THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Effects of surface treatment and shade on the color, translucency, and surface roughness of high-translucency self-glazed zirconia materials

Siyu Li, DDS, PhD,[a] Xinyue Zhang, ME,[b] Wei Xia, PhD,[c] and Yihong Liu, DDS, PhD[d]

ABSTRACT

Statement of problem. The impact of different surface treatments and shades on the color, translucency, and surface roughness of high-translucency self-glazed zirconia materials is unclear.

Purpose. The purpose of this in vitro study was to investigate the effects of different external surface treatments (self-glazed, milled, polished, and glazed), intaglio surface treatments (milled and airborne-particle abraded), and shades (A1 and A3 shades) on the color, translucency, and surface roughness of high-translucency self-glazed zirconia materials, as well as the correlations among optical parameters, translucency, and surface roughness.

Material and methods. Eighty shade A1 and 80 shade A3 disks were fabricated with a thickness of 0.80 ±0.02 mm and divided into 16 groups (n=10). Different external and intaglio surface treatments were applied to the specimens. CIELab values were measured with a spectrophotometer, and color differences (ΔE_{00}) and relative translucency parameter (RTP) were calculated. Total transmittance (Tt%) and reflectance (R%) were tested with a spectrophotometer equipped with an integrating sphere. Surface roughness (Ra and Rz) (μm) was measured with a noncontact 3-dimensional laser scanning microscope. One specimen from each group was subjected to scanning electron microscope (SEM) examination. Data were analyzed with ANOVA and the Tukey post hoc test. The correlation among optical parameters, translucency, and surface roughness was investigated by using Pearson correlation analysis (α=.05).

Results. The effects of external surface treatments, intaglio airborne-particle abrasion, and shades on ΔE_{00}, RTP, and Ra values of the disks were significantly different (P<.001). The smoothest external polishing surface had the greatest RTP and color difference (P<.001). Shade A3 disks had lower RTP and Tt% values than shade A1 disks (P<.001). ΔE_{00} had a highly positive relationship with the RTP (A1: r=0.884, P<.001; A3: r=0.859, P<.001). SEM images demonstrated that surface treatments affected the surface texture of monolithic zirconia ceramics.

Conclusions. Different surface treatments affected the surface roughness, translucency, and final color of zirconia materials. The smoothest external polishing surface had the greatest RTP and color difference. Different shades influenced the translucency, as the darker the disk shade, the lower the translucency. The RTP was appropriate as an auxiliary indicator for evaluating the color of a dental ceramic. (J Prosthet Dent 2022;128:217.e1-e9)

Recently, a self-glazed zirconia[1-4] (SGZ; Erran Tech) formed by additive 3-dimensional gel deposition with superior surface smoothness has been developed. Factors such as surface structure, color, and translucency are important for esthetic restorations.[5] The esthetic value of a ceramic restoration is influenced not only by the translucency and color of the restorative material but also by its surface texture and thickness.[6] Different surface treatments such as polishing and glazing can change the color,[7-9] translucency,[10] and surface roughness[9-17] of monolithic zirconia restorations, which will modify the optical properties of restorations.[18,19] However, information regarding the effect of airborne-particle abrading the intaglio surface on the optical properties of monolithic zirconia is lacking.

Supported by the National Natural Science Foundation of China grants 51772007 and 52111530189 and the Swedish Foundation for International Cooperation in Research and Higher Education grant CH2020-8762.

[a]Assistant Professor, Department of General Dentistry, Peking University School and Hospital of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, PR China.
[b]Engineer, Center of Digital Dentistry, Peking University School and Hospital of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, PR China.
[c]Associate Professor, Department of Engineering Science, Uppsala University, Uppsala, Sweden.
[d]Associate Professor, Department of General Dentistry, Peking University School and Hospital of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, PR China.

Clinical Implications

In the tested zirconia material, external surface polishing is not recommended because it generates the greatest color difference and increases translucency. An increase in the color saturation of zirconia materials may reduce their translucency.

To obtain optimum esthetic results, restoration optical properties must match those of natural teeth.[20] A key factor is translucency[20-24]: light transmission between complete opacity and transparency.[25] If most of the light is absorbed and diffusely reflected, the material will appear opaque,[26,27] but if the light is scattered within the object and most of it is diffusely transmitted, it will appear translucent.[27] Thus, the translucency of a ceramic depends on light scattering and absorption.[28,29] A consensus among dental studies on the different methods adopted to quantify translucency is lacking.[20] Total transmittance (Tt %) represents direct transmission, which is the unaffected, straight light penetrating the translucent specimen from one side to the other.[30] Recently, the relative translucency parameter (RTP), relative to the colors[31] of the actual backing used in the color difference determinations, has been suggested.

Roughness has an influence on brightness,[32] 1 of the 3 elements of color.[33] Therefore, roughness can be assumed to lead to color difference. The arithmetic average height (Ra) and maximum height (Rz) are the most commonly used surface roughness metrology parameters.[34] However, the effects of different surface treatments on color, translucency, and surface roughness are still controversial, and any correlation is not well understood. Furthermore, studies on the correlation between translucency and shade for ceramic materials are sparse.

Therefore, the aim of this in vitro study was to evaluate how the color difference, translucency, and surface roughness of high-translucency monolithic SGZ material were influenced by different external and intaglio surface treatments and shades, as well as the correlation among optical parameters, translucency, and surface roughness. The null hypotheses were that different external intaglio surface treatments and shades would not affect the color difference, translucency, and surface roughness of zirconia materials and that no correlation would be found among optical parameters, translucency, and surface roughness.

MATERIAL AND METHODS

A total of 160 Ø10×0.80 ±0.02-mm sintered disks were fabricated and divided into 16 groups based on 2 zirconia shades and different surface treatments (n=10/group) (Table 1). The sample size was based on the statistical analysis of preliminary test results and from previous studies.[27,35,36]

Different external and intaglio surface treatments were performed on the groups as described in the previous study.[37] Both external and intaglio milled surfaces were formed by milling the first formed self-glazed surfaces. The external surfaces were manually polished in groups PM and PA, the intaglio surfaces were airborne-particle abraded with 50-µm aluminum oxide in groups SA, MA, PA, and GA, and the external surface was glazed in groups GM and GA. The surfaces of the disks were made parallel, and the thickness of the specimens was reassessed with a meter (Model 325-204, Sanliang; Jingyou Co Ltd) to ensure a thickness of 0.80 ±0.02 mm after surface treatments.

