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RESEARCH AND EDUCATION

Color accuracy of different types of monolithic multilayer precolored zirconia ceramics

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ABSTRACT

Statement of problem. The use of monolithic multilayer precolored zirconia facilitates the production of esthetic restorations in a convenient and straightforward manner. However, the accuracy of the final color is not clear.

Purpose. The purpose of this in vitro study was to determine the color accuracy of different types of monolithic multilayer precolored zirconia ceramics of varying thicknesses.

Material and methods. Eighty cubical A2-shade monolithic multilayer precolored zirconia ceramic specimens (15×15 mm) of 2 different thicknesses (1.0 mm and 1.5 mm) and 4 zirconia brands (UPCERA EXPLORE [UPEX], KATANA Zirconia STML [STML], Enamel ZR Multi-5 [EZM5], and Aidite 3D Pro Zir [A3DM]) were fabricated and divided into 8 groups (n=10). The Commission Internationale de l'Eclairage (CIELab) values were measured against 3 different backing substrates (gray, transparent, and A2) by using a spectrophotometer. The color difference (ΔE) between the backing substrates of each group and the Vita A2 Shade Guide, translucency parameter (TP), and chroma (C) values were calculated to evaluate the accuracy of the final color. Statistical analysis was performed by using ANOVA and the post hoc Tukey HSD tests (α=.05).

Results. The ΔE values for UPEX and STML exceeded the clinically acceptable thresholds for gray and transparent backing substrates (ΔE>3.7) and were higher than those for the A2 backing substrate. A3DM showed less ΔE from the shade guide for all the backing substrates (P<.05), and the corresponding ΔE values were within the clinically acceptable threshold (ΔE<3.7). The TP value was inversely proportional, and the C value was proportional to thickness. For the zirconia ceramics with identical thicknesses, UPEX and STML exhibited the highest TP values, and A3DM showed the lowest C value (P<.05).

Conclusions. At a specific thickness, color accuracy was mainly affected by the type of monolithic multilayer precolored zirconia ceramic, and the high transparency of ceramics will cause color differences. (J Prosthet Dent 2020;■:■-■)

The recently developed monolithic multilayer precolored zirconia ceramics do not need coloring by immersion or brushing the coloring solution over the zirconia surface before sintering.[1-4] Advantages include avoiding any reduction in strength from the staining process.[5,6] In addition, the precolored zirconia blocks facilitate the laboratory steps,[2,7] and the clinical procedures are straightforward and convenient.[8] Monolithic multilayer precolored zirconia ceramics are polychromatic and translucent and have multilayer shade and translucency gradients.[9-13] They have been considered as an excellent restorative dentistry option,[14-18] eliminating the risk of chipping with bilayer material restorations[11,17,19,20] such as metal-ceramic[21,22] or veneered zirconia.[23,24] However, as the final color of monolithic multilayer precolored zirconia cannot be modified with staining or a veneering porcelain, it must match the natural tooth. The effects of the thickness of monolithic zirconia ceramic on the final color[7,25-27] and its optical properties[28-30] have been investigated. However, studies on the accuracy of the final color for different types of monolithic multilayer precolored zirconia ceramics are lacking. Therefore, the purpose of this in vitro study was to investigate the color accuracy of 4 different types of monolithic multilayer precolored zirconia ceramics with varying thicknesses.

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Clinical Implications

The type of porous zirconia blocks and different transparencies affected the final color of monolithic multilayer precolored zirconia ceramics. These factors should be considered to achieve optimal esthetics.

The null hypothesis was that no significant difference in color accuracy would be found between the different types of zirconia ceramics tested.

MATERIAL AND METHODS

Four types of monolithic multilayer precolored zirconia ceramic blocks were used in this study (Table 1). Plate-shaped (15×15 mm) specimens in 2 different thicknesses (1.0 mm and 1.5 mm) were located upright in the center of A2-shade zirconia disks and produced with computer-aided design and computer-aided manufacturing (CAD-CAM) (Fig. 1). A total of 80 multilayer precolored porous zirconia specimens were prepared and sintered according to the manufacturers' instructions.

