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RESEARCH AND EDUCATION

Evaluation of the color and translucency of glass-infiltrated zirconia based on the concept of functionally graded materials

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ABSTRACT

Statement of problem. Infiltrated zirconia has promising mechanical properties. However, information about its optical behavior is scarce.

Purpose. The purpose of this in vitro study was to evaluate the color and translucency of zirconia submitted to infiltration and aging.

Material and methods. Sixty zirconia disks were machined. Ten disks received no treatment (NT group), 10 disks were immersed in a coloring liquid (A2 group), and 10 disks were immersed in a fluorescent liquid (F group). The other 30 disks were submitted to the same treatments plus glass infiltration (NT+I, A2+I, and F+I groups). The coordinates L*, a*, and b* and the Y tristimulus values were obtained to calculate the color (ΔE_{00}), lightness, chroma, and hue differences; the translucency parameter (TP); and the contrast ratio (CR) associated with the specimens. After aging in an autoclave for 4 hours (T1), new measurements were made. Two- and 3-way ANOVAs were used to analyze color differences, TP, and CR. The lightness, chroma, and hue differences were evaluated by a repeated measures ANOVA. Multiple comparisons were made with the Tukey honestly significant difference (HSD) test (α=.05).

Results. The greatest color differences were observed in the A2+I group (11.23 ΔE_{00}) (P<.001). Aging affected the chroma of the colored groups (P=.013 and P=.001) but did not affect their translucency (P=.347 for TP and P=.132 for CR). The greatest TP values were found in the NT and NT+I groups (2.54 and 2.34, respectively), whereas the CR was equal to or close to 1 in all groups.

Conclusions. Color differences were observed in the glass-infiltrated groups. The TP and CR were affected by infiltration. Aging did not influence the optical behavior of the specimens. (J Prosthet Dent 2019;121:547.e1-e7)

Because of its biocompatibility, excellent mechanical properties, good chemical stability, and satisfactory optical properties, yitria-stabilized tetragonal zirconia polycrystal (Y-TZP) has become one of the most popular materials for dental restorations.[1,2] However, limitations inherent to this material can compromise its optical and mechanical performance and, consequently, its longevity; its susceptibility to aging is one of those limitations.[3] This phenomenon occurs progressively and spontaneously when zirconia is kept in contact with water or a humid environment and has multiple consequences, including surface degradation, microcracks, and a considerable medium- to long-term decrease of its mechanical resistance.[4-6]

The optical properties of zirconia are also a cause for concern. Although some translucent zirconias have been marketed for manufacture of monolithic crowns, the most used zirconia is a white material with poor translucency resulting from its high refractive index, low absorption coefficient, and high opacity in the visible and infrared electromagnetic spectra.[7-9]

Additive and paint-on techniques have been suggested to optimize the optical behavior of zirconia.[10] In the additive technique, precolored porous zirconia blocks have been developed by introducing metal oxides into

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Clinical Implications

Glass infiltration is indicated to minimize the aging and improve the mechanical properties of zirconia. However, it may compromise the optical properties of the zirconia, especially when this material is previously colored by immersion techniques.

the yttria-tetragonal zirconia polycrystal powder.[11-14] Painting techniques allow the technician to enhance esthetics by immersing zirconia in coloring solutions before sintering or by hand-painting with coloring solutions (brush infiltration).[13,15-20] However, white zirconia maintains its colorimetric properties after accelerated aging protocols, whereas these properties in colored zirconia may be altered due to hydrothermal degradation, causing them to become darker, more red, more yellow, and more opaque.[21-24]

Optimization of ceramic materials by applying concepts inspired by nature, such as functionally graded materials (FGMs), has been proposed.[25,26] FGMs are characterized by the ability to present spatial variations in their structure and/or chemical composition to improve properties and functionalities that cannot be achieved with homogeneous materials.[27,28] Based on this concept, metal-porcelain, zirconia-porcelain, and zirconia-glass interfaces have been idealized with a gradual transition of composition and properties.[25,29,30] A gradual transition between metal and porcelain resulted in a 100% increase in interface adhesion, thus suggesting that the application of this concept can improve the mechanical behavior of the system.[31] In the case of zirconia prostheses, the main challenge is to manufacture a structure with strong bonding to the ceramic veneering (for bilaminar prostheses) or a surface more resistant to hydrothermal degradation (for abutments and monolithic crowns) to achieve favorable mechanical and optical behaviors.[29,30,32]