The A1 and A3 shade substrates were fabricated with composite resin (Ceram.x one Universal Nano-Ceramic Restorative; Dentsply Sirona). A silicone putty (Rapid Soft; Coltène AG) mold with cylindrical-shaped holes (Ø12 × 8 mm) was prepared and coated with petroleum jelly. Shade A1 and A3 composite resin was filled in the mold and light polymerized. The composite resin substrates were separated from the mold, ground to 8 mm in thickness[38] with abrasive paper grit 1000, polished with abrasive paper grit 1500 under water cooling, ultrasonically cleaned with distilled water for 10 minutes, and dried.

All disks and substrates 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 and was removed with ethyl alcohol after each shade measurement. The colorimetric data of shade A1 disks on the A1 substrate and shade A3 disks on the A3 substrate were assessed by using a dental spectrophotometer (CrystalEye; Olympus). The disks were placed on the center of the substrates first and then placed in a dark chamber, and the position of the dental spectrophotometer probe was standardized on the center of the specimens. Color measurements were conducted 3 times for each specimen, and the L^*, a^*, b^* values were recorded. Shade measurements were performed by an experienced dentist (S.L.). The spectrophotometer was calibrated before each measurement. The centers of the middle third of the unglazed A1 and A3 VITA classical shade guide tabs were used as the references[36] (A1: L^*=82.2, a^*=-0.5, b^*=16.9; A3: L^*=75.1, a^*=3.8, b^*=24.8). Values of 0.8 and 1.8 were considered as the perceptibility threshold (PT) and acceptability threshold (AT) [39] in this study. ΔE_{00} was calculated from[40]

$$\Delta E_{00}=\sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2+\left(\frac{\Delta C'}{k_C S_C}\right)^2+\left(\frac{\Delta H'}{k_H S_H}\right)^2+R_T\frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

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

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

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

Table 2. Results of three-way ANOVA with dependent variable ΔE_{00}

Source of Variation	Type III Sum of Squares	df	Mean Square	F	P
EST	183.473	3	61.158	504.533	<.001
IST	6.404	1	6.404	52.828	<.001
DS	56.336	1	56.336	464.757	<.001
EST×IST	0.252	3	0.084	0.694	.557
EST×DS	8.469	3	2.823	23.289	<.001
IST×DS	0.821	1	0.821	6.773	.010
EST×IST×DS	0.667	3	0.222	1.834	.144
Error	17.455	144	0.121	—	—
Total	273.877	159	—	—	—

DS, disk shade; EST, external surface treatment; IST, intaglio surface treatment.

Table 3. Results of three-way ANOVA with dependent variable RTP

Source of Variation	Type III Sum of Squares	df	Mean Square	F	P
EST	177.015	3	59.005	391.629	<.001
IST	0.218	1	7.827	61.445	<.001
DS	36.758	1	36.758	243.973	<.001
EST×IST	4.273	3	0.784	7.453	.195
EST×DS	7.686	3	2.562	17.005	<.001
IST×DS	1.300	1	1.300	8.626	.004
EST×IST×DS	2.594	3	0.349	1.739	.157
Error	21.696	144	0.151	—	—
Total	251.540	159	—	—	—

DS, disk shade; EST, external surface treatment; IST, intaglio surface treatment.

The colorimetric data of shade A1 and shade A3 disks on black (L^*=12.6, a^*=-0.8, b^*=-3.7) and white (L^*=94.2, a^*=-0.9, b^*=1.7) backings (S 0300-N and S 9000-N; NCS) were respectively measured by using the same dental spectrophotometer and by following the same protocol as for the shade measurements. Optical contact between specimens and backings was obtained with a saturated sucrose solution. RTP was calculated by using the following formula[31]:

$$RTP_{CIEDE200} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)\right]^{½}$$

A spectrophotometer (Lambda 950; PerkinElmer) with a Ø150-mm integrating sphere was used to evaluate the Tt% and R%. Measurement conditions were as follows: wavelength range of 380 to 780 nm, band width of 2.0 nm, scan speed of 1333 nm/min, data interval of 1.0 nm, and a xenon light source. To reduce errors, all measurements were repeated once in sequence.[41] Since the human eye is most sensitive to 555 nm,[41] the average Tt% and R% values at the wavelength of 555 nm were used to compare the specimens.

The surface roughness (Ra and Rz) (μm) of the specimens was measured with a noncontact 3-dimensional laser scanning microscope (VK-X200; Keyence) at ×1000 magnification. For each specimen, 3 different locations (95.80×71.85μm in size) were chosen and scanned for 3-dimensional surface profiling. The mean values of the 3 measurements for each specimen were used as the Ra and Rz values.

One specimen from each group was subjected to SEM examination. The specimens were cleaned in an ultrasonic bath with 75% ethyl alcohol for 10 minutes, air dried, and gold coated in a vacuum sputter coater (SBC-12 Ion Sputter Coater; KYKY Technology Development Ltd). The specimens were examined with an SEM (Mira 3 LMH; Tescan, Brno) operated at 10.0 kV, and images of each specimen were obtained at magnifications of ×500, ×2000, and ×20 000.

The values of different variables were calculated and statistically analyzed by using a statistical software program (IBM SPSS Statistics, v25.0; IBM Corp). Three-way ANOVA and the Tukey post hoc test were used to analyze the effects of external intaglio surface treatments and of disk shades on CIE Lab, ΔE_{00}, RTP, Tt%, and R% values. One-way ANOVA was performed to analyze the results of Ra and Rz measurements. The correlation between different variables was investigated by using Pearson correlation analysis (α=.05).

RESULTS

Three-way ANOVA and multiple comparisons assessed by the Tukey test revealed that ΔE_{00}, RTP, Tt%, and R% values were all significantly different among external surface treatments (*P*<.001), intaglio surface treatments (*P*<.001), and disk shades (*P*<.001). The interaction effect among the 3 parameters was not significant (ΔE_{00}: *P*=.144; RTP: *P*=.157) (Tables 2 and 3).