The color of the specimens was measured through the Commission Internationale de l'Eclairage (CIELab) system by using a dental spectrophotometer (Shade Pilot; DeguDent GmbH) (Fig. 1C)[31] calibrated by using the manufacturer-provided white balance plate before the test and after every 10 measurements. The specimens were placed in the center, and the angle between the sensor and specimens was set at 89-91 degrees. Each of the CIELab values (L^* [lightness], a^* [red-green], and b^* [yellow-blue]) was measured against 3 different backing substrates (gray, A2, and transparent).

The gray backing substrate (L^*=39.5, a^*=-0.8, and b^*=0.6) was a standardized professional photography card (QP Card 101; QPcard AB). The A2 backing substrates were fabricated as follows. A 40×40-mm paraffin wax pattern was cast in a nickel-chromium alloy (KERA N Ni-Cr alloy; Eisenbacher Dentalwaren ED GmbH), airborne-particle abraded, coated with A2 opaque porcelain (GC Initial Paste Opaque; GC Corp), and fired (AUSTROMAT 624; DEKEMA Dental-Keramiköfen GmbH) according to the manufacturer's instructions (L^*=74.4, a^*=1.1, and b^*=23.3). The transparent backing substrate used a clear glass sheet, which was suspended at 100 cm above the bench during testing to avoid the objects below affecting the results.

Color differences (ΔE) between each group and the Vita A2 shade guide (L^*=73.7, a^*=1.3, and b^*=18.0) against each backing substrate were calculated by using the following CIELab color difference formula[32]: $\Delta E=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$, where ΔL^*, Δa^*, and Δb^* refer to the difference along the value, red-green, and yellow-blue coordinates.

Translucency parameter (TP) values were determined by calculating the color difference for the specimen against the black and white backing substrates by using the following formula[33]: $TP=[(L^*_B-L^*_W)^2+(a^*_B-a^*_W)^2+(b^*_B-b^*_W)^2]^{1/2}$, where the subscripts B and W refer to the color coordinates against black (L^*=22.3, a^*=-0.5, and b^*=-0.9) and white (L^*=90.9, a^*=-0.7, and b^*=1.8) backing substrates (QP Card 101; QPcard AB). A TP value of 100 corresponds to a completely transparent layer; the greater the TP value, the lower the masking ability of the material. The chroma values (C) were calculated by using the following formula[34]: $C=[(a^*)^2+(b^*)^2]^{1/2}$.

The normality of distribution was analyzed by using the Shapiro-Wilk test. As all data exhibited normal distribution, parametric tests were conducted. Data were statistically evaluated through 3-way repeated measures ANOVA with fixed factors of types of zirconia blocks, thickness, and backing substrates after post hoc comparisons with the Tukey honestly significant difference (HSD) test. The TP and C values were analyzed with 2-way ANOVA by using the factors describing the thickness and type of zirconia blocks, followed by the post hoc Tukey HSD test. All analyses were performed by using a statistical software program (IBM SPSS Statistics, v24; IBM Corp) (α=.05).

RESULTS

The results of 3-way repeated measurements ANOVA for CIELab color values are presented in Table 2. The ANOVA indicated a significant interaction among the 3 factors. The means and standard deviations of all the obtained data are included in Tables 3-5. For the gray (Table 3) and transparent (Table 4) backing substrates, the a^* and b^* values increased with an increase in thickness for the same type of zirconia blocks, but the L^* value change depended on the materials. Regardless of thickness, the highest L^* values were observed for EZM5 against the gray backing substrate and for A3DM and EZM5 against the transparent backing substrate. A3DM exhibited the highest a^* values and lowest b^* values against both backing substrates. Against A2 backing substrates (Table 5), the L^* and b^* values decreased, but the a^* values increased with an increase in thickness for the same type of zirconia blocks. EZM5 showed the highest L^*, A3DM showed the highest a^* values, and UPEX and STML showed the highest b^* values.

The color differences (ΔE) between each type of monolithic multilayer precolored zirconia ceramic and the Vita A2 shade guide against different backing substrates are seen in Figure 2. The ΔE for UPEX and STML in both thicknesses against the gray or transparent

