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Effect of Thermocycle Aging on Color Stability of Monolithic Zirconia

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Abstract

Background: The color stability of dental restorative materials is important for long-term clinical success. **Objectives:** The objective of this study was to examine the effect of thermocycling on the color and translucency stability of monolithic zirconia. **Materials and methods:** A total of 80 disc-shaped specimens (1 cm diameter) were produced from monolithic zirconia material, Katana High Translucent (Kuraray Noritake Dental, Kurashiki, Japan). The specimens were prepared in four different thicknesses: 0.5 mm, 1 mm, 1.5 mm and 2 mm. Before thermocycling, color measurements of the specimens were made by a spectrophotometer (Spectro Shade TM MICRO; MHT Optic Research AG, Milan, Italy). After the thermal aging procedure, the color measurement was repeated. Data obtained from the study were analyzed with descriptive statistics, correlation analysis, one-way ANOVA and Tukey's tests. **Results:** After thermocycling, the L^*, a^*, b^* values decreased at all thicknesses. The maximum change in the L^*, a^* and b^* values was observed in 0.5-mm-thick specimens, while the least change was observed in 2-mm-thick specimens. The amount of color change in the specimens after thermocycling was found to be the highest in 0.5-mm-thick specimens ($\Delta E = 0.91 \pm 0.02$), and the lowest in 2-mm-thick specimens ($\Delta E = 0.85 \pm 0.01$). While a statistically significant color change (ΔE) was observed in 0.5-mm-thick specimens ($p < 0.05$), a statistically insignificant color change (ΔE) was observed ($p > 0.05$) in 1-mm, 1.5-mm, and 2-mm-thick specimens. After thermocycling, the translucency parameter (TP) values decreased at all thicknesses. The highest change in the TP values was observed in 0.5-mm-thickspecimens (1.09 ± 0.03), while the lowest change was observed in 2-mm-thickspecimens (0.40 ± 0.04). While a statistically significant change in the TP values was observed in 0.5-mm-thick specimens ($p < 0.05$), there was a statistically insignificant change in the TP values of 1-mm, 1.5-mm and 2-mm-thick specimens ($p > 0.05$). **Conclusion:** Although the color and translucency values after thermocycling exhibited statistically significant changes in the 0.5 mm thickness group, a statistically significant difference was not observed in the other thickness groups.

Keywords

Monolithic Zirconia, Color, Translucency, Thermocycling

1. Introduction

Monolithic zirconia restorations have many advantages such as enabling for minimal invasive tooth preparation, causing minimal wear on the opposing teeth and exhibiting high flexural strength. Besides, these restorations can be produced in the laboratory with computer-assisted manufacturing (CAD/CAM) systems in a short time without adding any porcelain [1]-[6]. In recent years thanks to the production and the use of high translucent monolithic zirconia materials, the esthetic success of restorations has increased [7].

One of the main goals in prosthetic dentistry is obtaining high esthetics by producing dental restorations that mimic the color and translucency of natural teeth. For long-term clinical success, the color stability of dental restorative materials is as important as their mechanical properties. The esthetic success of restorations mimicking natural tooth color depends on the color stability of the material used [8] [9].

Dental restorations are always subjected to various stresses/forces in the oral environment [10]. Temperature changes occur with the effect of food, drinks and breathing; pH changes occur due to the chemical content of foods in the mouth [11]. These oral environmental factors may affect the physical and chemical structure of the restorative materials. With laboratory tests, it is possible to have foresight about the long-term clinical behaviors of dental restorative materials [12].

Thermocycling of test specimens has been proposed as an effective method, in order to mimic the natural aging process of dental restorations and imitate oral conditions in laboratory environment [13] [14]. Thermocycling is one of the most commonly used artificial aging methods in dentistry [15].

Previous studies investigated the effect of monolithic zirconia thickness on the optical properties [16] [17] [18] [19]. Also, some studies investigated color stability of monolithic zirconia restorations [20] [21] [22] [23] [24]. However, information regarding the effect of thermocycling on the optical properties of high translucent monolithic zirconia ceramic with different thicknesses is lacking.