An FGM whose surface was composed of glass-infiltrated zirconia with a mixture of silicate-based glass powder has been reported to have improved hardness, elastic properties, and fracture and fatigue resistances after infiltration,[32-34] suggesting that the presence of glass protected the Y-TZP from hydrothermal degradation. Another study[35] evaluated the translucency of glass-infiltrated zirconia and reported that the infiltrated specimens had higher translucency than those not infiltrated. However, although the zirconia tested had been submitted to a previous coloring process, no color evaluation was reported. Although these were in vitro studies, if thresholds are applied, it is possible to translate the laboratory results into the clinical environment.[36-38]

Several studies have evaluated the color and/or translucency of zirconia submitted to coloring using the coloring liquids without glass infiltration.[13,16,17,19,22,39-45] The results suggest a divergent optical behavior, especially regarding the translucency of ceramics, thus causing considerable controversy about the use of those liquids.[44] That divergent behavior is caused by the different oxides present in the coloring liquids and by the type of material and coloring technique used, mainly after aging.[12-17,22,24]

The purpose of this in vitro study was to evaluate the optical behavior (color and translucency) of zirconia before and after infiltration based on the FGM concept and application of an accelerated aging protocol. The null hypotheses tested were that the colorimetric parameters of the zirconia would not change after infiltration, that translucency would not be affected by the presence of glass, and that aging would not alter the colorimetric parameters tested, for both infiltrated and noninfiltrated specimens.

MATERIAL AND METHODS

Sixty disks of Y-TZP (Prettau Zirkon; Zirkonzahn) were machined from a digital design and divided into 3 groups (n=20): disks that received no treatment (NT), disks that were immersed in a coloring liquid (A2), and disks that were immersed in a fluorescent liquid (F). After sintering, the disks were 2-mm thick and 12 mm in diameter. Ten disks from the NT group received no laboratory treatment and were sintered at 1600°C (N.5 Program; Zirkonzahn). Ten disks from the A2 group were immersed in a coloring liquid (Color Liquid Prettau; Zirkonzahn) for 10 seconds and left to dry on absorbent paper under a heating lamp (Zirkonlampe 250; Zirkonzahn) for 30 minutes before being sintering. Ten disks from the F group were immersed in a fluorescent modifier liquid (Liquid Fluoreszenz; Zirkonzahn) for 5 seconds, dried, and sintered.

The other 30 disks were infiltrated with a translucent glass (VITA In-Ceram S1; VITA Zahnfabrik) based on the FGM concept. For the infiltration procedure, the following protocol was used: immersing or not the disks in the liquids; presintering at 1410°C for 2 hours; cooling at 10°C per minute until 600°C; maintaining the disks in the oven until the temperature reached 450°C; complete cooling at room temperature; applying the glass to the disks; and sintering cycle at up to 1480°C for 2 hours. The infiltrated zone (FGM) was confirmed by scanning electron microscopy (TM3030; Hitachi), as seen in Figure 1. The disks from the NT+I, A2+I, and F+I groups were infiltrated according to the protocol with VITA In-Ceram S1.

The initial color of the disks was measured using the CIELab system and named T0 (without aging). The L*, a*, and b* coordinates were measured using a spectrophotometer (CM-2600 d; Konica Minolta) in the reflectance mode with the following configurations:

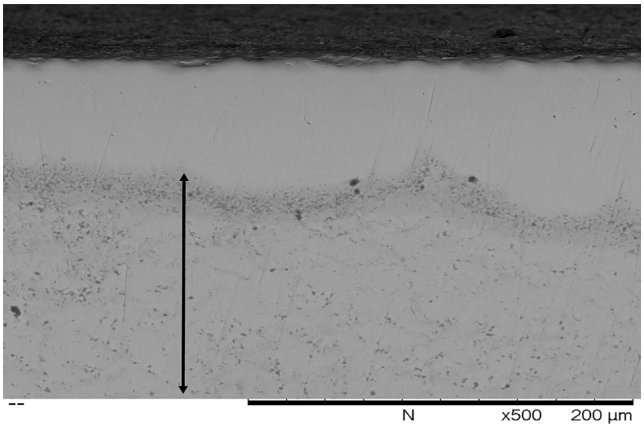

Figure 1. Micrograph of area infiltrated by glass (arrow). Original magnification ×500.