Table 1. Materials used and their specifications

Material	Chemical Composition: Main Compounds	Chemical Composition: Yttria Content	Manufacturer	Lot Number	Code
EXPLORE	ZrO_2 (>86.8%) Y_2O_3 (5.8-9.7%)	3Y-TZP + 5Y-PSZ	Shenzhen Upcera Dental Technology Co	L2181213279	UPEX
KATANA Zirconia STML	ZrO_2 (88-93%) Y_2O_3 (7-10%)	5Y-PSZ	Kuraray Noritake Dental Inc	DULPA	STML
Enamel ZR Multi-5	ZrO_2 (>92.8%) Y_2O_3 (6.9%)	4Y-PSZ + 5Y-PSZ	Tanaka Dental Co	AHJ22104	EZM5
3D Pro Zir	ZrO_2 (90-95%) Y_2O_3 (4-10%)	4Y- PSZ + 5Y-PSZ	Aidite Technology Co, Ltd	2019061-3D-2	A3DM

Data compiled from manufacturer guidelines and literature sources. Yttria content: 3Y-TZP, 3 mol% yttria-partially stabilized tetragonal zirconia polycrystal; 4Y-PSZ, 4 mol% yttria-partially stabilized zirconia; 5Y-PSZ, 5 mol% yttria-partially stabilized zirconia.

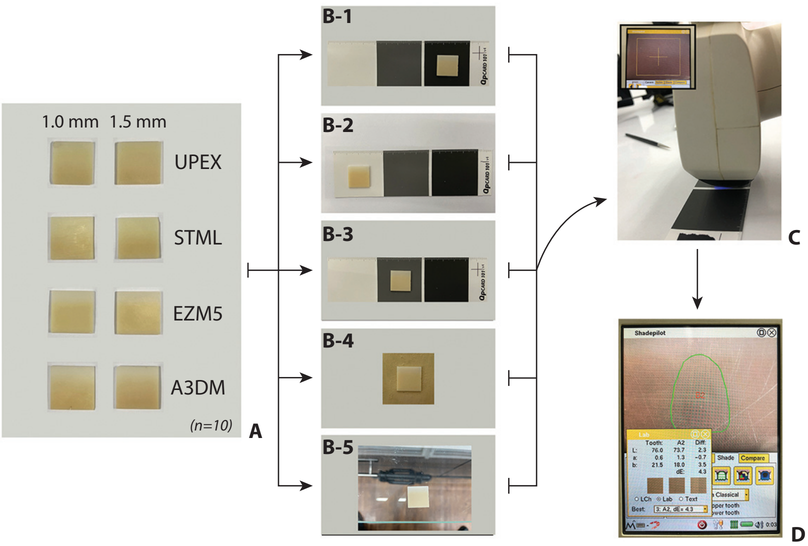

Figure 1. Zirconia specimens and color measurement steps. A, Eight different groups of specimens prepared (n=10, N=80). B, Color measurements under 5 different backing substrates: black, white, gray, A2, and transparent. C, Dental spectrophotometer (Shade Pilot) used to measure CIELab value of each specimen. D, After color measurement, monochrome analysis performed (the comparison group standard value of Vita A2 shade guide).

backing substrates were clinically perceptible (ΔE>3.7).[35] Against the A2 backing substrates, ΔE was only clinically perceptible for EZM5 with a 1.0-mm thickness (ΔE=3.76). The ΔE for A3DM at both thicknesses against each backing substrate were within the clinically acceptable threshold (ΔE<3.7). The post hoc Tukey HSD tests (Tables 3-5) revealed that the ΔE of A3DM showed no significant difference between A2 and gray (P=1.000 at 1.0 mm; P=.112 at 1.5 mm) or A2 and transparent (P=.992 at 1.0 mm; P=.857 at 1.5 mm) backing substrates; however, there was statistically significant difference (P<.05) among other types. For all tested specimens, no significant differences between the ΔE against gray and transparent backing substrates were observed (P>.05).

The TP and C values for monolithic multilayer precolored zirconia ceramics at 1.0-mm and 1.5-mm thicknesses are seen in Figure 3. The 2-way ANOVA (Table 6) showed that the thickness and type of zirconia had a significant effect on the TP and C values (P<.05). The results of the post hoc Tukey HSD tests indicated that for an identical zirconia type, all specimens with a 1.5-mm thickness had significantly high C values and lower TP values (P<.05). For different types of zirconia blocks with identical thickness values, UPEX and STML exhibited significantly higher TP values than those for EZM5 and A3DM (P<.05). A3DM showed significantly lower C values than UPEX, STML, and EZM5 (P<.05).

