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ORIGINAL ARTICLE

Effect of Beverages on Color Change of Glazed Monolithic Zirconia Ceramic

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ABSTRACT
Objective: To assess the effect of beverages on the color change of glazed monolithic zirconia ceramic. **Material and Methods:** This *in vitro* study evaluated 18 A2-shade disc-shaped monolithic zirconia specimens measuring 10 x 2 mm. All specimens were sintered, coated with a thin layer of glaze paste, heated in a vacuum furnace, and were subjected to 5000 thermal cycles at 5 and 55 °C. The specimens were then randomized into three groups (n=6) for immersion in orange juice, tea, and distilled water for 135 minutes/day for 24 days and incubated. The color of specimens was measured before and after immersion by a spectrophotometer, and the color change (ΔE) was calculated according to the CIE L*a*b* color space. Data were analyzed using one-way ANOVA and Tukey's post-hoc test (alpha=0.05). **Results:** All three groups experienced a color change after immersion ($p<0.05$). The ΔE was maximum in tea (2.05±1.04) and minimum in orange juice (0.81±0.57). Significant differences were noted between orange juice and tea ($p<0.001$), and distilled water and tea ($p<0.001$) in ΔL, and orange juice and tea ($p=0.023$), and distilled water and tea ($p=0.030$) in ΔE. **Conclusion:** The results indicated that tea caused maximum color change and maximum reduction in lightness (L*) in glazed monolithic zirconia ceramic; however, the color change was within the clinically acceptable range ($\Delta E<3.7$).

Keywords: Dental Materials; Ceramics; Color; Spectrophotometry.

Introduction

Discoloration of dental ceramics is a common concern for patients and dental clinicians, which can be annoying, especially in the esthetic zone, and it has a direct adverse effect on smile attractiveness [1]. Gradual color change of ceramic restorations often occurs due to the consumption of colored foods and beverages over a long period [2]. The advances in dental material science and technology have minimized such complications; however, the discoloration of some ceramic types still occurs under different conditions, such as temperature rise and consumption of colored or acidic foods and beverages [3]. Thus, selecting a ceramic type with optimal color stability is often challenging for many dental clinicians.

Among different ceramic types available in the market, zirconia has gained increasing popularity due to its higher strength [4]. Due to the high prevalence of chipping of the veneering porcelain of zirconia cores, monolithic zirconia was introduced to the market, eliminating the need for veneering. It can also be used in areas with limited space. The effect of beverages on the color change of different ceramic types has been previously evaluated. However, studies regarding the color change of glazed monolithic zirconia restorations following exposure to beverages or mouthwashes are limited [4-6].

The available studies on color change of other ceramic topics have reported controversial results. For instance, some authors believe that the pH of drinks is the main factor responsible for the discoloration of ceramics [7,8]. In contrast, others believe that heat and intensity of the color of the beverages are the main influential factors in this respect [9-11]. Glazing increases the strength and improves the surface quality and color stability of ceramics. Also, evidence shows that glazed surfaces have optimal color stability and surface properties [12].

Considering the gap of information regarding the color stability of zirconia-based all-ceramic restorations in the market, the availability of different surface treatments, as well as the increasing use of monolithic zirconia and the significance of its color stability and esthetics, this study aimed to assess the effect of some commonly consumed beverages on color change of glazed monolithic zirconia. The null hypothesis was that the beverages would not cause a significant discoloration in monolithic zirconia, and tea, distilled water and orange juice would have no significant difference with each other in this respect.

Material and Methods

Study Design and Sampling

This *in vitro*, experimental study evaluated A2-shade monolithic zirconia discs (Dentium Co. Ltd., Seoul, Korea) measuring 10 x 2 mm [12,13]. The minimum sample size was calculated to be six specimens in each group according to a previous study by Palla et al. [4] and assuming α=0.05, β=0.2, mean standard deviation of 0.2, and minimum significant difference in ΔE of 0.5, using PASS 11 Software (NCSS, LLC, Kaysville, Utah, USA).

Specimen Preparation

A2-shade monolithic zirconia blocks (Dentium Co. Ltd., Seoul, Korea) were used to fabricate 18 disc-shaped zirconia specimens measuring 10 x 2 mm by a computer-aided design/computer-aided manufacturing (CAD/CAM) system [14]. For this purpose, the specimens were first designed in the respective software and were then milled by the milling machine (CORITEC 350i; Imes-Icore GmbH, Eiterfeld, Germany) [12,13]. All specimens were sintered in a furnace (Programat s1 1600; Ivoclar Vivadent AG, Liechtenstein, Austria). For this purpose, the samples were first heated to 800°C according to the manufacturer's instructions. Next, the temperature increased to 1510°C at a speed of 15°C/minute and the specimens were kept at this temperature for 2 hours. Next, the temperature decreased to 200°C at 30°C/minute. The total sintering time was 4 hours [15]. The thickness of specimens was measured by a digital caliper (500-171-20B; Mitutoyo, Kanagawa, Japan) [1]. The specimens were then coated with a thin layer of glaze paste (IPS e.max Ceram Glaze; Ivoclar Vivadent AG, Liechtenstein, Austria) and heated in a vacuum furnace according to the manufacturer's recommendations [12].