The CIE $L^*a^*b^*$ color system, which allows detecting small color changes, has been used in dentistry for many years. The system defines color by these 3 factors; $L^*a^*b^*$, where values provide a numerical description of the color position in a 3-dimensional color space [25]. In the present study, the calculation of color differences using CIE $L^* a^* b^*$ formulae allowed for comparisons in previous studies [21] [22] [23] [24]. Also, the translucency parameter that (TP) was used in order to determine the translucency values of objects is defined as the color difference of an object on the white (*w*) and a black (*b*) background [26] [27]. The degree of color change in the CIE $L^* a^* b^*$ system is denoted by ΔE. In the present study, perceptibility threshold was set at $\Delta E_{ab} = 1.2$ units, and the clinical acceptability threshold was set at $\Delta E_{ab} = 2.7$ units [28].

Dental shade-matching instruments have been used to overcome imperfections and inconsistencies of traditional shade matching [29]. Spectrophotometers are accurate, useful and flexible instruments for color matching in dentistry [29] [30]. This device can measure the amount of light energy reflected from an object at 1 to 25 nm intervals along the visible spectrum [31] [32]. They also allow colors to be classified numerically in an easier and more precise way, so that transfer process and communication can be improved [33] [34].

The purpose of this study was to investigate the effect of different thicknesses and thermocycling on color and translucency of monolithic zirconia. The null hypothes was that, thermocycling and differences in thickness had significant effect on color and translucency of monolithic zirconia at clinically perceptible level.

2. Methodology

This study was conducted in Ataturk University, Faculty of Dentistry, Erzurum, Turkey in March 2018. In the present study, the specimens were produced with the CAD/CAM system from high translucent monolithic zirconia (Katana High Translucent; Kuraray Noritake Dental, Kurashiki, Japan), with thicknesses of 0.5 mm, 1 mm, 1.5 mm and 2 mm. Disc shaped specimens were 1 mm in diameter. There were 20 specimens in each group. The specimens were sintered in a furnace (Protherm Furnaces; Alser Teknik Seramik, Turkey) for 2 hours at 1550˚C. After cooling the specimens at the room temperature, the surface finishing process was carried out under water with sandpaper #180. The thicknesses of the specimens were measured by a digital caliper (Absolute Digimatic Caliper, Mitutoyo Corporation, Aurora, IL, USA) (**Figure 1**).

Figure 1. Thickness measurement of specimens by a digital caliper.

Following the manufacturer's instructions, spectrophotometer (Spectro Shade, MHT Optic Research AG, Niederhasli, Switzerland) was calibrated before each measurement. After numbering 80 specimens, CIE $L^* a^* b^*$ values were measured for each specimen by the spectrophotometer. For each specimen, measurements were performed from three different points on the black (b), white (w) and gray (g) backgrounds and the average values were obtained (**Figure 2**).

L, a, b values of the specimens were measured by spectrophotometer on white (w) and black (b) backgrounds. The translucency parameter (TP) was calculated by this formula:

$$\text{TP} = [(L_b - L_w)^2 + (a_b - a_w)^2 + (b_b - b_w)^2]^{1/2}$$

After the first measurements, thermocycling were applied to monolithic zirconia specimens in a specially designed device which consists of 4 tanks with deionized water at standard temperatures [11] [35]. All specimen groups were subjected to 5000 thermocycles. The specimens were immersed for 15 seconds in each tank according to the following sequence: 5˚C to 37˚C to 55˚C to 37˚C according to ISO 11405 standards [21].

The translucency parameter (TP) values of the specimens which were subjected to thermocycling were recalculated. The ΔE formula was used to assess the effect of thermocycling on the color stability of the specimens with different thicknesses.

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

The statistical analyses of the study were performed by using IBM SPSS 20.0 package program. Descriptive statistics were used to determine the mean L^*, a^*, b^* values of the monolithic zirconia material at different thicknesses. The Pearson correlation test was performed to determine the relationship between the thicknesses of the specimens, and L^*, a^*, b^* and TP values. For repeated measurements, in the comparison of the specimens subjected to thermocycling in terms of TP, ΔL, Δa, Δb and ΔE variables according to the thickness, the one-way ANOVA analysis was performed. Tukey's test was performed to compare the different monolithic zirconia thicknesses. The results for $p < 0.05$ were considered statistically significant.