DISCUSSION

The null hypothesis was rejected because the results indicated that the final color accuracy varied depending on the type of zirconia blocks, even with identical thicknesses. The experimental results showed that thickness affected the transparency and final color of monolithic multilayer precolored zirconia ceramics, which was consistent with the results of previous studies.[11,25-27] However, the type of zirconia block was

Table 2. Three-way repeated measures analysis of variance (source from Sphericity Assumed) for CIELab values (*L**, *a**, *b**, and *ΔE*) with fixed factors of types of zirconia blocks, thickness, and backing substrates

Source of Variation	Type III Sum of Squares	df	Mean Square	F	P
*a**					
Type	42.55	3	14.183	435.15	<.001
Error (Type)	0.88	27	0.033	—	—
Thick	11.97	1	11.971	378.91	<.001
Error (Thick)	0.28	9	0.032	—	—
Back	284.97	2	142.486	13135.73	<.001
Error (Back)	0.20	18	0.011	—	—
Type×Thick	1.01	3	0.336	7.41	.001
Error (Type×Thick)	1.22	27	0.045	—	—
Type×Back	1.86	6	0.309	16.80	<.001
Error (Type×Back)	0.99	54	0.018	—	—
Thick×Back	0.28	2	0.141	4.28	.030
Error (Thick×Back)	0.60	18	0.033	—	—
Type×Thick×Back	0.49	6	0.081	2.63	.026
Error (Type×Thick×Back)	1.66	54	0.031	—	—
*b**					
Type	108.67	3	36.223	142.12	<.001
Error (Type)	6.88	27	0.255	—	—
Thick	19.55	1	19.551	50.71	<.001
Error (Thick)	3.47	9	0.386	—	—
Back	1272.98	2	636.490	4329.32	<.001
Error (Back)	2.65	18	0.147	—	—
Type×Thick	0.25	3	0.082	0.18	.911
Error (Type×Thick)	12.52	27	0.464	—	—
Type×Back	11.87	6	1.979	9.29	<.001
Error (Type×Back)	11.50	54	0.213	—	—
Thick×Back	20.26	2	10.130	51.37	<.001
Error (Thick×Back)	3.55	18	0.197	—	—
Type×Thick×Back	0.61	6	0.102	0.60	.730
Error (Type×Thick×Back)	9.15	54	0.170	—	—
*L**					
Type	948.15	3	316.051	960.53	<.001
Error (Type)	8.88	27	.329	—	—
Thick	12.24	1	12.240	32.78	<.001
Error (Thick)	3.36	9	0.373	—	—
Back	1031.03	2	515.515	4614.25	<.001
Error (Back)	2.011	18	0.112	—	—
Type×Thick	25.86	3	8.618	19.51	<.001
Error (Type×Thick)	11.93	27	0.442	—	—
Type×Back	10.73	6	1.789	9.13	<.001
Error (Type×Back)	10.58	54	0.196	—	—
Thick×Back	15.75	2	7.877	55.88	<.001
Error (Thick×Back)	2.54	18	0.141	—	—
Type×Thick×Back	0.51	6	0.085	0.38	.891
Error (Type×Thick×Back)	12.18	54	0.225	—	—
ΔE					
Type	83.90	3	27.967	572.92	<.001
Error (Type)	1.32	27	0.049	—	—
Thick	10.49	1	10.488	80.62	<.001
Error (Thick)	1.17	9	0.130	—	—

(*continued on next page*)

Table 2. (*continued*) Three-way repeated measures analysis of variance (source from Sphericity Assumed) for CIELab values (L^*, *a**, *b**, and *ΔE*) with fixed factors of types of zirconia blocks, thickness, and backing substrates

Source of Variation	Type III Sum of Squares	df	Mean Square	F	P
Back	56.16	2	28.081	386.19	<.001
Error (Back)	1.31	18	0.073	—	—
Type×Thick	2.79	3	0.930	9.22	<.001
Error (Type×Thick)	2.72	27	0.101	—	—
Type×Back	146.19	6	24.365	248.80	<.001
Error (Type×Back)	5.29	54	0.098	—	—
Thick×Back	1.24	2	0.620	5.45	.014
Error (Thick×Back)	2.049	18	0.114	—	—
Type×Thick×Back	2.309	6	0.385	2.903	.016
Error (Type×Thick×Back)	7.159	54	0.133	—	—

Table 3. Means ±standard deviation of CIE L^*, a^*, b^*, and *ΔE* values of each group measured against gray backing substrate