d/8-degree measurement geometry, 2-degree standard observer, 360- to 740-nm (10-nm interval) wavelength, area of illumination/measurement at small area view (3 mm), specular component excluded, and D65 standard illuminant. The repeatability and validity of the CM-2600 d spectrophotometer are presented in the manufacturer's instruction manual. The color of the disks was analyzed on an absolute white background (CIE calibration standard: L*=92.717; a*=–1.391; b*=4.184), and their translucency parameter (TP), on a black background (CIE calibration standard L*=6.789; a*=–0.055; b*=1.451). Measurements to obtain the contrast ratio (CR) were also made on the white and black backgrounds by the CIEXYZ system. Propylene glycol was applied between the disks and on the base to ensure optical continuity.[46] The same operator (C.A.M.V.) measured each disk 3 times in its center.

The disks were subjected to an accelerated aging protocol for 4 hours in an autoclave (Stern Weber) at 134°C (T1).[3] They were kept in heat-resistant ceramic containers and covered with distilled water. After cooling, they were again measured using the spectrophotometer. The color differences according to the coordinates were calculated using the CIEDE2000 formula[47]:

$$\Delta E_{00}=\left[\left(\frac{\Delta L'}{K_L S_L}\right)^2+\left(\frac{\Delta C'}{K_C S_C}\right)^2+\left(\frac{\Delta H'}{K_H S_H}\right)^2+ R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2},$$

where ΔL′, ΔC′, and ΔH′ are the differences in lightness, chroma, and hue; R_T is a rotation function that explains the interaction between chroma and hue in the blue region; S_L, S_C, and S_H are weighting functions; and the parametric factors K_L, K_C, and K_H are terms to be adjusted, which in this study were set to 1.[48,49] For the uncolored groups (NT, NT+I, F, and F+I), the following reference means were used: L*=88.143; a*=–0.775; and b*=3.034. For the colored groups (A2 and A2+I), the following reference means were used: L*=72.811; a*=0.710; and b*=14.361.

The TP was determined by the color differences between the disks on the white and black backgrounds. The higher the value found, the greater the translucency of the material is.[20] For the calculation of TP, the CIELab formula was used, where B and W refer to the coordinates obtained on the black and white backgrounds, respectively[50]:

$$TP=\left[\left(L_B^*-L_W^*\right)^2+\left(a_B^*-a_W^*\right)^2+\left(b_B^*-b_W^*\right)^2\right]^{1/2}.$$

The CR was obtained using the CIEXYZ system and defined as the ratio of the luminous reflectance (Y tristimulus value) on a black background (B) to the luminous reflectance on a white background (W).[50] The CR was calculated using the following formula:

$$CR=\frac{Y_B}{Y_W}.$$

The 3-way ANOVA (for NT, NT+I, F, and F+I groups) and 2-way ANOVA (for A2 and A2+I groups) were used to evaluate the color differences (ΔE_{00}). The lightness (ΔL′), chroma (ΔC′), and hue differences (ΔH′) were analyzed by repeated measures ANOVA. The values of the TP and CR were analyzed by the 3-way ANOVA (laboratory treatment, infiltration, and aging). Multiple comparisons were made with the Tukey HSD test (α=.05).

RESULTS

Table 1 shows the mean values of the differences in color (ΔE_{00}), lightness (ΔL′), chroma (ΔC′), and hue (ΔH′) of the TP and of the CR. Tables 2 to 5 present the results of the statistical analyses for the color, lightness, chroma, and hue differences. The greatest color differences were observed when the glass was infiltrated in colored disks (A2+I=11.23 ΔE_{00}). The results showed that the differences in lightness and chroma were more evident in these disks, that they became brighter (15.13 ΔL′), and that their color tended toward green (–6.11 ΔC′) (*P*<.001) (Table 5). The lightness also increased in the NT+I group (Table 3). Aging did not influence the color of the NT and F groups, irrespective of the presence of infiltrated glass (*P*=.163). When color, lightness, and hue were evaluated, significant interactions were observed between the groups and presence/absence of an infiltration process (*P*<.001) (Tables 2 and 3). However, color and chroma differences in the A2 and A2+I groups were significantly affected by aging (*P*=.013 and *P*=.001) (Tables 4 and 5).

