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Effect of surface topography on the color of dental porcelain

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The objectives of this study were to evaluate the color difference depending on the surface topography of roughness and glazing, and to determine the effects of color measuring geometry and the standard illuminant on the color of a dental porcelain. Disk specimens of A3 shade were fired with commercial dental porcelain for PFM. Specimens were divided into non-polished (ST 1), polished with 200, 400, 1000, 1500-grit SiC papers (ST 2, 3, 4, 5) and glazed (ST 6) groups. After measuring the average surface roughness (Ra), color was determined under the illuminant A and D65 on a spectrophotometer with the specular component excluded (SCE) and included (SCI) geometry. Ra values were significantly influenced by the surface topography. With the SCE, the CIE L^* value after glazing was significantly lower than that after polishing. Color differences (ΔE^*) measured with the SCE were higher than those with the SCI (2.61–4.66 *vs*. 0.93–1.57). Therefore the SCE geometry seemed to more accurate protocol for the color measurement of dental porcelain.

1. Introduction
Color of the tooth and of dental materials is commonly measured in reflected light by visual or instrumental technique. Instrumental measurements can quantify color and enable the practitioner and technician to communicate color more uniformly and precisely than with a visual technique. However, attaining an ideal esthetic result with dental porcelain is difficult due to complicated optical properties of this material.

Two types of color measuring instruments, colorimeter and spectrophotometer, are used. Parameters in the instrumental color measurement such as the measuring geometry, illuminant and illuminating/viewing configuration can influence the color measurement. A spectrophotometer with an integrating sphere can operate two different measuring geometries, specular component included (SCI) and specular component excluded (SCE). The specular component is the reflected light from the surface such that the angle of reflection equals the angle of incidence. Two standard illuminants are recommended in the CIE Specification; illuminant A represents light from the full radiator at absolute temperature of 2856 K, and D65 represents a phase of daylight at 6504 K [1, 2].

Color of porcelain restorations may be affected by various optical phenomena like scattering, transmission, absorption, reflection and refraction of the restorative material and the tooth. In addition, surface gloss, texture and roughness can also alter the color of porcelain restorations [3]. Therefore an accurate understanding of the influence of surface topography on measured color is essential for the fabrication of tooth-like porcelain restorations. Moreover, the color measuring geometry of the SCE and the SCI may influence color measurement when the surface is not uniform. In a previous study, it was clear that the color measuring geometry and the standard illuminant influenced the color measurement of dental resin composites [4]. However, the effect of the surface topography on the color of dental porcelain depending on the measuring geometry and the illuminant has not been clearly confirmed.

The objectives of this study were to evaluate the color difference of a dental porcelain material depending on the surface roughness (Ra) and glazing, and to determine the effects of color measuring geometry (SCE *vs*. SCI) and the standard illuminant (A *vs*. D65) on the color of a commercial dental porcelain.

2. Materials and methods
Commercial dental porcelain (VITA Omega 900, 61375, VITA, Germany) was studied. Disc specimens (10.0 mm in diameter, 1.0 mm in thickness after firing) were prepared with A3 shade enamel porcelain. Moistened porcelain powder was packed into a mold (13.0 mm in diameter) and was condensed using a vibration and blotting technique. Firing procedure was performed on a tray in a porcelain furnace (Austromat 3001, Dekema, Austria) following the manufacturer's instructions.

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Thirty-six specimens were divided into six groups, and were coded as follows; ST 1 was the specimen after firing, ST 2, 3, 4, or 5 was the specimen polished with 200, 400, 1000, or 1500-grit SiC paper respectively after firing, and ST 6 was the specimen glazed after firing. For polishing, the specimen was rubbed against a sheet of wet SiC paper for 50 strokes of 15 cm in length. Glazing was performed by heating gradually to 450 °C and maintained for 4 min, and then heating to 920 °C for 40 s.

Surface roughness (Ra) was measured with a surface profilometer (Surtronic 3P, Taylor–Hobson, England). Ten measurements were made with a cutoff value of 0.8 mm and measuring length of 3 mm. Prior to measuring, the profilometer was calibrated against a reference block, of which the Ra value is 6.07.