Group	*L**	*a**	*b**	*ΔE*
UPEX 1.0 mm	69.08 ±0.46^{a}	-0.99 ±0.09^{a}	15.84 ±0.22$^{a, d}$	4.42 ±0.26$^{\alpha}$
UPEX 1.5 mm	69.11 ±0.53^{a,b}	-0.60 ±0.14^{b}	16.42 ±0.42$^{a, b}$	4.04 ±0.36$^{\alpha}$
STML 1.0 mm	69.68 ±0.59^{a,c}	-1.45 ±0.14^{c}	15.78 ±0.58$^{a, d}$	4.49 ±0.33$^{\alpha}$
STML 1.5 mm	68.86 ±0.58^{b,c}	-0.79 ±0.18^{a,b}	16.51 ±0.63^{a,b}	4.31 ±0.45$^{\alpha}$
EZM5 1.0 mm	74.24 ±0.43^{d}	-0.65 ±0.25^{d}	16.16 ±0.50^{a,b}	2.60 ±0.36$^{\beta}$
EZM5 1.5 mm	74.08 ±0.83^{d}	-0.07 ±0.25^{e}	16.85 ±0.27^{b}	1.79 ±0.32$^{\gamma}$
A3DM 1.0 mm	72.91 ±0.39^{e}	-0.04 ±0.16^{e}	14.58 ±0.77^{c}	2.52 ±0.40$^{\beta}$
A3DM 1.5 mm	73.66 ±0.41^{e}	0.34 ±0.20^{f}	15.39 ±0.77$^{c, d}$	1.84 ±0.47$^{\gamma}$

Within same column, different letters indicate groups statistically different from each other based on post hoc comparisons by Tukey HSD test ($P<.05$).

more influential in affecting the final color than the thickness. Although the restoration can be modified by external staining, this decreases the brightness rather than changing the color of zirconia.[27,28]

Hee-Kyung Kim and Sung-Hun Kim[30] reported that different types of zirconia had different translucencies because of differences in yttrium oxide content. An increase in yttrium oxide content increases the amount of nonbirefringent cubic phase, thereby increasing transparency.[8,15,29] However, the yttrium oxide content was not related to translucency in the present study because the internal structure of the zirconia blocks tested (UPEX, EZM5, and A3DM) was composed of different YSZ materials (Table 1, Fig. 1),[8] which resulted in different transparencies in different layers.

The clinically acceptable threshold of color difference (*ΔE*) between the compared teeth considered as a match in the oral environment has been reported to be *ΔE*<3.7.[35] Regardless of the type of zirconia blocks, the *ΔE* (Fig. 2) measured against gray and transparent backing substrates were similar. The *ΔE* for UPEX and STML exceeded the clinically acceptable threshold against gray (Table 3) and transparent (Table 4) backing

Table 4. Means ±standard deviations of CIE L^*, a^*, b^*, and ΔE values of each group measured against transparent backing substrate

Group	L^*	a^*	b^*	ΔE
UPEX 1.0 mm	69.26 ±0.42^{a}	-1.19 ±0.13^{a}	15.22 ±0.41^{a}	4.60 ±0.25$^{\alpha}$
UPEX 1.5 mm	68.88 ±0.55^{a}	-0.69 ±0.11^{b}	16.50 ±0.24^{b}	4.23 ±0.36$^{\alpha}$
STML 1.0 mm	69.16 ±0.40^{a}	-1.49 ±0.13^{c}	15.29 ±0.39^{a}	4.89 ±0.18$^{\alpha}$
STML 1.5 mm	68.51 ±0.32^{a}	-0.94 ±0.13^{d}	16.63 ±0.30^{b}	4.62 ±0.23$^{\alpha}$
EZM5 1.0 mm	73.03 ±0.45$^{b, c}$	-0.65 ±0.16^{b}	15.52 ±0.53^{a}	2.71 ±0.33$^{\beta}$
EZM5 1.5 mm	73.22 ±0.56^{b}	-0.13 ±0.14^{e}	16.58 ±0.48^{b}	1.84 ±0.26$^{\gamma}$
A3DM 1.0 mm	72.36 ±0.38^{c}	-0.16 ±0.13^{e}	13.93 ±0.47^{c}	3.09 ±0.28$^{\beta}$
A3DM 1.5 mm	73.34 ±0.41^{b}	0.22 ±0.17^{f}	15.08 ±0.61^{a}	2.07 ±0.39$^{\gamma}$

Within same column, different letters indicate groups statistically different from each other based on post hoc comparisons by Tukey HSD test ($P<.05$).

