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RESEARCH AND EDUCATION

Effects of surface treatments and abutment shades on the final color of high-translucency self-glazed zirconia crowns

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ABSTRACT

Statement of problem. Achieving excellent esthetics with monolithic self-glazed zirconia crowns in anterior teeth is challenging, and the impact of different surface treatments and abutment shades on the final color is unclear.

Purpose. The purpose of this in vitro study was to evaluate the effects of different external surface treatments (self-glazed, milled, polished, and glazed), different intaglio surface treatments (milled and airborne-particle abraded), and different abutment shades on the color difference of high-translucency self-glazed zirconia crowns.

Material and methods. Sixty shade A1 and 60 shade A3 crowns were fabricated with a thickness of 0.80 ±0.02 mm and randomly divided into 12 groups (n=10). Different external and intaglio surface treatments were applied. Shade A1 and A3 abutments were made with composite resin. Color was measured with a spectrophotometer and expressed in CIELab coordinates, and color differences (ΔE_{00}) between specimens and references were calculated. The data were analyzed with ANOVA and the Tukey post hoc test. The impact of different surface treatments and abutment shades on the color difference were compared by using multiple linear regression (α=.05).

Results. The effects of external surface treatments, intaglio airborne-particle abrasion, and abutment shades on the L*, a*, b* and ΔE_{00} values of the final color of the crowns were significantly different (*P*<.001). Polishing resulted in the greatest ΔE_{00} value among all external surface treatments (*P*<.001). The average ΔE_{00} values of all crowns on the A3 abutment were higher than those of all crowns on the A1 abutment (*P*<.001). The influence on the color difference was abutment>external surface treatment>intaglio surface treatment.

Conclusions. Different surface treatments affected the final color of zirconia crowns, and a greater impact was seen with external surface treatments than with intaglio surface treatments. External polishing resulted in the greatest color difference. The abutment shade had the most effect on the color difference, as the darker the abutment color, the greater the color difference. (J Prosthet Dent 2021;126:795.e1-e8)

Matching the color of natural teeth with zirconia restorations is a major challenge.[1,2] As the primary color of zirconia is white to ivory, manufacturers provide zirconia blocks in various tooth-like colors. Recently a zirconia (SGZ; Erran Tech) with superior surface smoothness that mimics the optical appearances of natural enamel has been marketed with the term "self-glazed."[3-5] This self-glazed zirconia has been reported to have better strength than conventional zirconia,[5] with excellent esthetics in terms of color and translucency gradients,[6] and has been reported to be suitable for esthetic anterior restorations, reducing the tooth preparation needed for less-fracture-resistant ceramics.[5]

Some factors such as polishing,[7-10] glazing,[7,8] sintering procedure,[11,12] abutment,[1,9,13-17] cement,[1,9,15,17-19] coping type,[13] type and thickness of ceramic,[1,13-15,17,18,20-24] and surface texture[25,26] have been cited as influencing the final color

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Clinical Implications

When restoring anterior teeth with zirconia crowns, external surface polishing is not recommended because it generates the greatest color difference. The color effects of various surface treatments (external self-glazed, milled, and glazed) were similar. This study identified abutment shade as having the most influence on final color, followed by the external surface treatments.

of ceramic prostheses. However, studies on the effect of airborne-particle abrasion on the final color of zirconia are lacking.

Surface treatments can change surface texture,[27] which will modify the optical properties of dental restorations.[28] A rough surface may provide diffuse light reflection, whereas a smooth surface provides more specular reflection. However, the interaction of light with different surface textures remains a complex phenomenon.[29]

The purpose of this in vitro study was to evaluate how the color difference of high-translucency monolithic self-glazed zirconia crowns was influenced by different external surface treatments (self-glazed, milled, polished, and glazed), intaglio surface treatments (milled and airborne-particle abraded), abutment shades (A1 and A3), and different locations in the crown (cervical, body, and incisal). The null hypotheses were that different external and intaglio surface treatments and abutment shades would not affect the color difference of high-translucency monolithic self-glazed zirconia crowns.