The average L^*, a^*, b^*, and ΔE_{00} values are shown in Figures 1, 2. RTP values are presented in Figure 3. A1 disks had a greater RTP than A3 disks (*P*<.001). Statistically significant positive correlations were found

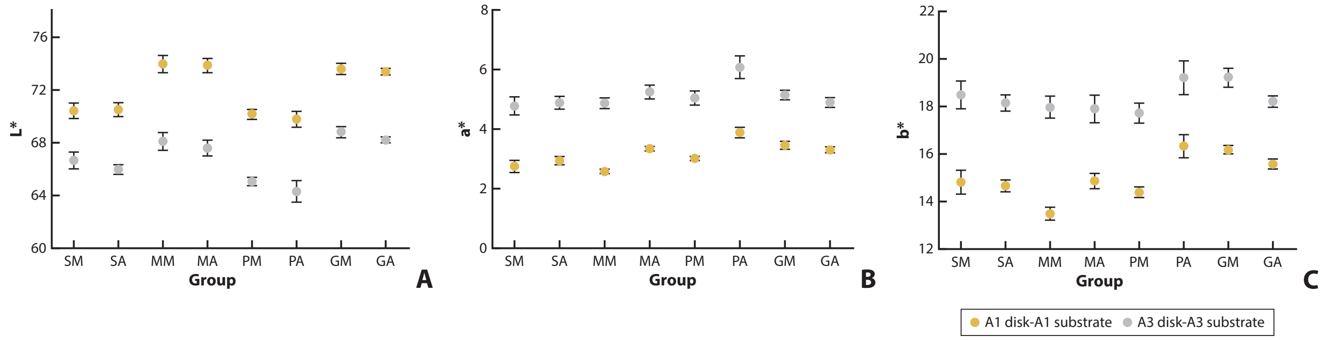

Figure 1. Mean L*, a*, b* values of disks on different substrates among 8 groups. X-axis represents 8 different groups of disks. A, Mean L* values. B, Mean a* values. C, Mean b* values. a*, redness (+)/greenness (-); b*, yellowness (+)/blueness (-); GA, glazed/airborne-particle abraded; GM, glazed/milled; L*, lightness; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SA, self-glazed/airborne-particle abraded; SM, self-glazed/milled.

between the RTP and ΔE_{00} according to the Pearson correlation coefficients (Table 4).

For all the A1 and A3 disks, the wavelength distributions of Tt% and R% for all groups are shown in Figures 4, 5. The Tt% values were basically opposite to R % values (Figs. 4, 5), and A1 disks had greater Tt% values than A3 disks (P<.001).

The Ra and Rz values are shown in Table 5. One-way ANOVA showed that Ra and Rz values do not differ among milled surfaces of groups (SM, MM, MA, PM, and GM) and among airborne-particle–abraded surfaces (SA, MA, PA, and GA). The average Ra and Rz values of the same surfaces of the previously mentioned groups were combined and listed in Table 5, representing the surface roughness of different surfaces. The highest surface roughness values were for airborne-particle–abraded surfaces, while polished surfaces showed the smoothest surface among all surfaces (A1: P<.001; A3: P<.001). For both A1 and A3 specimens, the results of 1-way ANOVA and the Tukey post hoc test for both Ra and Rz measurements showed significant differences among all 5 surfaces (A1: P<.001; A3: P<.001) (Tables 6 and 7).

Generally, SEM analysis confirmed the results of the roughness test (Figs. 6, 7). The self-glazed surface exhibited a relatively smoother surface than the milled surface (Fig. 6). The polished surface presented the smoothest surface (Fig. 6C), while the airborne-particle–abraded surface revealed the roughest surface with an irregular nonuniform texture (Figs. 6E, 7E). Glazing created a relatively smooth and uniform surface (Fig. 6D).

For both A1 and A3 disks, the Pearson correlation matrix showed a significant negative correlation between surface roughness (Ra) and ΔE_{00}, also between Ra and RTP (Table 4), indicating that the increase of ΔE_{00} and RTP values was affected by the decrease in surface roughness. Conversely, the results in Table 4 revealed a significant positive correlation between Ra and L* values, indicating that the higher the surface roughness, the greater the lightness.

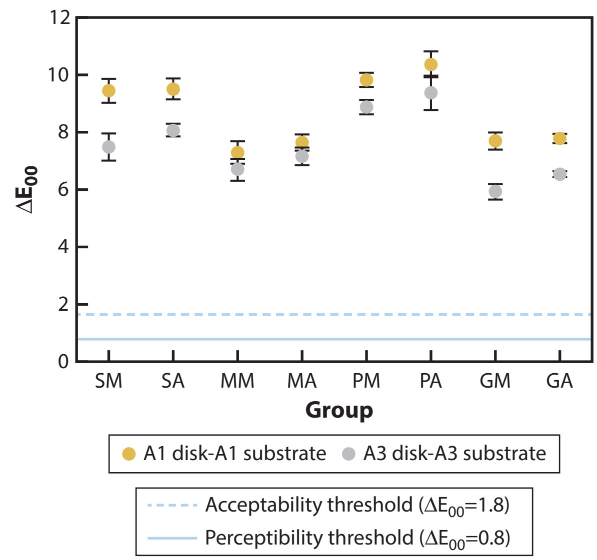

Figure 2. Mean ΔE_{00} values of disks on different substrates among 8 groups. X-axis represents 8 different groups of disks. *Dashed line* acceptability threshold and *solid line* perceptibility threshold. GA, glazed/airborne-particle abraded; GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SA, self-glazed/airborne-particle abraded; SM, self-glazed/milled.