Color was measured according to the CIE $L^*a^*b^*$ color scale under the standard illuminant A and D65 on a spectrophotometer (CM-3500d, Minolta, Japan) with the SCE and the SCI geometry [5]. The aperture diameter of the measuring port of the instrument was 3 mm, and the illuminating and viewing condition was CIE diffuse/8° geometry. White ceramic tile was used as the background, of which the CIE $L^* = 84.23$, $a^* = 0.23$ and $b^* = 1.78$ with the SCE under the illuminant A. All specimens were connected optically with the background using a refractive oil (refractive index = 1.5, Cargille, USA) during the measurement. Optical fluid was used to achieve optical contact [6–8].

Differences in the Ra value and the color difference (ΔE^*) were analyzed by ANOVA and Scheffe's multiple range tests (SPSS 7.0, SPSS, USA, $p = 0.05$). *T*-test was used to compare the color coordinates by the different measuring geometries. Multiple regression analysis was used to determine the correlation between the Ra value and color coordinates. The Ra value was used as a dependent variable, and six color coordinates (CIE L^*, a^* and b^* under the illuminant A and D65 with each of the SCE or SCI geometry) were used as independent variables in a forward regression analysis ($p = 0.01$). The impact of interrelated independent variables was eliminated when the tolerance between two influencing variables was lower than 0.30 [9].

3. Result

Ra values are presented in Table I. Ra value was influenced by the surface treatment from a one-way ANOVA ($p < 0.05$). Ra value after firing (ST 1) was the highest, and was different from those of ST 2–6 ($p < 0.05$). Ra value after polishing with 400, 1000 or 1500-grit SiC paper (ST 3–5) was lower than that after glazing (ST 6), however it was not significant ($p > 0.05$).

CIE L^*, a^* and b^* values measured with the SCE geometry are presented in Table II, and in Table III with the SCI geometry. With the SCE, the CIE L^* after glazing (ST 6) was lower than those after polishing (ST 2–5), regardless of the illuminant ($p < 0.05$). With the SCI, the CIE L^* after glazing (ST 6) was not different from those of ST 2, 3 and 5 ($p > 0.05$). Both with the SCE and SCI geometry, there were no general trends in the change of CIE a^* and b^* values after polishing and glazing. In both geometries, the CIE L^*, a^* and b^* measured under the illuminant A were higher than those under the D65. The CIE L^* measured with the SCE geometry were significantly lower than those with the SCI for all surface conditions ($p < 0.05$). CIE a^* and b^* measured with the SCE geometry were generally higher than those with the SCI, however it was not significant except some coordinates.

Color difference (ΔE^*) between the glazed (ST 6) and each of the other surface treatments are presented in Table IV. Under the standard illuminant A, ΔE^* values between the glazed (ST 6) and polished with 200, 1000 and 1500-grit SiC papers (ST 2, 4, 5) were visually perceptible (3.93–4.61) with the SCE geometry, however those values with the SCI were not perceptible (0.93–1.48) [10]. Regardless of the surface treatments, ΔE^* values measured with SCE were higher than those with the SCI (2.61–4.61 *vs.* 0.93–1.48). Under the standard illuminant D65, similar results to those under the illuminant A were found. However, the magnitude of ΔE^* value was generally higher than those under the illuminant A.

Correlations among the Ra value and the color coordinates are presented in Table V. As the Ra value increased, the CIE b^* with the SCE under the illuminant A decreased ($r = -0.30$), and the CIE L^* and b^* with the SCI under the illuminant A decreased ($r = -0.79$). CIE a^* value was not correlated with the Ra value.

4. Discussion

Illuminating and viewing configurations of color measuring instrument may influence the measured color. Color measurement can be classified according to the geometric configurations of illumination and detection employed. In the integrating sphere type, the specimen is illuminated at about 0° and the reflected light is detected diffusely, i.e., uniformly in all directions (0/D) or reverse direction (D/0). Some integrating sphere instruments have a port at the specular reflection position that can be covered by a white or black cap, thus permitting the specular component of the surface reflected light to be included (0/D-SCI) or excluded (0/D-SCE) [11, 12]. Increase in the translucency of enamel porcelain increases the amount of transmitted light, and decreases

TABLE I Average surface roughness (Ra in μm) depending on the surface treatments (Standard deviations are in parentheses)

ST 1 (firing)	ST 2 (200 grit)	ST 3 (400 grit)	ST 4 (1000 grit)	ST 5 (1500 grit)	ST 6 (glazing)
5.40 (0.09)	0.61 (0.03)	0.29 (0.02)[a]	0.21 (0.02)[a]	0.17 (0.01)[a]	0.30 (0.20)[a]

[a] Indicates no significant difference ($p > 0.05$).