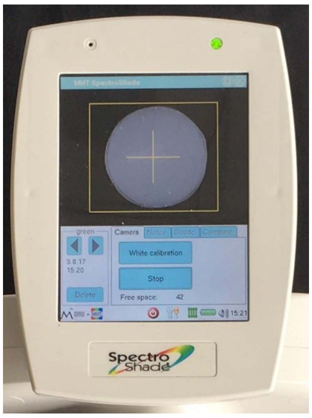

Figure 2. Color measurement of specimens.

3. Result

L, *a*, *b* values of monolithic zirconia specimens before thermocycling (L_1, a_1, b_1) and after thermocycling (L_2, a_2, b_2) are presented in **Table 1**. After thermocycling, the L^* values decreased, a^* and b^* values increased at all thicknesses. As the material thickness increased, while L_1^*, L_2^*, b_1^*, b_2^* values decreased, the a_1^*, a_2^* values increased ($p < 0.01$).

Changes in the L^* values (ΔL), a^* values (Δa) and b^* values (Δb) of the specimens with thermocycling are presented in **Table 2**. While the maximum ΔL (0.83 ± 0.01), Δa (0.30 ± 0.02), Δb (0.25 ± 0.03) values were observed in 0.5-mm-thick specimens. Minimum ΔL (0.80 ± 0.01), Δa (0.16 ± 0.01) and Δb (0.12 ± 0.02) values were observed in 2-mm-thick specimens. As the thickness increased, the ΔL, Δa and Δb values decreased ($p < 0.01$).

TP values of the specimens before (TP_1) and after (TP_2) thermocycling are presented in **Figure 3**. Mean TP_1 and TP_2 values of the specimens decreased as thickness increased ($p < 0.01$). Mean TP_1 and TP_2 values of the specimens were statistically different from each other at all thicknesses ($p < 0.001$).

After thermocycling, the TP values decreased at all thicknesses ($p < 0.05$). Maximum change in the TP values was observed in 0.5-mm-thick specimens (1.09 ± 0.03), while the minimum change was observed in 2-mm-thick specimens (0.40 ± 0.04). As the thickness increased, the change in the TP values decreased ($p < 0.05$). While there was a statistically significant difference ($p < 0.05$) between the change in the TP values of 0.5-mm-thick specimens and the change in the TP values of 1-mm, 1.5-mm, and 2-mm-thick specimens, there was not a statistically significant difference between the change in the TP values of the specimens with thicknesses of 1 mm, 1.5 mm and 2 mm ($p > 0.05$).

Color change (ΔE) values of the specimens with thermocycling are presented in **Figure 4**. After thermocycling the maximum color change was observed in

Table 1. L^*, a^* and b^* values of specimens before (L_1, a_1, b_1) and after (L_2, a_2, b_2) thermocycling.

Thickness	N	L_1	L_2	a_1	a_2	b_1	b_2
0.5 mm	20	76.06 ± 0.49	75.23 ± 0.03	−1.23 ± 0.03	−0.93 ± 0.01	22.04 ± 0.14	22.29 ± 0.01
1 mm	20	75.25 ± 0.20	74.63 ± 0.02	−0.59 ± 0.05	−0.38 ± 0.01	21.06 ± 0.13	21.20 ± 0.02
1.5 mm	20	74.04 ± 0.19	73.58 ± 0.18	0.14 ± 0.02	0.32 ± 0.01	20.52 ± 0.25	20.65 ± 0.01
2 mm	20	73.21 ± 0.10	72.83 ± 0.01	0.62 ± 0.02	0.78 ± 0.02	20.28 ± 0.35	20.40 ± 0.02

Table 2. ΔL, Δa, Δb values of specimens.

Thickness	N	ΔL	Δa	Δb
0.5 mm	20	0.83 ± 0.01[a]	0.30 ± 0.03[a]	0.25 ± 0.03[a]
1 mm	20	0.82 ± 0.02[b]	0.21 ± 0.02[b]	0.15 ± 0.02[b]
1.5 mm	20	0.81 ± 0.01[c]	0.18 ± 0.02[c]	0.13 ± 0.02[c]
2 mm	20	0.80 ± 0.01[d]	0.16 ± 0.02[d]	0.12 ± 0.02[d]

Similar superscript letters indicate no statistically significant difference ($p > 0.05$).

