that it varies depending on factors such as the color of the porcelain, the brand of the repair composite, and the illuminator. Therefore, the researchers recommended careful color matching between porcelain and repair composites. Unlike in our study, color differences among new generation monolithic zirconia ceramics, which may be attributed to metamerism, were assessed *in vitro* under four different illumination environments: D65, TL84, INCA-A, and D50. Our study observed a slight color change when transitioning from daylight to other illumination environments. However, this color change was clinically insignificant and did not yield a statistically significant result ($P < .05$). In our study, unlike the studies conducted by Corcodel *et al*., Lee *et al*., and Kim *et al*., several differences were observed. These differences include the use of a different brand of spectrophotometer for color measurement, performing color measurements in a completely dark environment solely illuminated by the color cabinet, and variations in the interior of the color cabinet. The fact that the structure does not reflect the incoming light can be attributed to the absence of secondary rays that could affect our measurement accuracy. Furthermore, monolithic zirconia, used for evaluating color change, is considered a more resistant material to color alterations in different illumination environments. Therefore, it is recommended to examine color changes in various illumination environments using varied materials.

Papageorgiou-Kyrana *et al*.[22] conducted a study on monolithic zirconia, in which pre-colored samples from various color groups and monolithic zirconia specimens, immersed in a solution during the sintering stage, underwent a thermal cycle of 5000 cycles. The results of this investigation consistently demonstrated ΔE values below 3.7 for colored zirconia, regardless of whether they were pre-shaded or characterized in coloring liquids within laboratory settings. No statistically significant variations in ΔE ($P > .05$) were observed among the different groups after thermocycling. All ΔE values remained below the perceptibility threshold of 3.7, ensuring their imperceptibility to an untrained observer. The L*, a*, and b* values of both liquid-shaded and pre-shaded zirconia specimens were unaffected by thermocycling. In contrast, our study exposed materials to 10000 thermal cycles, equivalent to one year of use. Despite using the ΔE_{00} formula for color difference determination, the recorded color change remained below clinically acceptable values ($\Delta E_{00} < 1.8$), resulting in statistically insignificant outcomes. Most of our samples exhibited a slight decrease in L* values after thermal aging, indicating a noticeable tendency towards increased redness in a* and heightened yellowness in b*. Nevertheless, these alterations did not achieve statistical significance, consistent with the observations in the study by Papageorgiou-Kyrana *et al*.

Sen and Isler[23] conducted a study investigating the microstructural, physical, and optical properties of high translucency VITA YZ HT, VITA YZ ST, and VITA YZ XT monolithic zirconia materials. They reported that the differences in optical properties were influenced by the thickness, type, yttrium content, and grain size of the ceramic material ($P < .05$). In our study, which aimed to examine the impact of yttrium content on the optical properties of similar materials, we observed that the yttrium content did affect the optical properties; however, this effect was not statistically significant ($P > .05$). Nevertheless, further studies are needed to investigate the extent of these changes under clinical conditions. This is because the clinical significance and color differences require additional parameters to establish a meaningful visual interpretation.

When evaluating the limitations of the study, it is noted that the geometry of the samples used differs from the complex restorations used clinically. It is thought that this difference may have influenced the results obtained. Furthermore, there are limitations such as selecting zirconia blocks from only one brand and maintaining constant sample thicknesses. The study employed a short-term artificial aging simulation, and it would be beneficial for future studies to assess the long-term effects of artificial aging on the material. Additionally, since the study was conducted *in vitro*, it does not fully reflect the oral environment. *In vivo* studies are recommended to provide a more accurate understanding of the effects of these variables on the optical properties of monolithic zirconia. An additional limitation of this study is associated with the spectrophotometer used for metamerism measurement. It has been noted that a variety of measurement tools are employed in different studies to evaluate color differences, potentially leading to divergent outcomes. Consequently, it is recommended that future research endeavors simultaneously consider various methodologies for assessing metamerism.

CONCLUSION

Within the limitations of this study, the following conclusions were reached:

The ΔE values obtained from color measurements of 0.5 mm thick monolithic zirconia materials in all illumination environments showed a color difference below the clinically acceptable threshold ($\Delta E < 1.8$). Therefore, it can be inferred that there is metamerism, but this situation does not reach a clinically concerning level.

Thermal aging had an impact on the color of monolithic zirconia materials. After thermal aging, the materials exhibited a tendency towards red and yellow colors, while the brightness levels decreased.

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