DISCUSSION

The null hypothesis that the color, translucency, and surface roughness of high translucency monolithic SGZ materials would not be influenced by different external intaglio surface treatments and shades was partially rejected because shade did not influence surface roughness. The null hypothesis that no correlation would be

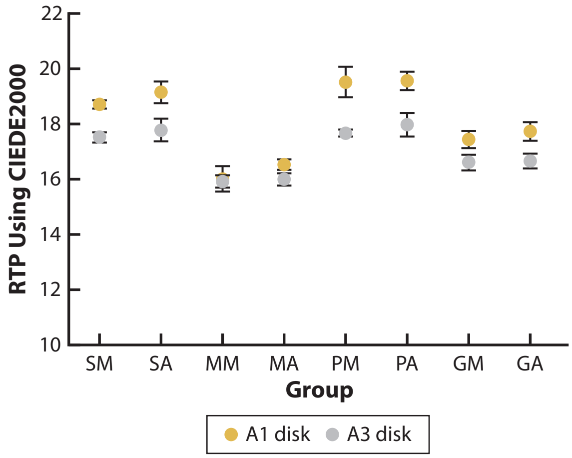

Figure 3. RTP using CIEDE2000 of different groups. X-axis represents 8 different groups of disks. GA, glazed/airborne-particle abraded; GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; RTP, relative translucency parameter; SA, self-glazed/airborne-particle abraded; SM, self-glazed/milled.

Table 4. Pearson correlation analysis between variables evaluated

Variable 1	Variable 2	Pearson Correlation Coefficient (r) A1 Disks	Pearson Correlation Coefficient (r) A3 Disks	*P* A1 Disks	*P* A3 Disks
ΔE_{00}	RTP	0.884	0.859	<.001[b]	<.001[b]
	Tt%	0.242	0.304	.030[a]	<.001[b]
	R%	0.487	0.565	<.001[b]	<.001[b]
	L*	-0.990	-0.991	<.001[b]	<.001[b]
	a*	0.242	0.496	.031[a]	<.001[b]
	b*	0.233	0.024	.037[a]	.832
Roughness (Ra)	ΔE_{00}	-0.943	-0.913	<.001[b]	<.001[b]
	RTP	-0.882	-0.809	<.001[b]	<.001[b]
	Tt%	-0.308	-0.189	.005[b]	.094
	R%	-0.327	-0.341	.003[b]	.002[b]
	L*	0.938	0.856	<.001[b]	<.001[b]
	a*	-0.182	-0.280	.107	.012[a]
	b*	-0.234	-0.139	.037[a]	.219

a*, redness (+)/greenness (-); b*, yellowness (+)/blueness (-); L*, lightness; R%, reflectance; RTP, relative translucency parameter; Tt%, total transmittance. Positive Pearson's correlation coefficient (r) indicates positive correlation between 2 variables. Negative r indicates negative correlation. lrl: 0.8 to 1.0, very strong correlation; 0.6 to 0.8, strong correlation; 0.4 to 0.6, moderate correlation; 0.2 to 0.4, weak correlation; 0.0 to 0.2, very weak correlation or no correlation. [a]Statistically significant correlation (*P*<.05). [b]Statistically significant correlation (P<.01).

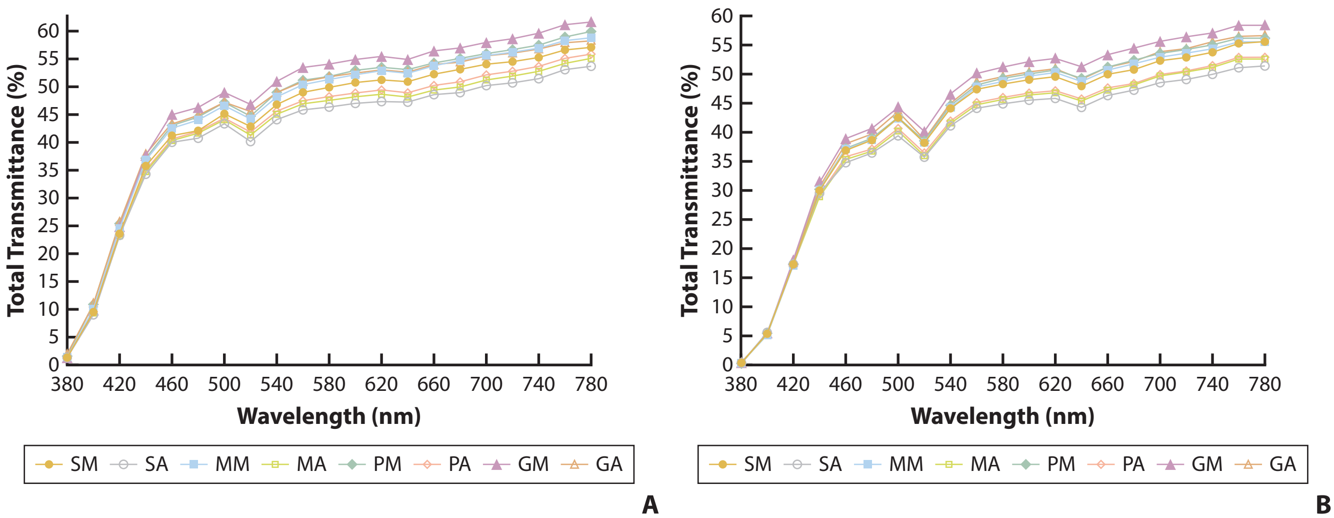

Figure 4. Wavelength distribution of Tt% for shade A1 and A3 groups. A, Shade A1. B, Shade A3. GA, glazed/airborne-particle abraded; GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; SA, self-glazed/airborne-particle abraded; SM, self-glazed/milled; Tt%, total transmittance of light as a percentage.

found among optical parameters, translucency, and surface roughness was rejected.

Surface treatment can change the surface roughness of zirconia materials. Polishing significantly reduced surface roughness in the present study, consistent with previous studies.[15,16] The reduced roughness of the polished specimens was also evident in the SEM analysis, showing a visible improvement in the smoothness of the zirconia surface after polishing (Fig. 6C). Although the ×20 000 SEM images showed that the glazed surface (Fig. 7D) was smoother than the polished surface (Fig. 7C), when measuring the surface roughness (×1000 magnification), the glazed surface presented a wavy surface caused by the brushing of the glaze liquid that increased its surface roughness. Previous studies on surface roughness have mainly focused on wear [16] and plaque accumulation,[42] while information about the effect of surface roughness on color is lacking. In the current study, the Pearson correlation analysis showed that surface roughness (Ra) was highly negatively correlated with ΔE_{00} but highly positively correlated with the L* value (Table 4). The correlations indicated that different