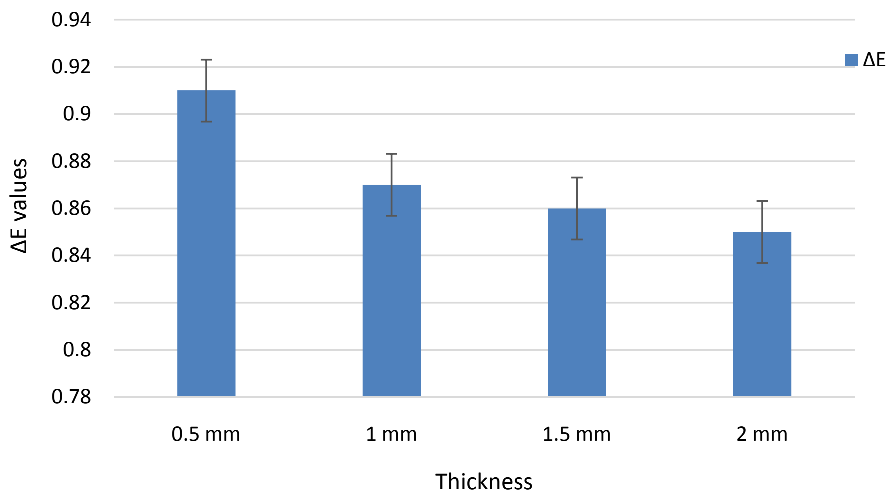

Figure 3. ΔE values of specimens.

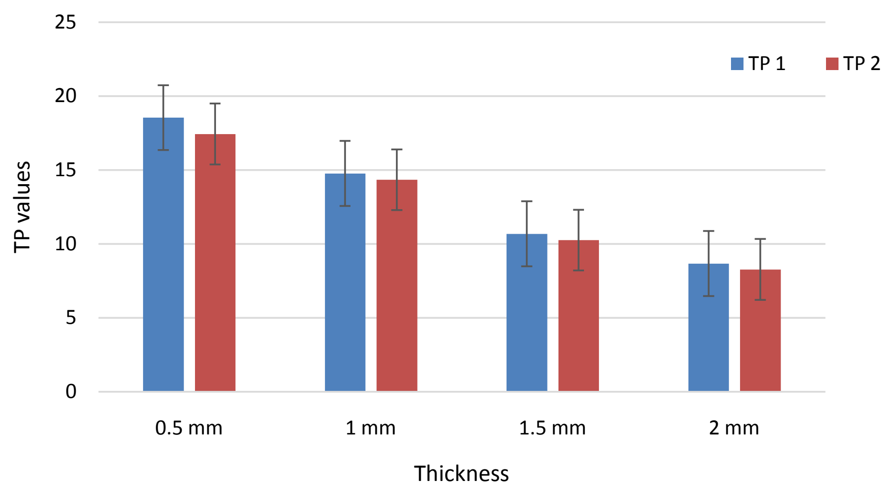

Figure 4. TP values before (TP_1) and after (TP_2) thermocycle.

0.5-mm-thick specimens ($\Delta E = 0.91 \pm 0.02$), while the minimum color change was observed in 2 mm-thick-specimens ($\Delta E = 0.85 \pm 0.02$). At all thicknesses, a color change was observed below 1.2 ΔE units, which is the perceptibility threshold. ΔE decreased, as the thickness increased ($p < 0.01$). A statistically significant difference was occured between the mean ΔE values of the groups ($p < 0.001$). While there was a difference between 0.5-mm-thick specimens and other thicknesses ($p < 0.05$), there was not a difference between 1-mm, 1.5-mm and 2-mm-thick specimens ($p > 0.05$).

4. Discussion

The null hypothesis which was that, thermocycling and differences in thickness had significant effect on color and translucency stability of monolithic zirconia at clinically perceptible level, was rejected. Because, in this study, color changes after thermocycling was observed less than perceptibility level (1.2 ΔE units) at all thicknesses groups.

Color and translucency have a significant effect on the esthetic success of the restorations [36]. In this study, the changes in translucency and color of the material were evaluated. Color measurements were performed according to the CIE Lab system by referencing to the study of Hamza *et al.* [22]. In the present study, by referencing to the studies on the subject [37] [38], 2 ΔE units were defined as clinically perceivable, while 3.7 ΔE units as clinically acceptable color change.

The reproduction of color and translucency of natural teeth would be one of the main goal for esthetic dental restorations. Color stability of a restoration throughout the functional lifetime is as important as the mechanical properties of the material. Color changes of a restorative material over time may limit the longevity and quality of restorations [8] [9].