Table 5. Means ±standard deviations of CIE L^*, a^*, b^*, and ΔE values of each group measured against A2 backing substrate

Group	L^*	a^*	b^*	ΔE
UPEX 1.0 mm	74.79 ±0.47^{a}	1.55 ±0.17^{a}	21.57 ±0.34^{a}	2.16 ±0.19$^{\alpha}$
UPEX 1.5 mm	73.17 ±0.47^{b}	1.69 ±0.13^{b}	21.19 ±0.36$^{a, b}$	1.72 ±0.36$^{\alpha}$
STML 1.0 mm	74.86 ±0.57^{a}	0.95 ±0.19^{d}	21.48 ±0.46$^{a, d}$	2.21 ±0.06$^{\alpha}$
STML 1.5 mm	72.79 ±0.51^{b}	1.70 ±0.14^{b}	21.19 ±0.51$^{a, e, f}$	1.77 ±0.26$^{\alpha}$
EZM5 1.0 mm	78.14 ±0.33^{c}	1.66 ±0.17^{b}	20.74 ±0.32$^{b, d, f}$	3.76 ±0.24$^{\beta}$
EZM5 1.5 mm	77.34 ±0.69$^{c, d}$	1.94 ±0.28^{c}	20.59 ±0.33$^{b, e}$	3.25 ±0.42$^{\gamma}$
A3DM 1.0 mm	77.03 ±0.65^{d}	2.06 ±0.14^{c}	19.21 ±0.47^{c}	2.86 ±0.38$^{\gamma}$
A3DM 1.5 mm	76.88 ±0.57^{d}	2.29 ±0.20^{c}	19.18 ±0.73^{c}	2.84 ±0.26$^{\gamma}$

Within same column, different letters indicate groups statistically different from each other based on post hoc comparisons by Tukey HSD test ($P<.05$).

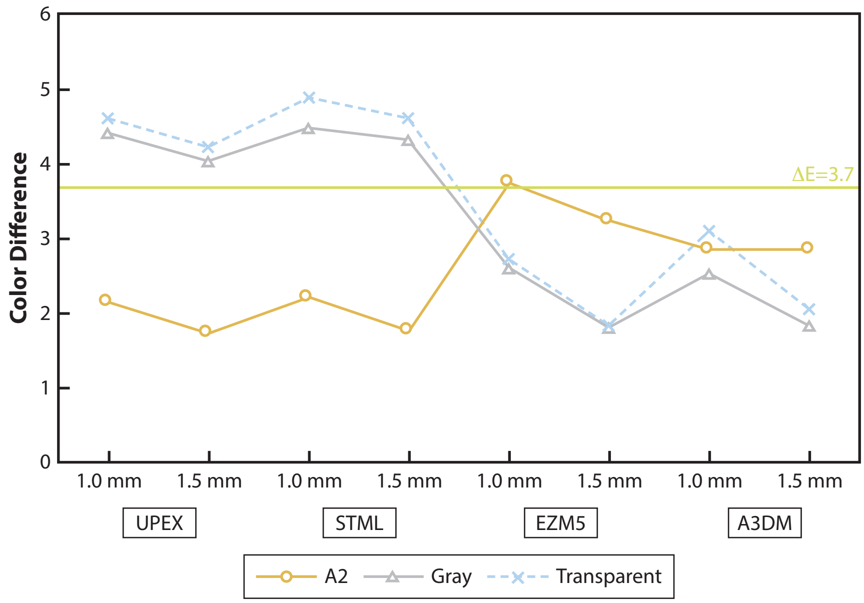

Figure 2. Color differences (ΔE) for different materials against various backing substrates. Horizontal line represents clinically acceptable threshold of ΔE=3.7.

substrates (ΔE>3.7) and were higher than those for A2 backing substrate (Table 5). This can be explained by high transparency, resulting in more light entering and larger scattering from zirconia; thus, the background color affected the final color considerably.[12,13] Transparency may not be a key factor during the selection of monolithic multilayer precolored zirconia blocks.