MATERIAL AND METHODS

The shape of a shade guide tab (VITA Classical; VITA Zahnfabrik) was scanned with a dental cast scanner (3Shape D2000; 3Shape A/S). The 3D data were used to design a maxillary right central incisor crown to replicate the dimensions of the shade guide tab in the standard tessellation language (STL) format. The thickness of the crowns was set at 0.80 mm with a tolerance of ±0.02 mm. In total, 120 specimens were fabricated for shade A1 (n=60) and A3 (n=60) and were divided into 12 groups (n=10/group) (Table 1, Fig. 1). The sample size was based on the statistical analysis of preliminary test results and from previous studies.[10,29-32] The thickness of crowns was assessed with a pachymeter (Model 325-204 Sanliang; Jingyou Co, Ltd) to be 0.80 ±0.02 mm.

In group SM, external self-glazed surfaces were formed by additive 3D gel deposition, and the intaglio surfaces were then formed by milling. In groups MM, MA, PM, PA, and GM, external self-glazed surfaces were formed first, and then both external and intaglio surfaces were formed by milling. All specimens were then sintered without pressure in a muffle furnace at 1450 °C for 90 minutes in air to obtain a relative density above 99.9%. After that, the specimens were furnace-cooled to room temperature.[3,5] In groups PM and PA, the external surfaces were manually polished with a sequence of 3 diamond-impregnated silicone tips (HP 0105 E; Toboom Shanghai Precise Abrasive Tool Co, Ltd) and a felt wheel (Super-Snap Buff; Shofu Inc) with polishing paste (Pearl Surface; Kuraray Noritake Dental Inc). The polishing step was performed with light pressure in single-direction circular movements for 60 seconds.[33] The specimens were rinsed, ultrasonically cleaned (VGT-800; Kejing Inc) for 60 seconds in distilled water, and then air-dried. In groups MA and PA, the intaglio surface was airborne-particle abraded with 50-μm aluminum oxide. The airborne-particle abrasion was performed by making circular movements at a distance of 10 mm with 0.2-MPa pressure for 30 seconds, and the intaglio surface was rinsed for 20 seconds and air-dried. In group GM, the external surface was coated with a thin layer of glaze liquid (IPS e.max Ceram Glaze Paste; Ivoclar Vivadent AG) and sintered in a vacuum in a ceramic furnace (Programat P310; Ivoclar Vivadent AG) with the glaze firing protocol at 930 °C for 30 seconds. The crowns were reassessed with a pachymeter to ensure a thickness of 0.80 ±0.02 mm after surface treatments.

Table 1. Self-glazed zirconia crown groups investigated by different external and intaglio surface treatments

Group	SM	MM	MA	PM	PA	GM
External surface	Self-glazed	Milled	Milled	Polished	Polished	Glazed
Intaglio surface	Milled	Milled	Airborne-particle abraded	Milled	Airborne-particle abraded	Milled

GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

Shade A1 and A3 abutments were fabricated with composite resin (Fig. 2). Shade A1 and A3 composite resin (Ceram.x one Universal Nano-Ceramic Restorative; Dentsply Sirona) was filled in a crown coated with petroleum jelly and light-polymerized. The composite resin abutments were then separated.

All crowns and composite resin abutments were ultrasonically cleaned with distilled water for 10 minutes and dried before shade measurements. A transparent neutral shade evaluation paste (RelyX; 3M ESPE) was used to simulate the color of resin adhesive. The evaluation paste was removed with ethyl alcohol after each shade measurement.

The colorimetric data of shade A1 and A3 crowns on different shade abutments were assessed by using a dental spectrophotometer (CrystalEye; Olympus). The crown and abutment were fixed in a typodont with

