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Original

Effects of specular component and polishing on color of resin composites

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Abstract: This study evaluated the effects of the specular component mode of specular component included (SCI) and specular component excluded (SCE), and the grit size of final polishing with SiC paper on color of different types of resin composites and shades. Resin disks of 2 mm in thickness were made with regular, opaque and enamel shades for each of the following: supra-nano spherical filled Estelite Σ Quick (EQ), organic filled hybrid Clearfil Majesty (CM), and S-PRG filled nano-hybrid Beautifil II (B2). One week after curing, the surface roughness and color were measured. Color differences between 3000- and 1000-grit, and between 3000- and 180-grit final polishing groups were calculated. Comparison of L*a*b* between SCI and SCE modes showed that the L* values with SCI were significantly higher than those with SCE in 1000- and 3000-grit groups for EQ and CM, and in 3000-grit group for B2. Comparison of total color differences (ΔE*ab) between SCI and SCE modes for all resin composites and shades in all polishing groups showed that the ΔE*ab with SCE were higher than those with SCI except for opaque shade of EQ with white background in 1000-grit group in which the ΔE*ab values were same. The effect of the specular component mode and polishing on color differed among the resin composites and shades. (J Oral Sci 52, 599-607, 2010)

Keywords: polishing; color; resin composites; shades; specular component included; specular component excluded.

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Introduction

Resin composites have been widely used because of their excellent esthetic properties. The ultimate esthetics of a tooth-colored restorative is highly influenced by the final surface polish (1,2). The esthetic success of a restoration is directly related to its optical appearance. Surface roughness and color are among the important factors that dominate the perceived visual appearance of resin composite restorations (3). Although correlations among these factors may vary among different types of resin composites and shades, to our knowledge, no information about them is available. Size and shape of resin composite fillers affect surface morphology of resin composites subjected to finishing procedures (1,4,5). Polishing also causes changes in surface smoothness (6). Filler particle technology is a factor influencing optical properties and wear resistance of resin composite restorations (7). By reducing filler particle size, an improvement of surface smoothness is expected (8).

A spectrophotometer with an integrating sphere can operate using two different specular component modes. One mode is the specular component included (SCI) and the other is the specular component excluded (SCE). The specular component is reflected light from the surface such that the angle of reflection equals the angle of incidence (9). There are standards and recommendations that include the measurement geometries defined as *d*/0 and *t*/0, where *d* represents diffuse illumination (SCE) and t represents total illumination that are included in the diffuse and the specular component (SCI). The other character (0) represents the incident-viewing angle of the receiver optics as measured from the specimen normal (10). To improve accuracy, matt standards are required in reflectance colorimetry to simplify the problem of fully excluding or including the specular component in the measurement, as they diffusely reflect light equally in all directions (11). Specularly reflected components from some surfaces (paint surfaces that are glossy, semi-glossy or matt) were spread over a considerably wide range from the regular direction (12). The surface of esthetic dental materials such as resin composites is not totally reflecting or matt. Thus, inclusion or exclusion of the specular component may be important for the color measurement of resin composites. However, limited information on the effects of the differences in the specular component mode of SCI and SCE has been reported (13). Previous studies reported that the color change of resin composites differed between the SCI and SCE modes (13-15). The normally accepted theory in color science is that the SCE mode approximates the view with the naked eye, whereas the SCI mode is adequate to analyze the intrinsic color of objects. However, to our knowledge, no information is available to demonstrate the theory for esthetic dental materials including resin composites.

Recently, a new supra-nano spherical filled composite resin (Estelite Σ Quick, Tokuyama Dental Co., Tokyo, Japan) was developed based on the sol-gel method that controls the diameter of fillers and also changes the refraction rate of fillers (16). A nano-hybrid resin composite with a surface reaction typed pre-reacted glass-ionomer (S-PRG) filler was developed by applying PRG technology (Beautifil II, Shofu Co., Kyoto, Japan). The PRG technology is based on forming a glass-ionomer phase only on the surface of a glass core layer by means of an acid-base reaction between special surface-fractured multi-functional fluoroboroaluminosilicate glass filler and polycarboxylic acid in the presence of water. Clearfil Majesty (Kuraray Co., Tokyo, Japan) is a hybrid resin composite that includes pre-polymerized organic fillers. To our knowledge, no information is available to date on the influences of specular component modes and surface roughness on the color factors for different resin composites and shades.

The objective of the present study was to evaluate the effects of specular component modes and the grit size of SiC paper on color of three different types of resin composites and different composite shades (regular, opaque and enamel shades).

Materials and Methods

Properties, types and shades of the resin composites used in this study are shown in Table 1.