Table 1. Averages and standard deviations of color (ΔE_{00}), lightness ($\Delta L'$), chroma ($\Delta C'$), and hue differences ($\Delta H'$); translucency parameter (TP); and contrast ratio (CR) according to aging times (T0 and T1) in groups infiltrated and not infiltrated

	NT		NT+I		A2		A2+I		F		F+I	
	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1
ΔE_{00}	0.82 ±0.22	1.08 ±0.25	3.05 ±0.28	2.99 ±0.49	1.03 ±0.15	1.20 ±0.22	11.23 ±0.56	10.42 ±0.47	5.55 ±0.12	5.52 ±0.14	2.83 ±0.23	3.01 ±0.32
$\Delta L'$	0.51 ±0.34	0.49 ±0.98	4.68 ±0.56	4.69 ±0.84	0.33 ±0.38	0.74 ±0.25	15.13 ±0.67	14.26 ±0.63	8.46 ±0.42	8.46 ±0.41	4.23 ±0.35	4.53 ±0.51
$\Delta C'$	0.61 ±0.57	0.79 ±0.56	−0.15 ±0.45	0.06 ±0.39	0.66 ±0.46	1.27 ±0.58	−6.11 ±0.86	−4.91 ±1.18	1.01 ±0.40	1.27 ±0.36	−0.08 ±0.24	−0.34 ±0.45
$\Delta H'$	−0.27 ±0.09	−0.33 ±0.13	−0.78 ±0.16	−0.77 ±0.16	−0.96 ±0.08	−0.75 ±0.16	0.92 ±0.38	0.51 ±0.33	−1.77 ±0.44	−1.54 ±0.34	−1.01 ±0.11	−0.96 ±0.10
TP	2.54 ±0.55	2.34 ±0.71	1.06 ±0.63	1.19 ±0.64	2.12 ±0.44	2.19 ±0.41	1.04 ±0.34	1.27 ±0.84	0.67 ±0.47	0.73 ±0.38	1.04 ±0.29	1.31 ±0.59
CR	0.94 ±0.01	0.95 ±0.02	0.98 ±0.02	0.99 ±0.03	0.98 ±0.01	0.97 ±0.01	0.97 ±0.03	1.00 ±0.02	0.99 ±0.01	0.99 ±0.01	0.98 ±0.01	0.98 ±0.02

The TP results showed significant differences regarding the groups tested and presence/absence of an infiltration process (*P*<.001) (Table 6). Aging did not affect translucency (*P*=.347). The highest TP values were found in disks without treatment (NT=2.54 and NT+I=2.34). Regarding the CR, its results were equal to or very close to 1, thus confirming the opacity of the zirconia tested, regardless of the laboratory treatment, presence of infiltrated glass, or aging. However, the CR values showed significant differences between the groups tested (*P*<.001) and the presence/absence of an infiltration process (*P*<.001) (Table 7). Aging did not affect the CR (*P*=.132). The highest opacity values were found in the colored and infiltrated group (A2+I=1.00).

Table 2. Three-way ANOVA of color differences (ΔE_{00}) for groups NT, F, NT+I, and F+I regarding laboratory treatment, infiltration, and aging

Variation Factor	SS	df	MS	F	*P*
Groups NT and F	100.698	1	100.698	1264.71	<.001
Infiltration	1.5097	1	1.509	18.961	<.001
Aging	0.157	1	0.157	1.981	.163
Groups×infiltration	109.637	1	109.637	1376.98	<.001
Groups×aging	0.003	1	0.003	0.041	.839
Infiltration×aging	0.016	1	0.016	0.207	.650
Groups×infiltration×aging	0.379	1	0.379	4.770	.032
Error	5.732	72	0.079		
Total	218.135	79			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

DISCUSSION

The present study evaluated the optical properties of glass-infiltrated zirconia, based on the concept of FGMs. The results showed that the color and translucency of the zirconia were altered after glass infiltration in almost all the tested groups, which rejects the first 2 hypotheses. The last hypothesis was partially accepted, although aging changed the color and chroma of the groups that were colored, because it did not alter the TP and CR.