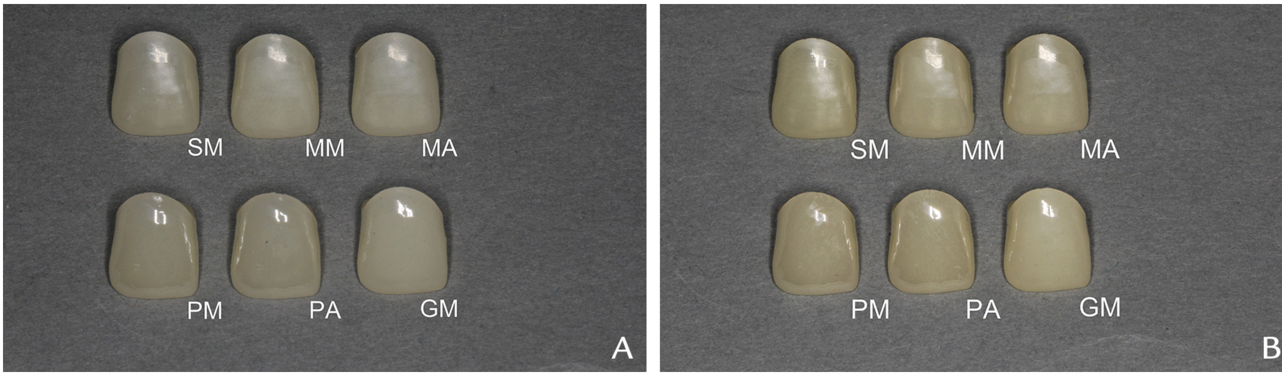

Figure 1. Six groups of self-glazed zirconia crowns of each shade. A, Shade A1. B, Shade A3. GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

artificial gingiva (Standard flagship model; Nissin). The data of the cervical, body, and incisal location of each crown were measured after the model was put in a dark chamber. The position of the dental spectrophotometer probe was standardized on the labial surface of the crowns. Each location (cervical, body, and incisal) of each crown was measured 3 times. The L*, a*, b* values were recorded.[34] Shade measurements were performed by a trained dentist (S.L.). The spectrophotometer was calibrated before each measurement.

ΔE_{00} has been recommended because it provides better adjustments in color difference evaluation.[35] Values 0.8 and 1.8 were considered as the perceptibility threshold (PT) and acceptability threshold (AT), respectively,[36] in this study. ΔE_{00} was calculated by using the following formula[31,37-39]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2+\left(\frac{\Delta C'}{K_C S_C}\right)^2+\left(\frac{\Delta H'}{K_H S_H}\right)^2+R_T\frac{\Delta C'}{K_C S_C}\frac{\Delta H'}{K_H S_H}}.$$

The unglazed A1 and A3 VITA Classical shade guide tabs were used as references for the crown shade measurement. The L* a* b* values and ΔE_{00} were calculated and statistically analyzed by using a statistical software program (IBM SPSS Statistics, v25.0; IBM Corp). A four-way analysis of variance (ANOVA) and the Tukey post hoc test were used to analyze the effects of 4 parameters (external and intaglio surface treatments, abutment, and different location of crown) on the final color of the crowns. One-way ANOVA was used for comparisons of the L*, a*, b* and ΔE_{00} values among different groups. The independent *t* test was used to evaluate the effect of airborne-particle abrasion on the L*, a*, b* and ΔE_{00} values between groups MM and MA and groups PM and PA. A multiple linear regression (MLR) analysis was used to compare the influence of the 4 parameters on ΔE_{00} (α=.05).

RESULTS

The four-way ANOVA revealed that the L*, a*, b* and ΔE_{00} values were significantly different among the external surface treatments (A1: P<.001; A3: P<.001), intaglio surface treatments (A1: P<.001; A3: P<.001), abutment shades (A1: P<.001; A3: P<.001), and different locations of the crown (A1: P<.001; A3: P<.001); the interaction effect among the 4 parameters was not significant (A1: P>.05; A3: P>.05) (Table 2, Table 3). Multiple comparisons assessed by the Tukey test showed the differences in the L*, a*, b* and ΔE_{00} values were statistically significant (A1: P<.001; A3: P<.001), except for the a* and b* values between the external self-glazed and milled surfaces of the A1 crown (a*: P=.298; b*: P=.081).

Figure 2. Shade A1 and A3 abutment specimens.

The average L*, a*, b* values of crowns on different abutments are presented in Figures 3 to 5. The average L* values of crowns on the A3 abutment were lower than those on the A1 abutment for all specimens in all 12 groups (P<.001). Group PM and group PA showed lower L* values than other groups (P<.001). The crowns showed a lower CIE L* value and higher CIE a* and b* values on the A3 abutment than on the A1 abutment (P<.001).