Before baseline color assessment, the specimens were cleaned in distilled water in an ultrasonic cleaner (Codyson Cleaner CD4820, Shenzhen Codyson Electrical Co., Shenzhen, China) at 37±1°C, 5% CO_2, and 100% humidity for 10 minutes [4]. The specimens were then randomly divided into three groups (n=6). The primary color of specimens was measured by a spectrophotometer (Ci6X; X-Rite, Inc., Grand Rapids, Michigan, USA) in D65 lighting conditions at 380 to 780 nm wavelength. The baseline L*, a*, and b* values were recorded using the CIE L*a*b* color space [1]. In this system, L indicates lightness, a* indicates redness-greenness, and b* indicates yellowness-blueness [1,4,16].

Aging Process

For this purpose, they were subjected to 5000 thermal cycles at 5 and 55 °C (with a dwell time of 20 seconds at each temperature and a transfer time of 20 seconds) in a thermocycler (Dorsa Group Co., Tehran, Iran) [17]. After thermocycling, the specimens were rinsed with water and dried with absorbent paper [1].

Staining Process

Tea solution was prepared by immersing one tea bag (Golestan, Iran) in 200 mL of 100°C water for 1 minute. Natural orange juice was used for the orange juice group, and distilled water (Avisa Shimi Teb Co., Iran) was used for the control group. The specimens were immersed in the solutions for 135 minutes/day for 24 days (54 hours). The immersion regimen is selected based on the following reasoning: 3 beverages per day and 1 minute of exposure for each cup, equivalent to 1095 minutes or 18 hours of exposure per year, 54 hours in three years [4]. The drinks were used at temperatures they are often consumed normally by individuals (to maximize the simulation of clinical conditions). Accordingly, the temperature of the tea solution was kept at 55°C, the temperature of orange juice was held at 5°C, and the temperature of distilled water was held at 37°C during the immersion period [1,4]. An incubator was used for this purpose (Gallenkamp Labs., Japan). The drinks were prepared fresh daily. The specimens were rinsed with distilled water for 30 seconds after removal from the colored solution to eliminate debris [1,18].

Color Measurement

The color of specimens was measured again after immersion by the same spectrophotometer, and the L*, a*, and b* values were recorded. The color change (ΔE) was calculated using the formula below [1,4,19]: $\Delta E= [(\Delta L)2 + (\Delta a)2 + (\Delta b)2]1/2$.

Statistical Analysis

Data were analyzed by one-way ANOVA followed by Tukey's test for pairwise comparisons using PASS Sample Size Software (NCSS LLC, Utah, USA) at the 0.05 level of significance. The results of normality and homoscedasticity were verified using the Kolmogorov-Smirnoff and Levene tests, respectively.

Results

Tables 1 and 2 present the baseline and post-immersion L*, a*, b*, and ΔE* values and the change in color parameters (ΔL, Δa, Δb, and ΔE), respectively. All three groups experienced a color change after immersion ($p<0.05$). The difference in ΔE was significant among the three groups ($p=0.014$), and ΔE was maximum in tea (2.05) and minimum in the orange juice group (0.81).

Table 1. Mean and standard deviation of L*, a* and b* color parameters at baseline and after immersion in the three groups.

Groups	Color Parameters					
	L_1±SD	L_2±SD	a_1±SD	a_2±SD	b_1±SD	b_2±SD
Orange Juice	52.78±36.0	54.78±20.0	04.1±04.0	10.1±19.0	76.13±31.0	23.14±58.0
Tea	23.78±56.0	42.76±69.0	98.0±18.0	53.1±56.0	75.13±53.0	53.13±98.0
Distilled Water	99.77±43.0	76.78±17.0	005.1±05.0	03.1±09.0	80.13±37.0	85.13±37.0

SD: Standard Deviation.

One-way ANOVA revealed a significant difference among the three groups in ΔL and ΔE ($p<0.05$). Thus, Tukey's test was applied for pairwise comparisons, which showed significant differences between orange juice and tea ($p<0.001$) and distilled water and tea regarding ΔL and ΔE parameters (Table 2). The difference in Δa ($p=0.06$) and Δb ($p=0.36$) was not significant among the three groups.