An FGM is a material that has an intelligent configuration and is designed to optimize its mechanical, chemical, and/or optical properties, thus improving its long-term performance.[27] In dentistry, the manufacture of FGMs has been inspired by dental tissues, enamel, and dentin, which have different compositions and mechanical and optical behaviors. As the modulus of elasticity of enamel is about 65 GPa and that of dentin is 20 GPa, the presence of a transition zone (enamel-dentin junction) considerably reduces the tension on the enamel.[27,28] This bioinspired approach has been the subject of several studies aimed to develop materials and prosthetic interfaces to reduce the number of flaws, including chipping and fracture in ceramic veneering.[31,32,35] From the optical point of view, natural teeth also present different colors that can rarely be reproduced perfectly with only immersion techniques. Typically, manual techniques of ceramic stratification are used to achieve esthetics.[2,18] Ideally, zirconia prostheses should be obtained with a single material that presents colorimetric variations in the monolithic form, which characterizes an FGM with functional optics.[14]

Before the present study, pilot studies were conducted with different glasses (VITA In-Ceram Z21, VITA In-Ceram Z22, VITA In-Ceram S1, and VITA Arzent; VITA Zahnfabrik). The infiltration capacity of glass, final color, sintering temperature, and time were also tested. Initially, the disks were presintered at 1350°C for 1 hour.[32,33] After cooling, they were covered with glass using a brush and then returned to the furnace at 1480°C for 2 hours. However, the disks curved toward the zirconia surface that received the glass, thus rendering it useless for optical evaluation. Therefore, the sintering parameters were redefined for achieving parallelism between the surfaces of the disks. Regarding the infiltration capacity, one of the glasses (VITA Arzent) did not infiltrate the zirconia. Two glasses (VITA In-Ceram Z21 and VITA In-Ceram Z22) created a graduated interface (FGM), but the infiltrated disks became grayish. Only the glass selected for this study (VITA In-Ceram S1) allowed the color of the disk to be transmitted.

Because traditional zirconia is white, coloring liquids have been extensively used.[10,16,23,42] The results of this study suggest that coloration with an A2 liquid was influenced by the infiltration process and the accelerated aging protocol. Although the glass was visually translucent, its presence altered the initial colorimetric patterns, thus increasing the lightness of the zirconia (L′),

Table 3. Multivariate ANOVA of lightness (ΔL′), chroma (ΔC′), and hue differences (ΔH′) for groups NT, F, NT+I, and F+I regarding laboratory treatment, infiltration, and aging

		ΔL′				ΔC′				ΔH′			
Variation Factor	**df**	**SS**	**MS**	**F**	***P***	**SS**	**MS**	**F**	***P***	**SS**	**MS**	**F**	***P***
Groups NT and F	1	296.294	296.294	827.083	<.001	0.356	0.356	1.817	.181	12.265	12.265	232.228	<.001
Infiltration	1	0.014	0.014	0.039	.843	22.392	22.392	114.228	<.001	0.192	0.192	3.651	.060
Aging	1	0.048	0.048	0.135	.714	0.196	0.198	1.004	.319	0.064	0.064	1.230	.271
Groups×infiltration	1	337.808	337.808	942.966	<.001	1.842	1.842	9.397	.003	6.598	6.598	124.926	<.001
Groups×aging	1	0.204	0.204	0.571	.452	0.198	0.198	1.013	.317	0.138	0.138	2.625	.109
Infiltration×aging	1	0.065	0.065	0.183	.670	0.274	0.274	1.402	.240	0.012	0.012	0.231	.632
Groups×infiltration×aging	1	0.162	0.162	0.452	.503	0.370	0.370	1.889	.173	0.074	0.074	1.417	.023
Error	72	25.793	0.358			14.114	0.196			3.802	0.052		
Total	79	660.390				39.745				23.150			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

whereas aging affected its chroma (C′). Shah et al[12] found a considerable increase in the b* coordinate caused by the use of higher concentrations of cerium and bismuth. Nakamura et al[22] and Alghazzawi[24] reported chromatic alterations due to hydrothermal degradation in colored zirconia and related this finding to the transformation of phases that occurred on its surface, which changed the optical reflection of the material. According to other studies, pigments from coloring liquids can act as impurities and cause crystallographic and microstructural changes that may affect the optical and mechanical properties of zirconia.[12,13]