The ΔE_{00} values of the 12 groups of crowns on the 2 shade abutments were compared to references (unglazed

Table 2. Results of four-way ANOVA with dependent variable ΔE_{00} of A1 crowns

Source of Variation	Type III Sum of Squares	*df*	Mean Square	F	*P*
EST	68.839	3	22.946	226.095	<.001
IST	5.993	1	5.993	59.054	<.001
Abutment	162.024	1	162.024	1596.443	<.001
DLC	188.902	2	94.451	930.641	<.001
EST×IST	25.411	2	12.706	125.191	<.001
EST×Abutment	1.614	3	0.538	5.302	.001
EST×DLC	8.521	6	1.420	13.993	<.001
IST×Abutment	0.004	1	0.004	0.037	.847
IST×DLC	1.561	2	0.781	7.691	.001
Abutment×DLC	12.209	2	6.104	60.147	<.001
EST×IST×Abutment	0.616	1	0.616	6.065	.014
EST×IST×DLC	0.619	4	0.155	1.525	.195
EST×Abutment×DLC	4.702	6	0.784	7.722	<.001
IST×Abutment×DLC	0.485	2	0.242	2.388	.093
EST×IST×Abutment×DLC	0.563	2	0.282	2.776	.064
Error	32.578	321	0.101	—	—
Total	857.651	359	—	—	—

DLC, different location of crown; EST, external surface treatment; IST, intaglio surface treatment.

Table 3. Results of four-way ANOVA with dependent variable ΔE_{00} of A3 crowns

Source of Variation	Type III Sum of Squares	*df*	Mean Square	F	*P*
EST	64.373	3	21.458	265.915	<.001
IST	8.827	1	8.827	109.391	<.001
Abutment	53.607	1	53.607	664.333	<.001
DLC	55.018	2	27.509	340.906	<.001
EST×IST	9.650	2	4.825	59.792	<.001
EST×Abutment	2.233	3	0.744	9.223	<.001
EST×DLC	3.163	6	0.527	6.533	<.001
IST×Abutment	0.021	1	0.021	0.261	.610
IST×DLC	1.407	2	0.704	8.720	<.001
Abutment×DLC	8.087	2	4.044	50.110	<.001
EST×IST×Abutment	0.558	1	0.558	6.912	.009
EST×IST×DLC	0.196	4	0.049	0.609	.657
EST×Abutment×DLC	2.246	6	0.374	4.640	<.001
IST×Abutment×DLC	0.052	2	0.026	0.322	.725
EST×IST×Abutment×DLC	0.112	2	0.056	0.694	.500
Error	25.903	321	0.081	—	—
Total	365.021	359	—	—	—

DLC, different location of crown; EST, external surface treatment; IST, intaglio surface treatment.

A1 and A3 shade tabs) (Fig. 6). For all groups, the ΔE_{00} values of both A1 and A3 crowns on the A3 abutment were higher than those on the A1 abutment (P<.001), and the average ΔE_{00} values in different locations were incisal > body > cervical, regardless of the crown shade and abutment shade (P<.001). For A1 crowns, the ΔE_{00} values of group PM were the greatest at all locations (P<.001), whereas group MM and group GM showed the lowest ΔE_{00} values (P<.001). For A3 crowns, the ΔE_{00} values of group SM were the lowest at all locations on both A1 and A3 abutments, whereas group PM and Group PA showed greater ΔE_{00} values (P<.001). No statistical difference in the ΔE_{00} values was found between group MM and group GM, regardless of the crown shade and location (P>.05).

For both the A1 and A3 crowns, the results of the MLR analysis (Table 4, Table 5) showed the influence on ΔE_{00} as, different location of crown>abutment>external surface treatment>intaglio surface treatment.

DISCUSSION

The null hypothesis that the color difference of high-translucency self-glazed zirconia crowns would not be influenced by different external and intaglio surface treatments and abutment shades was rejected. External