Table 2. Mean change in L*, a*, b, and ΔE* color parameters in the three groups.**

Groups	Color Parameters			
	ΔL	Δa	Δb	ΔE
Orange Juice	0.02	0.06	0.47	0.81
Tea	-1.81*	0.55	-0.21	2.05*
Distilled Water	0.77	0.02	0.05	0.86
p-value	<0.001	0.06	0.36	0.014

*Tukey's test revealed a significant difference between the Tea group and the orange juice/distilled water group regarding ΔE and ΔL.

In the tea group, the L* parameter shifted towards darkness, while the L* parameter did not undergo a significant change in the distilled water group. Thus, the specimens in the tea group were significantly darkened after immersion compared with the other two groups. The change in L* parameter was not significant in the orange juice group compared with the control group (Table 3).

In all three groups, the a* parameter shifted towards redness. The change in this parameter was greater in the tea group compared with other groups, but not significantly. The changes in b* parameter was small, and the difference in this respect was not significant among the three groups.

Table 3. Pairwise comparisons of the groups regarding ΔL and ΔE.

Parameters	Solution I	Solution J	p-value
ΔL	Orange Juice	Tea	<0.001
		Distilled water	0.127
	Tea	Distilled water	<0.001
ΔE	Orange Juice	Tea	0.023
		Distilled water	0.991
	Tea	Distilled water	0.030

Discussion

This study assessed the effect of some commonly consumed beverages on color change of glazed monolithic zirconia. The results showed that all three groups experienced discoloration, and the difference in this respect was significant among the three groups. Thus, the null hypothesis of the study was rejected.

The selection of monolithic zirconia for this study was because of its increasing popularity, optimal flexural strength, conservative tooth preparation, causing minimal wear of the opposing teeth, shorter laboratory and clinical fabrication times due to the use of CAD/CAM technology, and not requiring a veneering porcelain layer. Also, the preshade type of monolithic zirconia was used in this study since the evidence shows that the preshade type is more homogenous and has higher color stability than the externally shaded type.

Evidence shows that rough zirconia surfaces cause greater wear to the opposing teeth compared with polished and glazed zirconia surfaces. Also, rough zirconia surfaces have higher surface energy, which makes the restoration susceptible to aging. Kim et al. evaluated the effect of glazing and polishing on the color stability of monolithic zirconia and reported a significantly greater color change in polished specimens compared with glazed specimens [12]. The glazed group showed higher color stability due to having a smoother surface. Thus, monolithic zirconia specimens were glazed in the present study.

Also, zirconia thickness has a significant effect on color change. According to Tabatabaian et al. [20], a minimum of 0.9 mm zirconia thickness is required for a color match with the adjacent natural teeth. Also, Kim et al. showed that a 0.1 mm reduction in the thickness of 2-mm zirconia specimens caused a significant color change in restoration ($\Delta E>3.7$). Thus, specimens with 2 mm thickness were fabricated for the present study to better simulate the clinical setting.

In the present study, ΔE of specimens was 0.81 in orange juice, 2.05 in tea, and 0.86 in distilled water group. According to the literature, $\Delta E < 1$ is not perceivable by the human eye [20,21]. Two objects with $\Delta E < 2$ appear to have the same color as the human eye. $\Delta E < 3.7$ is clinically acceptable in the oral environment; however, higher values ($\Delta E > 5$) are detectable by the human eye and are not acceptable, and the restoration should be replaced [16,22]. Thus, in this study, the color change was within the clinically acceptable range in all three groups ($\Delta E < 3.7$). In the tea group, the L* parameter significantly decreased and shifted towards darkness, and the color change in this group was significantly greater than that in the other two groups. In all three groups, the a* parameter shifted towards redness. The change in this parameter was greater in the tea group compared with other groups, but not significantly. The changes in the b* parameter were small, and the difference in this respect was not significant among the three groups. The Δa and Δb were not significantly different among the three groups. Thus, the difference in ΔE of the groups was mainly due to their difference in ΔL.