During color measurement, it is important to control the loss of light through the edges of the specimens, especially in optical equipment with small area view. This phenomenon is known as the edge loss.[46] The use of liquids or gels with a low refractive index (distilled water, 1.7; glycerin gel, 1.9) between the disk and background improves the optical contact and reduces the edge-loss effect. Other strategies include the use of plane-parallel disks twice the size of the area view and measurements made in the center of the disk.

Although this research was in vitro, the color differences found can be compared with proposed perceptibility and acceptability thresholds to correlate with clinical conditions. In 2010, Guinea et al[36] determined thresholds for dental ceramics based on the CIELab (ΔE_{ab}) and CIEDE2000 (ΔE_{00}) formulas. For the CIEDE2000 system, those authors found acceptability values in ΔE_{00}=2.23 and perceptibility values in ΔE_{00}=1.25. When the results of this study were compared with the thresholds proposed by Guinea et al, all infiltrated groups showed color differences greater than the 2 thresholds, thus making these differences perceptible and unacceptable when compared with the initial color of the zirconia. However, the differences found in the untreated and fluorescent groups showed imperceptible color differences, even after aging. These findings agree with those of previous studies, in which the color differences in white zirconia were very discrete.[21,23]

Table 4. Two-way ANOVA of color differences (ΔE_{00}) for groups A2 and A2+I regarding infiltration and aging

Variation Factor	**SS**	**df**	**MS**	**F**	***P***
Infiltration	943.151	1	943.151	6057.792	<.001
Aging	1.055	1	1.505	6.775	.013
Infiltration×aging	2.378	1	2.378	15.271	<.001
Error	5.605	36	0.156		
Total	952.188	39			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

Zirconia has lower translucency than other ceramic materials.[7,43] The translucency of an object depends on its dispersion and absorption coefficients, grain size, and material density, as well as the thickness of the specimen.[16,44,50] Two methods (TP and CR) have been used for translucency analysis.[8,50] CR is a direct measure of opacity, whereas TP measures the translucency of the object considering a certain thickness.[50] The TP results in this study ranged from 0.67 (in the F group) to 2.54 (in the NT group). Low values of translucency were expected for the traditional zirconia used, and this was confirmed by high CR values. The use of coloring liquids may decrease translucency, although it is not affected by the number of color applications.[15,18,42] A decrease in translucency after the use of coloring and fluorescent liquids, as well as after infiltration, was also observed in the present study. When evaluating the translucency of white and colored zirconia submitted to glass infiltration, Zhang et al[35] reported that glass provided a gradual transition resulting in good optical depth. According to those authors, this might be related to the presence of pores, second phases, inclusions, or grains with diverse crystallographic orientation, which would be responsible for the light dispersion.[9,16] In the present study, the presence of glass within the zirconia microstructure probably prevented light transmission, thus contrasting with the findings of Zhang et al.[35]

Lui et al[37] proposed a translucency perception threshold (TPT) from the CR values and the perception of

Table 5. Multivariate ANOVA of lightness (ΔL′), chroma (ΔC′), and hue differences (ΔH′) for groups A2 and A2+I regarding infiltration and aging

		ΔL′				ΔC′				ΔH′			
Variation Factor	**df**	**SS**	**MS**	**F**	***P***	**SS**	**MS**	**F**	***P***	**SS**	**MS**	**F**	***P***
Infiltration	1	2004.697	2004.697	7499.380	<.001	420.623	420.623	623.357	<.001	24.965	24.965	340.255	<.001
Aging	1	0.539	0.539	2.017	.164	8.327	8.327	12.341	.001	0.110	0.110	1.507	.227
Infiltration×aging	1	4.020	4.020	15.040	.0004	0.864	0.864	1.281	.265	0.970	0.970	13.224	<.001
Error	36	9.623	0.267			24.2917	0.674			2.641	0.073		
Total	39	2018.880				454.106				28.687			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