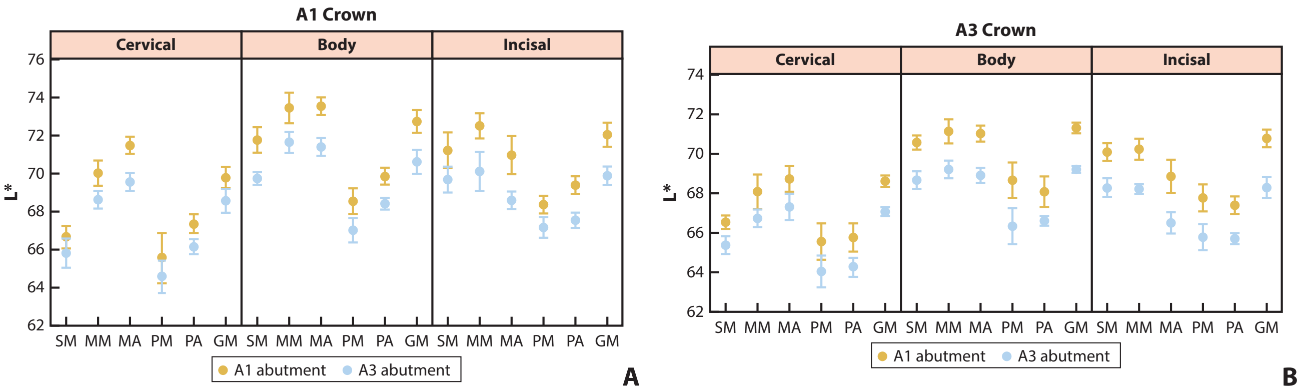

Figure 3. Mean L* values of crowns on different shade abutments among 6 groups. X-axis represents 6 different groups of crowns at cervical, body, and incisal locations. A, Mean L* values of A1 crowns. B, Mean L* values of A3 crowns. L*, lightness (black: L*=0, white: L*=100). GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

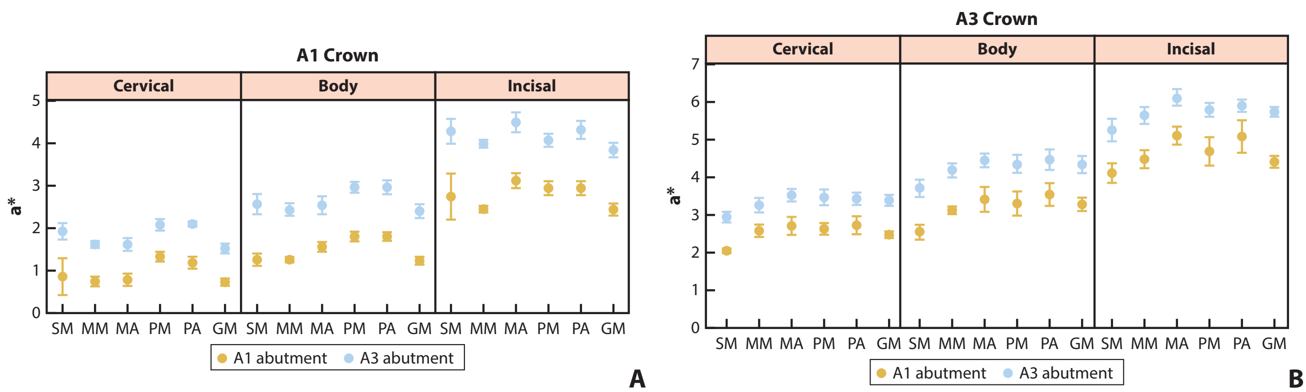

Figure 4. Mean a* values of crowns on different shade abutments among 6 groups. X-axis represents 6 different groups of crowns at cervical, body, and incisal locations. A, Mean a* values of A1 crowns. B, Mean a* values of A3 crowns. a*, Redness (a*>0)/greenness (a*<0). GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

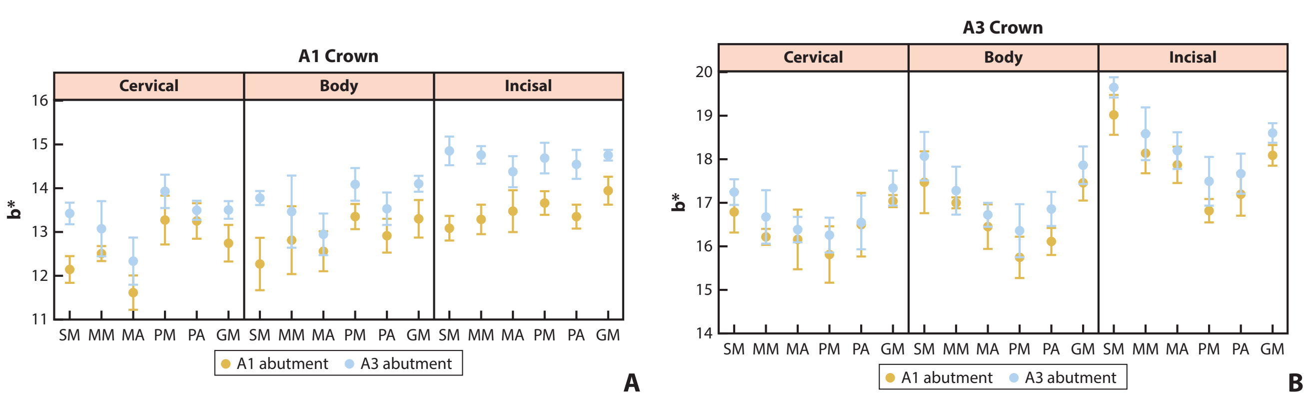

Figure 5. Mean b* values of crowns on different shade abutments among 6 groups. X-axis represents 6 different groups of crowns at cervical, body, and incisal locations. A, Mean b* values of A1 crowns. B, Mean b* values of A3 crowns. b*, Yellowness(b*>0)/blueness(b*<0). GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