TABLE II CIE L^*, a^* and b^* values by the surface treatments and the standard illuminant with the SCE geometry (Standard deviations are in parentheses)

	A			D65		
	L^*	a^*	b^*	L^*	a^*	b^*
ST 1 (firing)	45.66 (0.31)[a]	0.82 (0.04)	1.67 (0.08)	45.45 (0.40)[a]	0.55 (0.03)	1.40 (0.17)
ST 2 (200 girt)	47.25 (0.44)[a]	0.84 (0.13)	1.63 (0.31)	47.12 (0.79)[a]	0.54 (0.13)	1.45 (0.23)
ST 3 (400 girt)	46.41 (0.52)[a]	0.96 (0.06)	1.91 (0.08)	46.39 (0.42)[a]	0.61 (0.05)	1.67 (0.07)
ST 4 (1000 girt)	48.08 (0.62)[a]	1.02 (0.08)	2.23 (0.17)	47.87 (0.62)[a]	0.63 (0.04)	1.87 (0.18)[a]
ST 5 (1500 girt)	46.93 (0.47)[a]	0.84 (0.08)	1.71 (0.23)	47.16 (0.61)	0.57 (0.06)	1.50 (0.14)
ST 6 (glazing)	43.33 (0.29)[a]	1.26 (0.03)[a]	2.75 (0.05)[a]	43.08 (0.29)[a]	0.76 (0.03)[a]	2.43 (0.05)[a]
DG[b]	ST 6/2 3 4 5[c] ST 3/4	ST 6/1 2 4 5 ST 4/1 2 ST 3/1 2	ST 4/1 2 5 ST 3/1 2	ST 6/2 3 4 5 ST 1/2 4 5	ST 6/1 2 5 ST 2/3	ST 6/1 2 3 4 5 ST 4/1 2 5 ST 3/1 2

[a] Significantly different color coordinate by the measuring geometries of the SCE and the SCI (Compare with the values in Table III).
[b] DG means different groups from Scheffe's multiple comparison test ($p < 0.05$).
[c] /; Significantly different group marker.

TABLE III CIE L^*, a^* and b^* values by the surface conditions and the standard illuminant with the SCI geometry (Standard deviations are in parentheses)

	A			D65		
	L^*	a^*	b^*	L^*	a^*	b^*
ST 1 (firing)	46.40 (0.26)	0.79 (0.02)	1.53 (0.18)	46.20 (0.44)	0.52 (0.03)	1.31 (0.15)
ST 2 (200 grit)	47.96 (0.35)	0.71 (0.15)	1.35 (0.26)	48.51 (0.73)	0.47 (0.12)	1.19 (0.20)
ST 3 (400 grit)	48.35 (0.31)	1.00 (0.05)	1.94 (0.11)	48.16 (0.30)	0.64 (0.03)	1.70 (0.10)
ST 4 (1000 grit)	48.94 (0.51)	0.92 (0.12)	1.97 (0.09)	48.76 (0.51)	0.58 (0.07)	1.60 (0.22)
ST 5 (1500 grit)	48.05 (0.56)	0.83 (0.06)	1.61 (0.22)	47.88 (0.56)	0.57 (0.05)	1.39 (0.09)
ST 6 (glazing)	47.49 (0.53)	0.98 (0.03)	2.22 (0.09)	47.29 (0.53)	0.59 (0.03)	1.97 (0.09)
DG[a]	ST 1/2 3 4 5 6[b] ST 4/2 6	ST 2/3 4 6 ST 1/3 6	ST 2/3 4 6 ST 1/3 4 6 ST 5/4 6	ST 1/2 3 4 5 ST 6/2 4	ST 2/3	ST 6/1 2 4 5 ST 3/1 2 ST 2/4

[a] DG means different groups from Scheffe's multiple comparison test ($p < 0.05$).
[b] /; Significantly different group marker.