Table 6. Three-way ANOVA of translucency parameter (TP) for all groups regarding laboratory treatment, infiltration, and aging

Variation Factor	**SS**	**df**	**MS**	**F**	***P***
Groups/laboratorial treatment	16.641	2	8.320	27.305	<.001
Infiltration	11.294	1	11.294	37.062	<.001
Aging	0.271	1	0.271	0.891	.347
Groups×infiltration	18.531	2	9.265	30.405	<.001
Groups×aging	0.258	2	0.129	0.423	.655
Infiltration×aging	0.407	1	0.407	1.337	.250
Groups×infiltration×aging	0.038	2	0.019	0.063	.938
Error	32.911	108	0.304		
Total	80.354	119			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

Table 7. Three-way ANOVA of contrast ratio (CR) for all groups regarding laboratory treatment, infiltration, and aging

Variation Factor	**SS**	**df**	**MS**	**F**	***P***
Groups/laboratorial treatment	0.0086	2	0.0043	8.8	<.001
Infiltration	0.0058	1	0.0058	11.8	<.001
Aging	0.0011	1	0.0011	2.3	.132
Groups×infiltration	0.0164	2	0.0082	16.8	<.001
Groups×aging	0.0003	2	0.0002	0.3	.737
Infiltration×aging	0.0005	1	0.0005	0.9	.336
Groups×infiltration×aging	0.0030	2	0.0015	3.1	.050
Error	0.0530	108	0.0005		
Total	0.0887	119			

df, degrees of freedom; MS, mean of squares; SS, sum of squares.

different groups of observers to establish a correlation between the instrumental analysis and the visual perception of translucency. Those authors found that the overall mean TPT was 0.07 and that 50% of the study population perceived a difference in translucency at 0.06 CR. When the results of this study were compared with the TPT proposed by Lui et al,[37] all values were greater (equal or similar to 1) to the proposed threshold, which confirmed the opaque behavior of the tested material. Recently, Salas et al[38] determined the translucency perceptibility (TPT) and acceptability (TAT) thresholds using CIEDE2000 and CIELab color-difference formulas. The authors reported that the CIEDE2000 50:50% TPT_{00} was 0.62 and TAT_{00} was 2.62 units. According to these findings, all the translucency values (TP) found in the present study were higher than TPT_{00} and lower than TAT_{00}, suggesting that the translucency found was not perceptible but remained within the threshold of acceptability proposed by these authors.

A fluorescent liquid was used during the manufacturing of the specimens. Although color and fluorescence are not correlated optical properties, whenever possible, they should be evaluated because patients are exposed to light sources rich in ultraviolet light. In a previous study,[45] the analysis of the degree of fluorescence of zirconia specimens was performed using equipment that captures photographic images. Although this study used percentage results to assess the presence or absence of fluorescence, a more in-depth study would be necessary because the literature on the fluorescent behavior of zirconia is scarce. In this way, the authors of the present study also conducted studies to analyze the emission and excitation curves in fluorimeters, as well as fluorescence maps, and the results of these studies will be presented in a future article. In the meantime, according to the results obtained in this study, the use of the fluorescent liquid modified the optical behavior of the zirconia tested, especially in relation to its lightness (L*) and translucency (TP), and this finding indicates the change of optical behavior after the use of this liquid.

Different immersion times in coloring and fluorescent liquids, as well as the use of ultratranslucent zirconia, are the limitations of this study. Furthermore, the results obtained showed the need for further research, especially related to the fluorescence of dental zirconia. Further investigations are required to verify whether the fluorescence obtained with laboratory procedures is similar to the phenomenon in natural teeth, whether the coloration obtained with immersion liquids is constant and reproducible, and whether the coloration obtained is associated with glass infiltration or not.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Glass infiltration in the surface of the zirconia modified the L*, a*, and b* colorimetric parameters of the tested groups, resulting in large color differences, especially in the color group (A2+I).

2. The TP and CR were affected by infiltration, which decreased their values in all infiltrated groups.
3. Accelerated aging did not affect the translucency values (TP and CR) significantly but influenced the color and chroma of the colored specimens.

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