surface factors, including the texture, affect the color of ceramic materials, especially the L* value.[25,26] Chung[30] reported that color difference was mainly determined by the lightness rather than the hue and chroma. The findings of the present study indicated that polishing significantly reduced the lightness and, thus, increased color difference, consistent with previous studies.[7-9] The reason different external surface treatments have an

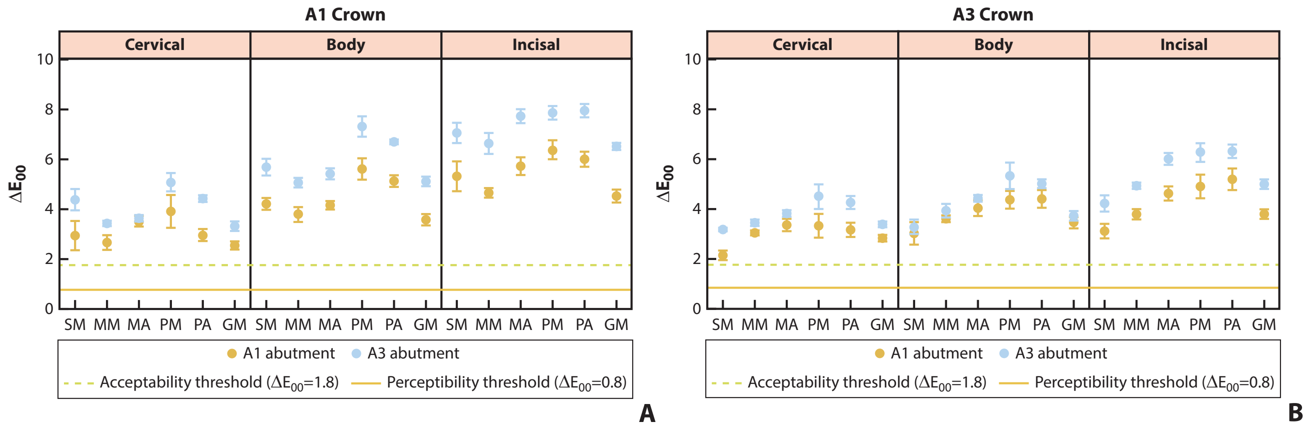

Figure 6. ΔE_{00} values of crowns on different shade abutments among 6 groups. X-axis represents 6 different groups of crowns at cervical, body, and incisal locations. *Dashed* line shows acceptability threshold, and *solid* line shows perceptibility threshold. A, Mean ΔE_{00} values of A1 crowns. B, Mean ΔE_{00} values of A3 crowns. ΔE_{00}, color difference; GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SM, self-glazed/milled.

Table 4. Results of MLR with dependent variable ΔE_{00} of A1 crowns

	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Variable	Beta	Std. Error	Beta	t	*P*	Tolerance	VIF
Constant	-0.378	0.220	—	-1.722	.086	—	—
IST	0.017	0.041	0.010	0.406	.685	1.000	1.000
EST	0.322	0.083	0.100	3.900	<.001	1.000	1.000
Abutment	1.428	0.079	0.463	18.125	<.001	1.000	1.000
DLC	1.395	0.048	0.738	28.929	<.001	1.000	1.000

DLC, different location of crown; EST, external surface treatment; IST, intaglio surface treatment; MLR, multiple linear regression; VIF, variance inflation factor.