TABLE IV Color difference (ΔE^*) between the glazed surface (ST 6) and the other surface treatments (Standard deviations are in parentheses)

Illuminant	Geometry	ST 1 (firing)	ST 2 (200 grit)	ST 3 (400 grit)	ST 4 (1000 grit)	ST 5 (1500 grit)
A	SCE	2.61 (0.37)	3.95 (0.40)	3.05 (0.39)	4.61 (0.44)	3.93 (0.52)
	SCI	1.28 (0.22)	1.12 (0.34)	0.93 (0.42)	1.48 (0.16)	1.06 (0.10)
D65	SCE	2.76 (0.34)	3.90 (0.42)	3.28 (0.18)	4.66 (0.43)	4.41 (0.40)
	SCI	1.30 (0.27)	1.53 (0.64)	0.94 (0.43)	1.57 (0.18)	1.03 (0.16)

TABLE V Correlations between the optical properties and the Ra value

Geometry	Equation from the multiple regression analysis	Multiple correlation coefficient
SCE	$Ra = -0.37\ Ab^* + 2.42$	0.30
SCI	$Ra = -1.45\ AL^* - 0.69\ Ab^* + 72.01$	0.79

[a] AL^* and Ab^* means the CIE L^* and b^* value measured with standard illuminant A, respectively.
[b] All the results were significant at the level of $p = 0.01$.

the specular and diffuse reflection of the opaque and dentin porcelain. Therefore, D/0 configuration was recommended for measuring the color of translucent dental materials [13]. With the D/0 type illuminating/viewing configuration, the discrimination of the color of dental porcelain with varied surface topography was possible [14]. In the present study, the influence of the measuring geometry on the color of porcelain after varied surface treatments was evaluated using an integrating-sphere spectrophotometer of CIE diffuse/8° configuration, which is the modified D/0 type configuration.

Of the CIE standard illuminants, illuminant D65 is generally used since it is representative of average daylight at different locations, and its correlated color temperature (6500 K) agrees with the correlated color temperature (6000–7000 K) of global daylight [15]. Any alteration in the intensity of light will also alter the color of an object. When lighting matches the color of the object illuminated, it becomes more heavily saturated. Light sources can also affect the Value of the Munsell Color System. In the present study, CIE L^*, a^* and b^* values measured under the illuminant A was higher than those under the D65. Therefore, color of tooth and corresponding esthetic materials were matched better to the illuminant A than D65.

After firing and glazing a dental porcelain restoration, some modifications by grinding are required for shaping and occlusal adjustment. After the modified surface is polished or reglazed to improve the appearance and to inhibit plaque accumulation, it has been reported that the Ra values varied depending on the clinical polishing systems, and ranged from 0.22 to 1.35 µm [16]. These Ra values after polishing are within the same range of or higher than those after polishing with 400–1500-grit SiC papers in the present study (Table I). In the present study, SiC papers were used to standardize the polishing procedure, and this polishing method can be applied only to *in vitro* studies.

There are debates on the efficiency of polishing techniques compared to reglazing of dental porcelain. Several studies have determined the Ra values after polishing with different polishing techniques, and compared to those of glazed surfaces. It has been reported that there were no significant differences for the Ra values between the final polished surfaces and the glazed surfaces [17, 18]. It was possible to obtain a surface as smooth or smoother using several polishing methods than that with glazing [19]. In the present study, the Ra value after glazing was not significantly different from those after polishing with 400–1500-grit SiC papers (Table I). Therefore, considering the Ra value only, the reglazing procedure following shape adjustment can be omitted if the porcelain surface is polished with SiC papers finer than 400-grit. Although there was a small discrepancy in the Ra values between the polished and glazed surfaces, however, the color difference between two surfaces was perceivable ($\Delta E^* > 3.3$) since the ΔE^* value was in the range of 3.93–4.66 with the SCE in the present study. Therefore the polishing technique that can reduce the color difference compared to the glazed surface should be employed. If that is hard to obtain, glazing procedure seems to be essential for the proper color matching of porcelain. High ΔE^* values of 3.93–4.66 with the SCE was not duplicated when measured with the SCI ($\Delta E^* = 0.93$–1.57).

In other studies on the polishing of dental porcelain, use of a diamond polishing paste alone was not sufficient to restore a polished surface to its original glazed surface [20, 21]. On visual examination, polishing pastes produced a surface equal to or better than glazing, while on the SEM examination, glazing produced a better surface [22]. In the present study, the Ra value after glazing was not significantly different from those after polishing. However, the color difference between the polished and glazed surface was perceivable. It is obvious that color of dental porcelain is influenced by other surface characteristics than those measured by the Ra value.