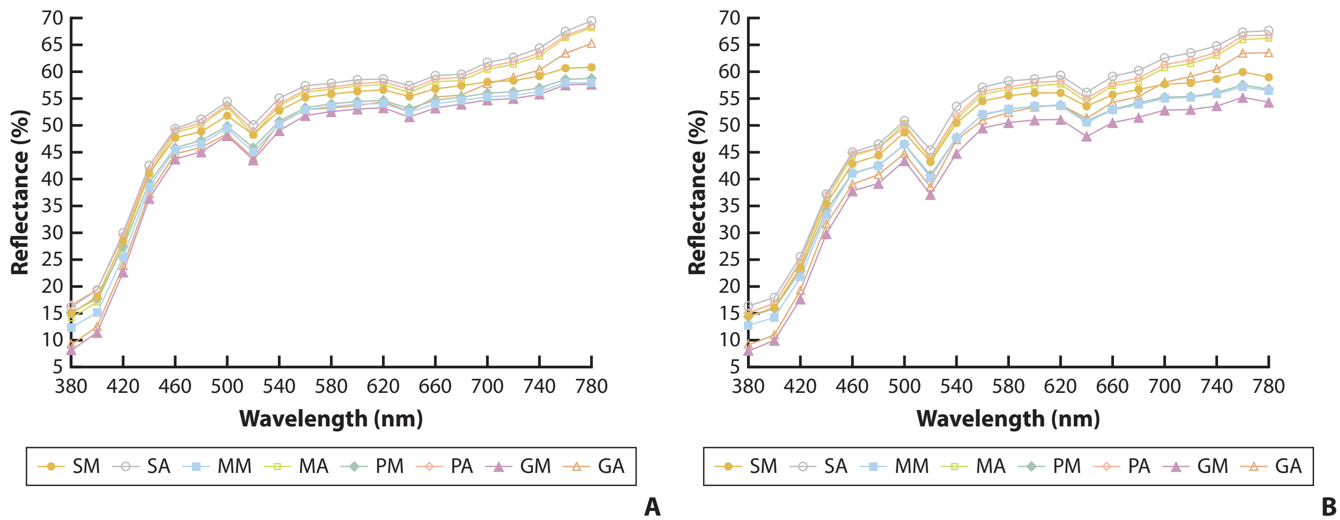

Figure 5. Wavelength distribution of R% for shade A1 and A3 groups. A, Shade A1. B, Shade A3. GA, glazed/airborne-particle abraded; GM, glazed/milled; MA, milled/airborne-particle abraded; MM, milled/milled; PA, polished/airborne-particle abraded; PM, polished/milled; R%, reflectance of light as a percentage; SA, self-glazed/airborne-particle abraded; SM, self-glazed/milled.

Table 5. Mean and SD of surface roughness values (μm)

	A1				A3			
	Ra		Rz		Ra		Rz	
Surface	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**
Self-glazed	0.15[a]	0.02	1.73[a]	0.11	0.17[a]	0.01	1.84[a]	0.06
Milled	0.59[b]	0.01	3.83[b]	0.07	0.58[b]	0.02	3.81[b]	0.17
Polished	0.08[c]	0.00	0.28[c]	0.02	0.09[c]	0.00	0.28[c]	0.01
Glazed	0.32[d]	0.04	5.33[d]	0.27	0.36[d]	0.04	5.51[d]	0.23
Airborne-particle abraded	0.73[e]	0.02	7.19[e]	0.24	0.73[e]	0.01	7.31[e]	0.13
	F=1749.686	—	*F*=2030.516	—	*F*=2090.823	—	*F*=1366.968	—

SD, standard deviation. Analysis of variance and Tukey post hoc test. Different superscript letters in same column denote statistically significant difference among different surfaces ($P<.05$).

Table 6. Results of 1-way ANOVA with dependent variable Ra of A1 and A3 disks

Shade	Source of Variation	Type III Sum of Squares	df	Mean Square	F	*P*
A1 disks	Ra	3.430	4	0.858	1749.686	<.001
	Error	0.022	45	0.000	—	—
	Total	3.452	49	—	—	—
A3 disks	Ra	3.378	4	0.844	2090.823	<.001
	Error	0.018	45	0.000	—	—
	Total	3.396	49	—	—	

Table 7. Results of 1-way ANOVA with dependent variable Rz of A1 and A3 disks

Shade	Source of Variation	Type III Sum of Squares	df	Mean Square	F	*P*
A1 disks	Rz	345.460	4	86.365	2030.516	<.001
	Error	1.914	45	0.043	—	—
	Total	347.374	49	—	—	—
A3 disks	Rz	357.578	4	89.394	1366.968	<.001
	Error	2.943	45	0.065	—	—
	Total	360.520	49	—	—	

surface treatments changed the surface roughness and texture, affecting light transmission and reflection, thus changing the L^* value. Chung[33] reported that color difference was mainly determined by lightness, as also found in the present study (Table 4). In the present study, polishing significantly reduced surface roughness, with less light reflection (Fig. 5) and more light transmission (Fig. 4), resulting in the lowest L^* value (Fig. 1A) and the greatest RTP (Fig. 3) and the greatest color difference (Fig. 2). This finding was consistent with those of 3 previous studies[7,8,37] but contrary to Elif et al.[36] The conflicting results might be because different brands of zirconia, polishing protocol, and materials were used.

Previous studies[10,13,23] reported that the translucency of zirconia materials was not affected by the surface treatment. However, both RTP and Tt% values were significantly affected by different surface treatments in the present study ($P<.001$), possibly because the material type had a significant effect on translucency.[31] Furthermore, both the RTP and Tt% values of A1 disks were