Table 5. Results of MLR with dependent variable ΔE_{00} of A3 crowns

	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Variable	Beta	Std. Error	Beta	t	*P*	Tolerance	VIF
Constant	-0.219	0.166	—	-1.321	.187	—	—
IST	0.272	0.031	0.258	8.763	<.001	1.000	1.000
EST	0.671	0.062	0.318	10.777	<.001	1.000	1.000
Abutment	0.837	0.059	0.416	14.097	<.001	1.000	1.000
DLC	0.734	0.036	0.595	20.176	<.001	1.000	1.000

DLC, different location of crown; EST, external surface treatment; IST, intaglio surface treatment; MLR; multiple linear regression; VIF, variance inflation factor.

effect on color modification is because of the influence of external surface roughness.[7] Smooth surfaces reflect incoming light, whereas rough surfaces diffuse light.[25] Polishing or glazing zirconia resulted in smooth surfaces, which could reflect more light than a rough surface.[10,24] As a result of the reflection of incoming light, lightness value increased.[21] However, in the present study, polishing resulted in the lowest lightness value and the greatest color difference, consistent with the study by Kim et al.[7] The reason for this conflict might be because of the differences in the brands of zirconia, polishing protocols, and materials tested. Furthermore, light-scattering could be an important factor because zirconia has a polycrystalline structure which can induce maximum scattering effect.[24]

Studies regarding the effects of different surface treatments on the optical properties of zirconia have mainly focused on polishing and glazing,[7-10,29] while information about the effect of airborne-particle abrasion on color is lacking. The results of this study showed that intaglio surface airborne-particle abrasion increased the color difference of crowns and that the influence of airborne-particle abrasion was reduced when the external surfaces were polished. This might be because the increased intaglio surface roughness caused by airborne-particle abrasion affected the crown's scattering, refraction, and reflection of light, thus affecting the final color of the crown. However, the effect of external surface treatment on the final color was greater than that of the intaglio surface treatment.

Previous studies have shown that the underlying tooth structure is a principal factor affecting the final color of ceramic restorations[1,13-16,18] and that changing the underlying color from a lighter background to a darker background resulted in increased color differences.[1,15,16] Chaiyabutr et al[15] reported that dark-colored abutment teeth presented the greatest ΔE values, consistent with the findings of the present study. Furthermore, the influence of the abutment shade on the final color of the crowns was found to be significant, affecting all the L*, a*, b* values (Figs. 3–5). The deeper the abutment shade, the lower the L* value and the higher the a* and b* values, which means the darker A3 abutment showed less lightness and more redness and yellowness than the A1 abutment. The study of Oh and Kim[13] also reported similar results.

Based on the results of the present study, the final color of the crowns varied in different locations, and the ΔE_{00} values were of the order incisal 1/3>body 1/3>cervical 1/3 (Fig. 6), which indicated that the thickness of the abutment affected the final color difference of the crowns. The thickness of the abutment gradually reduced from cervical to incisal, and the color difference from cervical to incisal increased accordingly. The results of the MLR analysis revealed that the different location of the crown and the abutment shade had more effects on the final color difference of crowns but that the influence of different locations of the crown on the final color actually reflected the influence of the abutment on the final color.

In addition to the abutment shade, ceramic thickness and ceramic type also play important roles in the final restoration color.[1,20] Farhad et al[20] reported that the minimum thickness of high-translucent monolithic zirconia restoration should be 0.9 mm to gain the acceptable final color ($\Delta E \leq 3.3$). In the present study, the ΔE_{00} values of all test groups were found to exceed the clinically acceptable threshold (ΔE_{00}=1.8); the reason might be that the thickness of the crowns in this study was only 0.8 mm. Clinicians could consider masking backgrounds with cement[19] or increasing the thickness and opacity of the ceramic.[17] Increasing ceramic thickness has been reported to improve color match.[16,18] The esthetics of a prosthesis depends on translucency and shade,[24] and the translucency of dental porcelain is largely dependent on light-scattering and thickness.[22,23,32] Different surface treatments result in the changing of the surface texture, which may influence light-scattering and light transmission and further influence translucency, influencing the final color.

Limitations of this in vitro study included that only the effects of different surface treatments and abutment shades on the final color of high-translucency self-glazed zirconia crowns were evaluated. Further studies should be conducted regarding the effects of different surface treatments on the translucency and surface texture of restorations and their relationship to shade. Despite improvements in manufacturing monolithic zirconia restorations, problems remain for replicating translucency and shade, and further progress is needed to achieve optimal esthetics.

CONCLUSIONS

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

1. The different external surface treatments significantly influenced the final color. Polishing significantly reduced the L* value, resulting in the maximum color difference.
2. Intaglio surface airborne-particle abrasion influenced the color difference slightly.
3. Abutment shade mostly influenced the final color. The darker the abutment color, the greater the color difference.
4. The influence on the final color difference was of the order, abutment>external surface treatment>intaglio surface treatment.

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