The C values of A3DM were lower than those for UPEX, STML, and EZM5 (Fig. 3) because the initial colors of UPEX, STML, and EZM5 are darker than the A2 shade. The resulting high transparency required the use of deep coloring pigments to adjust the color. With an increase in the coloring pigments, the C values increase, but the brightness decreases and the color difference becomes large.[2,3] Clinically, it is best to avoid choosing the zirconia block with too high a chroma value because the final color after firing will produce lower brightness than expected and a poor color match.[2,9,10] The results for ΔE for EZM5 were in contrast with those for other zirconia blocks. To prevent ΔE caused by high transparency, the brightness of EZM5 was increased, thereby increasing the C values and affording an initial color of zirconia block that closely matched the A2 shade. This resulted in a small ΔE for EZM5 against the gray and transparent backing substrates; however, a larger ΔE was found against the A2 backing substrate. A3DM showed low transparency, and ΔE measured against various backing substrates were small and within the clinically acceptable threshold (ΔE<3.7).

The results obtained in this article suggest that A3DM zirconia block exhibited the best color accuracy of all the specimens tested in this study. However, only one shade (A2) was tested, and different shades may produce

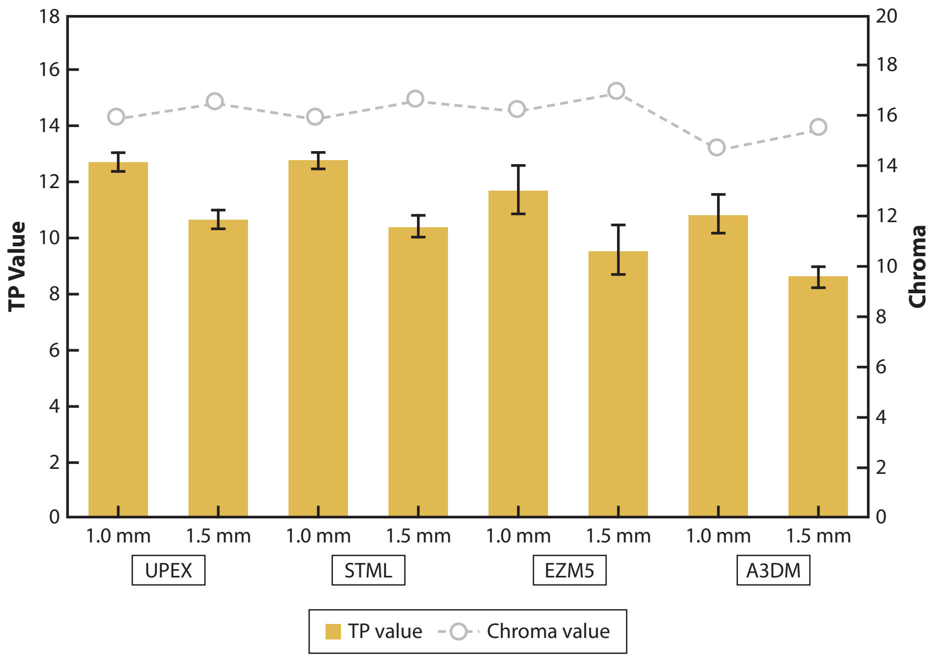

Figure 3. Translucency parameter (TP) and chroma (C) values of monolithic multilayer. Precolored zirconia ceramics at 1.0-mm and 1.5-mm thickness.

Table 6. Results of 2-way ANOVA on effects of types of zirconia blocks and thickness of translucency parameter (TP) and chroma (C) values

Source	Type III Sum of Squares	df	Mean Square	F	*P*
TP					
Type	53.09	3	17.696	55.15	<.001
Thickness	90.78	1	90.781	282.93	<.001
Type×Thickness	0.14	3	0.048	0.15	.930
Error	23.10	72	0.321	—	—
C					
Type	26.76	3	8.921	29.34	<.001
Thickness	9.11	1	9.111	29.96	<.001
Type×Thickness	0.17	3	0.056	0.18	.907
Error	21.89	72	0.304	—	—

different results. These factors should be investigated in future studies.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The type of zirconia block significantly affected the final color accuracy, and paradoxically high transparency causes color distortion.
2. In addition to thickness, assessment of the type, transparency, and initial color of the monolithic multilayer precolored porous zirconia blocks should be considered during the selection of zirconia ceramics to obtain optimal color accuracy and esthetics.

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