In the oral cavity, thermal alterations often occur due to different temperatures in the foods and drinks that are consumed. Thus, thermocycling was performed in this study to simulate the thermal alterations of the oral environment [16]. Thermal alterations can cause discoloration of monolithic zirconia restorations. Thermal stresses applied to polycrystalline materials with anisotropic crystals, such as zirconia ceramics, intensify the mechanical stresses due to differences in the expansion of crystals or their different phases. The intensity of stresses depends on the elastic properties and coefficient of thermal expansion of crystals and may even cause severe degradation in some cases. Thermal gradients can lead to tensile, compressive and even shear stresses and also enhance crack propagation. This would enhance water sorption and uptake of pigments and stains from colored foods and beverages or result in the release of metal oxides from the ceramics and affect their final color and gloss [16]. Also, exposure of yttria-stabilized tetragonal zirconia polycrystal structure to aqueous environments causes tensile stresses between the tetragonal and monoclinic phases, and the difference in energy between these two phases can lead to tetragonal to monoclinic phase transformation. Due to the changes in microstructure, superficial microcracks form and roughening occurs, which result in eventual stainability and discoloration of monolithic zirconia, and adversely affect its mechanical properties. This explains the mechanism of enhanced color change due to the thermocycling of specimens [15,16].

In the present study, the tea solution caused the maximum color change of specimens. Evidence shows that tea contains yellow stains. Thus, adsorption of stains by the ceramic surface is one reason for the discoloration caused by tea. Also, the 55° temperature of the tea solution probably increases the water sorption of specimens and enhances the uptake of pigments [16,23]. Colombo et al. [9] evaluated the color stability of zirconia ceramics after immersion in Coca-Cola and coffee. They showed that, unlike Coca-Cola, coffee caused significant color change in all types of zirconia. Also, they showed different behaviors of different zirconia types, such that some types experienced greater discoloration after prolonged exposure to the coffee solution. Derafshi et al. [24] evaluated the color stability of monolithic zirconia exposed to mouthwash and reported significant color change. Unlike our study, they reported minimum color change in distilled water, which may be due to the fact that they did not perform thermocycling. Palla et al. [4] assessed the color stability of lithium disilicate ceramics after aging and immersion in coffee, black tea, and fruit juice. They reported clinically acceptable color change in all groups except for the unglazed group immersed in tea. The color change caused by tea in their study ($\Delta E=4.99$) was greater than that in the present study ($\Delta E=2.05$), which may be due to the use of a different ceramic type or not glazing the ceramic surface in their research [4]. Xie et al. [25] evaluated the effect of acid treatment on dental zirconia and demonstrated immersion in hydrofluoric acid can create surface roughness in zirconia samples, especially with higher concentrations of HF acid. However, acetic acid and citric acid did not cause a significant surface deterioration compared to the control group. Orange juice is a beverage with a PH of approximately 3.5 and mainly contains citric acid; therefore, it is less likely to have a significant effect on the surface property of monolithic zirconia and its color changing accordingly.

Dos Santos et al. [1] assessed the effects of orange juice, cola, coffee, fruit juice, and artificial saliva on the optical properties of lithium disilicate ceramics. Similar to the present study, they showed the color change of all specimens. The color change was mainly related to changes in L* parameter, which was in agreement with the present results. However, unlike the present study, orange juice caused significantly greater color change in their specimens and exceeded the clinically acceptable threshold ($\Delta E=6.58$). This difference between the results of the two studies may be attributed to the use of different ceramic types and etch-ability of lithium disilicate ceramic [1].

This study had an *in vitro* design. It should be noted that the oral environmental conditions are different from those in the *in vitro* setting, and factors such as variations in the consumed foods and drinks, saliva flow, and interactions of different parameters can aggravate the color change of restorations. Saliva can dilute or neutralize the acidic pH of colored foods and beverages and decrease the intensity of discoloration. Also, regular oral hygiene can effectively reduce superficial staining of teeth. Moreover, specimens are exposed to coloring agents for a more extended period of time and both of their surfaces are exposed to the coloring agent *in vitro*, which is different from the clinical conditions, and results in greater discoloration *in vitro* [9].

Considering all the above, further investigations, especially in vivo studies, are required, taking into account the color change of zirconia to obtain more reliable results. Further studies are needed on the color stability of monolithic zirconia restorations exposed to different colored foods and beverages for longer periods of time.

Conclusion

The results indicated that tea caused maximum color change and maximum reduction in lightness in glazed monolithic zirconia ceramic; however, the color change was within the clinically acceptable range ($\Delta E<3.7$). Monolithic zirconia has clinically acceptable color stability; however, further studies are needed to confirm these findings.

Authors' Contributions

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EJ	https://orcid.org/0000-0002-5937-8687	Conceptualization, Data Curation, Writing - Review and Editing and Supervision.
ME	https://orcid.org/0000-0002-1819-2990	Methodology, Formal Analysis, Investigation, Writing - Original Draft and Writing - Review and Editing.
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FY	https://orcid.org/0000-0003-2686-1725	Conceptualization, Writing - Review and Editing and Supervision.
All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.		

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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