Many studies in the literature have examined the effect of the thickness of monolithic zirconia on its optical properties. In all of these studies, it was stated that as the thickness of monolithic zirconia increases, the translucency of the material decreases [16] [17] [18] [19]. Moreover, it was argued that the translucency of the monolithic zirconia produced by different manufacturers is different [18] [19]. In the present study, similarly to the studies in the literature [16] [17] [18] [19], the translucency decreased as the thickness of the material increased ($p < 0.001$).

In their study, Abdelbary *et al.* [23] investigated the effect of accelerated aging on the translucency of monolithic zirconia. As a result of their study, they stated that aging processes affected the TP values of monolithic zirconia specimens. When they compared the TP values before aging, they found out that there wasn't a statistically significant difference between the TP values of 0.5-mm and 0.8-mm-thick specimens, while there was a statistically significant difference between the TP values of the specimens with thicknesses of 0.8 mm, 1 mm and 1.2 mm. The researchers stated that as the thickness of monolithic zirconia increased, the TP values decreased. After the aging process, the TP values of 0.5 mm-thick-specimens exhibited statistically significant changes whereas the TP values of 0.8-mm, 1-mm and 1.2-mm-thick specimens exhibited statistically insignificant change.

Fathy *et al.* [24] in which they investigated the effect of hydrothermal aging on the translucency of monolithic and core zirconia, measured the TP values of 1-mm-thick monolithic zirconia specimens by performing color measurements before and after hydrothermal aging. They stated that TP values of monolithic zirconia specimens before and after aging were statistically significantly higher than the TP values of core zirconia. They indicated that after aging the TP values decreased in monolithic and core zirconia, and this change was statistically significant in both groups.

In their study in which they examined the effect of accelerated aging on the color stability of different ceramic systems, Hamza *et al.* [22] used 2-mm-thick translucent monolithic zirconia specimens. According to the CIE Lab system, they observed a statistically insignificant color change ($\Delta E^* = 0.8743 \pm 0.32837$) in translucent monolithic zirconia.

In the present study, similarly to the studies of Abdelbary *et al.* [23] and Fathy *et al.* [24] the TP values of the monolithic zirconia specimens subjected to thermocycling decreased. While there was a statistically significant difference between 0.5-mm-thick specimens and specimens of other thicknesses ($p < 0.05$), there was not a statistically significant difference between the TP values of 1-mm, 1.5-mm and 2-mm-thick specimens ($p > 0.05$). As a result of the study, similarly to many studies in the literature [16] [17] [18] [19], it was observed that the TP values decreased ($p < 0.001$) as the thickness of the material increased.

In the present study, similarly to the study of Hamza *et al.* [22] while the maximum amount of color change after thermocycling was observed in 0.5-mm-thick specimens ($\Delta E = 0.91 \pm 0.02$), the minimum amount of color change was observed in 2-mm-thick specimens ($\Delta E = 0.85 \pm 0.02$). At all thicknesses, a color change below the clinically perceptible threshold was observed.

Under clinical conditions, various dental ceramic materials are used in the mouth. One of the limitations of this study is the use of only one type of monolithic zirconia material. Under clinical conditions, the color and translucency of the restoration can be affected by the color of the underlying dental tissue and resin cement. In this study, not assessing the effect of the resin cement and dental tissue on the color was another limitation. Furthermore, under clinical conditions, a single surface of the restoration is exposed to fluids in the mouth. In this case, the change in color values obtained as a result of the study may vary from the values of color change obtained in the clinic. In the study, however, both surfaces of the specimens were subjected to the thermocycling procedure. Another limitation of the study was that before and after thermocycling the surface roughness of the specimens was not assessed. It is assumed that the change in surface roughness can affect the color changes of the specimens. It is suggested to evalute the effect of the lower dental tissue, resin cement color and surface roughness on the final color and translucency of different types of dental ceramics in further studies.

5. Conclusions

Within the limitations of this study, the following could be concluded:

1) TP, L^*, a^*, b^* values of the monolithic zirconia specimens decreased after thermocycling, at all thicknesses.

2) After thermocycling, color change (ΔE) which was below the clinically detectable color change limit, was observed at all thicknesses.

3) TP and ΔE values of specimens were differed according to thicknesses.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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