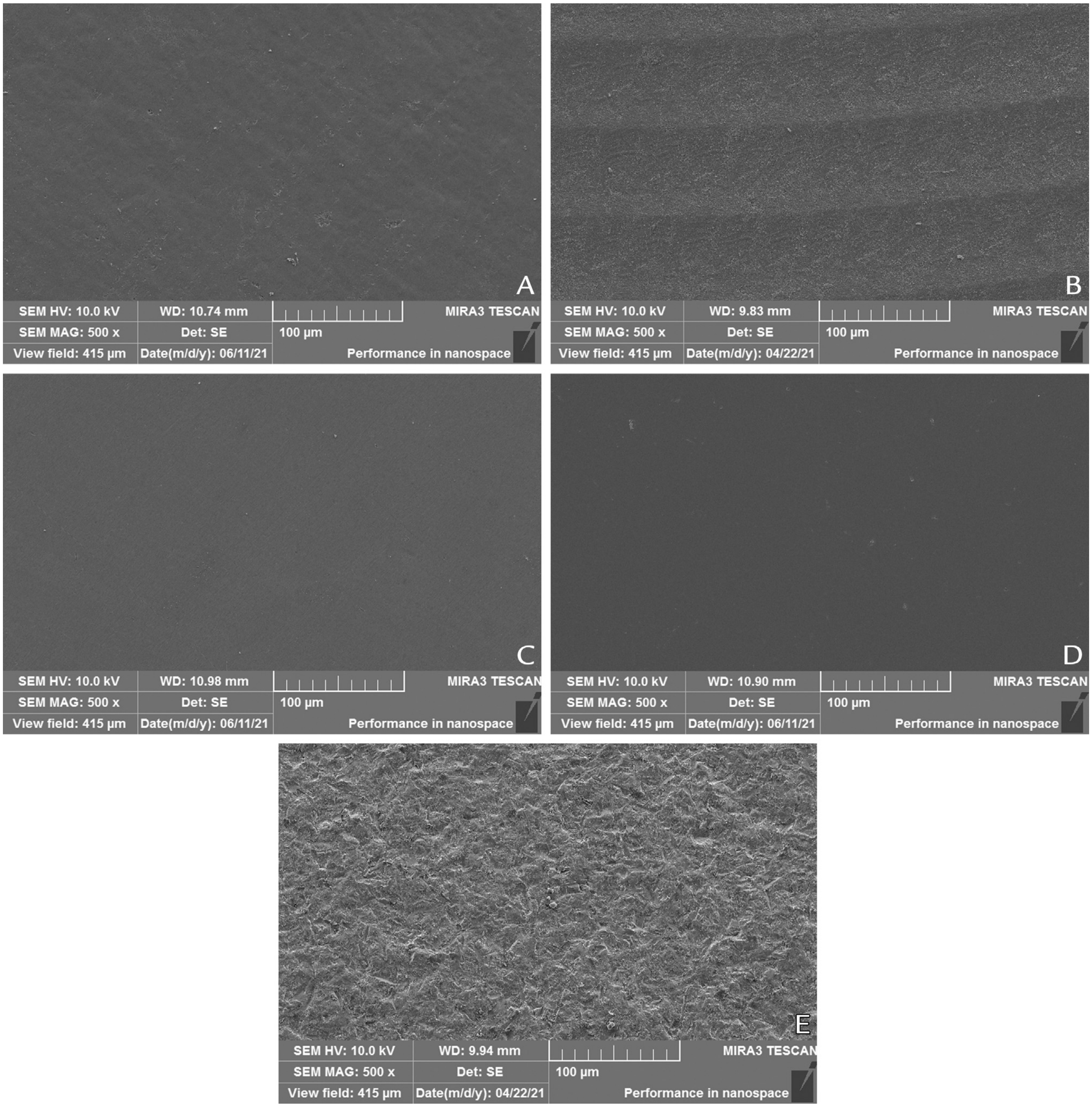

Figure 6. Surfaces of different zirconia (original magnification ×500). A, Self-glazed surface. B, Milled surface. C, Polished surface. D, Glazed surface. E, Airborne-particle–abraded surface.

greater than those of A3 disks (*P*<.001), which was consistent with Ioana et al,[24] indicating that lighter-shade ceramics have higher translucency.

Both Tt% and R% values are indicative of translucency; the greater the R% value, the more light is reflected, the lower the translucency of the material. The results of the present study demonstrated that R% and Tt% were opposite; the greater the R% value, the lower the Tt% value. In the present study, the high-translucency zirconia disks were used; therefore, the RTP counted the reflection rays not only from the external surfaces of the disks but also of the background color. In addition, the ceramic material scattered the incident light, which also affected the results of the RTP. Thus, the RTP concerns both the light transmission and light reflection and scattering, so the RTP can more comprehensively reflect translucency than Tt%. The results in Table 4 showed ΔE_{00} was highly positively correlated with the RTP (A1: r=0.884, *P*<.001; A3: r=0.859, *P*<.001), indicating that the RTP describes color difference better than Tt% (A1:

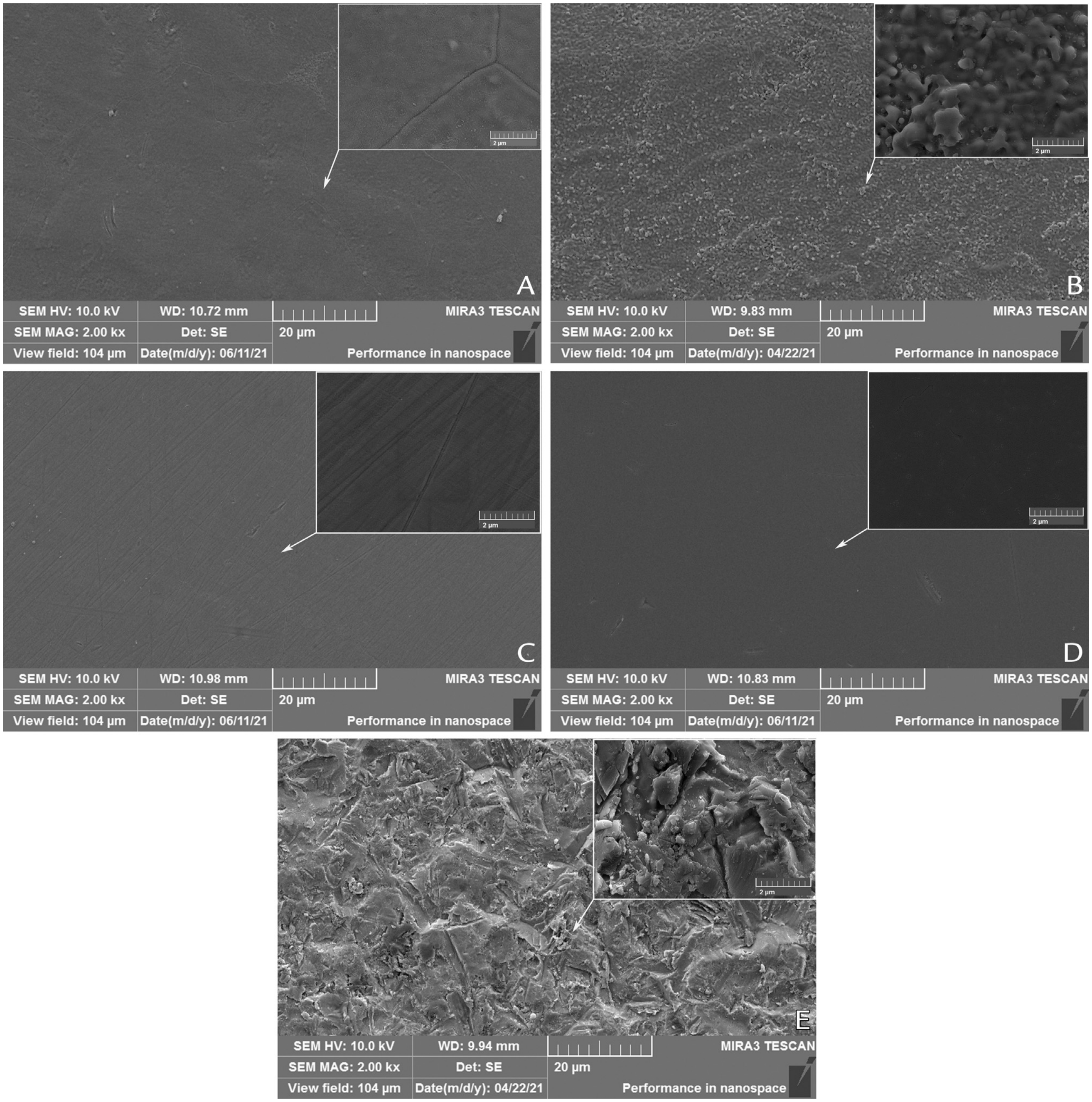

Figure 7. Surfaces of different zirconia (original magnification ×2000). A, Self-glazed surface. B, Milled surface. C, Polished surface. D, Glazed surface. E, Airborne-particle–abraded surface.

r=0.242, *P*=.03; A3: r=0.304, *P*<.001). The RTP is closer to the color changes seen by the naked eye than Tt% and is appropriate as an auxiliary indicator for evaluating the clinical color of ceramic restorations.

Limitations of this in vitro study included that the outer shape of the crown was curved rather than flat, affecting light transmission and reflection. Moreover, only 1 type of zirconia material and 2 shades were studied. Therefore, further studies should be conducted, and further progress is still needed to achieve optimal esthetics for monolithic zirconia ceramic restorations.

CONCLUSIONS

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

1. Different surface treatments significantly changed surface roughness, translucency, and the final color.

The smoothest external polishing surface had the greatest color difference.

2. Different shades significantly influenced the translucency. The darker the ceramic shade, the lower the translucency.
3. Color difference was positively correlated with the RTP, which was determined to be an appropriate auxiliary indicator for evaluating the color of dental ceramics.