Dependence of the lightness of paper on surface roughness was determined. Measured lightness of glossy white object with a polished surface can be less than that of grayer objects with a rough surface, although visually the former would look whiter [23]. Matte objects appear less intensely colored, showing higher Value (lightness) and lower Chroma than the corresponding glossy objects [24]. Similarly, in the present study, it was clear that surface topography influenced the color of the porcelain, especially the CIE L^* value. Although the glazed surface looked whiter, the CIE L^* value measured with the SCE was significantly lower than that of the polished surface. However, CIE a^* and b^* values increased after glazing, which is in accordance with a previous report [24]. The CIE L^* values measured with the two different measuring geometries were significantly different, and there was some correlation between the Ra values and CIE L^* values measured with the SCI.

In the instrumental color measurement of dental materials, results of measurement can be altered because the standard illumination emitted from the instrument can be scattered, absorbed, transmitted, reflected and even displaced in sideways directions as a result of the translucent optical properties of teeth and dental esthetic restorative materials [25]. Surface texture may affect the refraction or reflection of the light striking the porcelain restoration and it was assumed that the texture or surface topography of the restoration could dramatically change the Hue (color saturation) of the restorations [26]. The texture, curvature and gloss of porcelain restorations vary a great deal depending on the surface treatment of glazing or polishing, and resultantly modify the light striking this surface [27]. Changes of the CIE a^* and b^* values (Hue) by the surface topography were significant under some measuring conditions of the present study. The CIE a^* and b^* values were highest after glazing, and the ΔE^* values between the surface treatments were in the visually perceivable range when measured with the SCE geometry. However, the ΔE^* values were lower than the visually perceivable range (< 3.3) with the SCI geometry.

As the degree of gloss is increased, more incident light is reflected in the specular direction but less in other directions. The measured color depends on how much of the surface reflected light is detected. The SCI geometry detects virtually all of the lights of specular and other directions, in which case the measured color may be independent of surface gloss. Therefore, the difference in surface topography is not reflected on the measured color with the SCI geometry. On the other hand, the SCE geometry cuts out almost all specularly reflected light, and the measured color is a strong function of specimen gloss. Therefore, as was clarified in the present study, color differences by the surface conditions are large enough to be visually perceivable when measured with the SCE geometry. Since the surfaces of natural tooth and glazed porcelain are high glossy or change after service, the SCE geometry may be recommended as the configuration for the color measurement of dental porcelain.

In the present study, lacks of correlation among the Ra value and the CIE L^* and b^* values measured with different geometry and illuminant may be well due to the fact that all of color coordinates measured are interrelated, in conjugation with the fact that some other correlated variables has already accounted for a significant reduction in unexplained variability associated with regression. Including the specular component (SCI geometry) resulted in better correlation coefficient, however the multiple correlation coefficient was not so high as 0.79.

In practice, the thickness of porcelain veneers vary from 0.5 to 1.25 mm and that of all-ceramic crowns may range from 1.5 to 2 mm [28]. Therefore, the results of this study may not coincident with those of clinical conditions. Because of the inherent variation in optical properties of different porcelains, and the diversity of shade and thickness of porcelain, further study is indicted.

5. Conclusion

Variations in the measured color of dental porcelain materials depending on the surface topography were determined using a spectrophotometer. Within the limits of this study, the following conclusions were drawn:

1. The Ra values of dental porcelain were influenced by surface treatment, however the Ra value of glazed surface was not different from those after polishing with 400–1500-grit SiC papers.
2. With the SCE geometry, the CIE L^* value after glazing was lower than those after polishing with 200–1500-grit SiC papers. With the SCI, difference in the CIE L^* by the surface treatments was not significant.
3. Regardless of the surface topography, ΔE^* values measured with the SCE geometry were higher than those with the SCI.
4. The CIE L^* value measured with the SCE geometry was lower than that with the SCI regardless of the material ($p < 0.05$), and the CIE a^* and b^* values with the SCE were generally higher than those with the SCI.
5. The SCE geometry seemed to more accurate protocol for the color measurement of dental porcelain with different surface conditions.

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