REFERENCES

1. Shen ZJ, Liu L, Xu X, Zhao J, Eriksson M, Zhong Y, et al. Fractography of self-glazed zirconia with improved reliability. *J Eur Ceram Soc*. 2017;37:4339–4345.
2. Liu YH, Wang Y, Wang D, Ma J, Liu L, Shen ZJ. Self-glazed zirconia reducing the wear to tooth enamel. *J Eur Ceram Soc*. 2016;36:2889–2894.
3. Zhang Y, Han J, Zheng G, Lin H, Bai W, Zhao J, et al. Fatigue behaviours of the zirconia dental restorations prepared by two manufacturing methods. *Adv Appl Ceram*. 2017;116:368–375.
4. Cui XY, Shen ZJ, Wang XZ. Esthetic appearances of anatomic contour zirconia crowns made by additive wet deposition and subtractive dry milling: a self-controlled clinical trial. *J Prosthet Dent*. 2020;123:442–448.
5. Chen YM, Smales RJ, Yip KH, Sung WJ. Translucency and biaxial flexural strength of four ceramic core materials. *Dent Mater J*. 2008;24:1506–1511.
6. Skyllouriotis AL, Yamamoto HL, Nathanson D. Masking properties of ceramics for veneer restorations. *J Prosthet Dent*. 2017;118:517–523.
7. Kim HK, Kim SH, Lee JB, Han JS, Yeo IS. Effect of polishing and glazing on the color and spectral distribution of monolithic zirconia. *J Adv Prosthodont*. 2013;5:296–304.
8. Lucas CM, Carlos FBS, Ricardo HDJ, Laís RDSC, Stefania CK, Anuar AX. Influence of polishing systems on roughness and color change of two dental ceramics. *J Adv Prosthodont*. 2019;11:215–222.
9. Chu FCS, Chow TW, Chai J. Contrast ratios and masking ability of three types of ceramic veneers. *J Prosthet Dent*. 2007;98:359–364.
10. Kim HK, Kim SH, Lee JB, Ha SR. Effects of surface treatments on the translucency, opalescence, and surface texture of dental monolithic zirconia ceramics. *J Prosthet Dent*. 2016;115:773–779.
11. Khaled Q, Ahmad M, Ahed M, Nadim ZB, Brian JG. Surface roughness of monolithic and layered zirconia restorations at different stages of finishing and polishing: an in vitro study. *J Prosthodont*. 2019;287:818–825.
12. Caglar I, Ates SM, Yesil DZ. The effect of various polishing systems on surface roughness and phase transformation of monolithic zirconia. *J Adv Prosthodont*. 2018;10:132–137.
13. Manziuc MM, Gasparik C, Burde AV, Colosi HA, Negucioiu M, Dudea D. Effect of glazing on translucency, color, and surface roughness of monolithic zirconia materials. *J Esthet Restor Dent*. 2019;31:478–485.
14. Lee DH, Mai H, Thant PP, Hong S, Kim J, Jeong S, et al. Effects of different surface finishing protocols for zirconia on surface roughness and bacterial biofilm formation. *J Adv Prosthodont*. 2019;11:41–47.
15. Mahshid MB, Mansoure B, Rezvani MB, Jamshidian M. Effect of coarse grinding, overglazing, and 2 polishing systems on the flexural strength, surface roughness, and phase transformation of yttrium-stabilized tetragonal zirconia. *J Prosthet Dent*. 2017;118:658–665.
16. Bai Y, Zhao J, Si W, Wang X. Two-body wear performance of dental colored zirconia after different surface treatments. *J Prosthet Dent*. 2016;116:584–590.
17. Sabrah AH, Cook NB, Luangruangrong P, Hara AT, Bottino MC. Full-contour Y-TZP ceramic surface roughness effect on synthetic hydroxyapatite wear. *Dent Mater*. 2013;29:666–673.
18. Kim IJ, Lee YK, Lim BS, Kim CW. Effect of surface topography on the color of dental porcelain. *J Mater Sci Mater Med*. 2003;14:405–409.
19. Sevcan K, Önöral Ö, Huseyin A, Oguz O. Does the application of surface treatments in different sintering stages affect flexural strength and optical properties of zirconia? *J Esthet Restor Dent*. 2020;32:81–90.
20. Nogueira AD, Bona AD. The effect of a coupling medium on color and translucency of CAD-CAM ceramics. *J Dent*. 2013;41:e18–e23.
21. Lee WS, Kim SY, Kim JH, Kim WC, Kim WY. The effect of powder A2/powder A3 mixing ratio on color and translucency parameters of dental porcelain. *J Adv Prosthodont*. 2015;7:400–405.
22. Malkondu O, Tinastepe N, Kazazoglu E. Influence of type of cement on the color and translucency of monolithic zirconia. *J Prosthet Dent*. 2016;116:902–908.
23. Meral K, Bilge TB. Effects of accelerated artificial aging on the translucency and color stability of monolithic ceramics with different surface treatments. *J Prosthet Dent*. 2019;121:712.e1–712.e8.
24. Ioana SP, Razvan G, Diana D, Javier R, Maria MZ, Horatiu C. The effects of thickness and shade on translucency parameters of contemporary, esthetic dental ceramics. *J Esthet Restor Dent*. 2021;33:795–806.
25. Johnston WM. Review of translucency determinations and applications to dental materials. *J Esthet Restor Dent*. 2014;26:217–223.
26. Ebeid K, Wille S, Hamdy A, Salah T, El-Etreby A, Kern M. Effect of changes in sintering parameters on monolithic translucent zirconia. *Dent Mater*. 2014;30:419–424.
27. Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter AV, Vallittu PK, Närhi TO, et al. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. *Dent Mater*. 2015;31:1180–1187.
28. Ilie N, Stawarczyk B. Quantification of the amount of blue light passing through monolithic zirconia with respect to thickness and polymerization conditions. *J Prosthet Dent*. 2015;113:114–121.
29. Vichi A, Louca C, Corciolani G, Ferrari M. Color related to ceramic and zirconia restorations: a review. *Dent Mater*. 2011;27:97–108.
30. Paolo B, Vinícius FW, Maria EM, Candida P, Carlo M, Leonardo C. Translucency of IPS e.max and cubic zirconia monolithic crowns. *J Prosthet Dent*. 2018;120:269–275.
31. Alp G, Yilmaz B, Johnston WM. Effect of surface treatments and coffee thermocycling on the color and translucency of new generation CAD-CAM monolithic glass ceramics. *J Prosthet Dent*. 2018;120:263–268.
32. Cerci BB, Roman LS, Guariza-Filho O. Dental enamel roughness with different acid etching times: atomic force microscopy study. *Eur J Gen Dent*. 2012;1:187–191.
33. Chung KH. Effects of finishing and polishing procedures on the surface texture of resin composites. *Dent Mater*. 1994;10:325–330.
34. Sarikaya I, Güler AU. Effects of different polishing techniques on the surface roughness of dental porcelains. *J Appl Oral Sci*. 2010;18:10–16.
35. Tabatabaian F, Motamedi E, Sahabi M, Torabzadeh H, Namdari M. Effect of thickness of monolithic zirconia ceramic on final color. *J Prosthet Dent*. 2018;120:257–262.
36. Elif FK, Yurdanur U, Cem K, William MJ. Color and translucency of zirconia infrastructures and porcelain-layered systems. *J Prosthet Dent*. 2019;121:510–516.
37. Li S, Wang Y, Tao Y, Liu Y. Effects of surface treatments and abutment shades on the final color of high-translucency self-glazed zirconia crowns. *J Prosthet Dent*. 2021;126:795.e1–795.e8.
38. Oh SH, Kim SG. Effect of abutment shade, ceramic thickness, and coping type on the final shade of zirconia all-ceramic restorations: in vitro study of color masking ability. *J Adv Prosthodont*. 2015;7:368–374.
39. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27:1–9.
40. Luo MR, Cui G, Rigg B. The development of the CIE 2000 color difference formula: CIEDE2000. *Color Res Appl*. 2001;26:340–350.
41. Harada K, Raigrodski AJ, Chung KH, Flinn BD, Dogan S, Mancl LA. A comparative evaluation of the translucency of zirconias and lithium disilicate for monolithic restorations. *J Prosthet Dent*. 2016;116:257–263.
42. Song F, Koo H, Ren D. Effects of material properties on bacterial adhesion and biofilm formation. *J Dent Res*. 2015;94:1027–1034.

Corresponding author:

Dr Yihong Liu
Department of General Dentistry
Peking University School and Hospital of Stomatology
22 South Street Zhong Guan Cun, Haidian District
Beijing 100081
PR CHINA
Email: kqliuyh@163.com

Acknowledgments

The authors thank Erran Tech Ltd for manufacturing the disks by the wet deposition. The authors also thank Mrs Yongqing Tao for help with glazing procedure. The authors also thank Mr Hezhen Li for help with SEM analysis and Ms Yue Wang for help with Tt% and R% measurement.

CRediT authorship contribution statement

Siyu Li: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Xinyue Zhang:** Software, Validation. **Wei Xia:** Supervision, Funding acquisition. **Yihong Liu:** Conceptualization, Methodology, Supervision, Funding acquisition.

https://doi.org/10.1016/j.prosdent.2022.05.014