To make a standardized specimen, a 3-mm-thick mold with a 15-mm diameter hole was prepared. Resin composite was filled into the hole with clear plastic film on the top and light activated for 40 seconds using a quartz-tungsten halogen light-curing unit. The composite disk was then removed from the mold and the bottom side of the disk was also light activated for 40 seconds. Three polishing groups in which the final polishing was done with 180-, 1000- or 3000-grit SiC paper were prepared for each of the shades. In the 180-grit group, the top sides of resin disks were polished with 180-grit silicon carbide (SiC) paper; in the 1000-grit group, the top sides of resin disks were polished in order with 180-, 600-, 800- and 1000-grit SiC papers; and in the 3000-grit group, the top sides of the resin disks were polished in order with 180-, 600-, 800-, 1000- and 3000-grit SiC papers. The bottom sides of all the resin disks were polished with 800-grit SiC paper. Polishing was done under copious water flow to a final thickness of 2 mm as measured with a dial caliper (Mitsutoyo, Tokyo, Japan). For each of resin composites, a total of 9 groups classified by different shades and polishes were prepared. Thus, a total of 27 groups were prepared. Three disks were prepared for each group. The disks were stored in a 100% wet light-blocked container and stored in 23 ± 1°C for one week.

Color was measured with a spectrophotometer (CM-3600d, Konica Minolta, Tokyo, Japan) according to the CIE L*a*b* color scale relative to the standard illuminant D_{65} in the reflectance mode over white and black backgrounds

Table 1 Characteristics of resin composites tested

Resin Composite	Abbreviation	Composition	Type (Shade)
Estelite Σ Quick (Tokuyama Dental Co. Tokyo, Japan)	**EQ**	**Matrix:** Bis-phenolA diglycidylmethacrylate (Bis-GMA), Triethylene glycol dimethacrylate (TEGDMA) **Filler:** spherical silica-zirconia filler (100-300 nm average: 200 nm) **Filler loading:** 71 vol% (82 wt%)	Supra-nano spherical filled (A2, OA2, CE)
Clearfil Majesty (Kuraray Medical Co. Tokyo, Japan)	**CM**	**Matrix:** Bis-GMA, Hydrophobic aliphatic dimethacrylate, Hydrophobic aromatic dimethacrylate **Filler:** silanated barium glass filler pre-polymerized organic filler including nano filler (filler: 0.2- 100 μm, average; 0.7 μm) **Filler loading:** 66 vol% (78 wt%)	Hybrid (A2, OA2, XL)
Beautifil II (Shofu Co. Kyoto, Japan)	**B2**	**Matrix:** Bis-GMA, TEDGMA, Urethane diacryl (UDA) **Filler:** surface reaction type pre-reacted glass-ionomer (S-PRG) and Multi-functional (MF) glass fillers based on fluoroboroaluminosilicate glass (0.1 -4.0 μm, average: 0.8 μm) **Filler loading:** 68.6 vol% (83.3 wt%)	nano- hybrid (A2, A2O, Inc)

with the SCI and SCE modes, as described previously (15). In the CIE 1976 L*a*b* color scale, the L* value determines the psychometric lightness from black to white. The a*b* values are the psychometric chroma coordinates and indicate hue and chroma factors. The a* axis is red on the positive side and green on the negative side. The b* axis is yellow on the positive side and green on the negative side. The higher the numbers, the stronger the color factors are. The aperture diameter for the reflectance measurement was 7 mm, and the illuminating and viewing configurations were CIE diffuse / 8° (17). Measurements were repeated three times for each specimen under each color-measurement condition, and average values for three specimens of the same group (a total of nine measurements for each group) were calculated. The software employed was Spectra-Magic Version 2.11 (Konica Minolta).

Color differences (ΔE*ab) were calculated by the equation of $\Delta E^*ab = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)^2]^{1/2}$ between the 3000- and 1000-grit, and 3000- and 180-grit polishing groups for each of the shades of individual resin composites measured both on the white and black backgrounds and measured with the SCI and SCE modes.

Surface roughness (Ra, μm) of the specimens was evaluated using a laser scanning microscope (VK-8500, Keyence, Osaka, Japan) with a square measurement area of 100 × 100 μm. Measurements were made for three different areas on each specimen, and average values were calculated. Microscopic color views under 400x were taken for each specimen.

Data were analyzed by two-way ANOVA and Fisher's PLSD test at a significance level of $P < 0.05$ (Stat View J-5.0, SAS Institute Inc., Cary, NC, USA).

Results

Table 2 compares the influence of final grit size of SiC polishing paper and composite shade on the surface roughness (Ra) of resin composites. Comparison of Ra among different grit polishings for each shade of the same resin composite showed that the Ra in 180-grit polishing group was significantly lower than that in 1000- and 3000-grit groups. There was no significant difference of the Ra between 1000- and 3000-grit groups except for regular (A2) and enamel (CE) shades of EQ. For the A2 and CE shades of EQ, the order of Ra was 180- > 1000- > 3000-grit with significant differences among the polishing groups. For all the polishing groups and shades, the Ra of the EQ resin composite was significantly lower than that of the CM and B2 resin composites. There was no significant difference of Ra between CM and B2 except for enamel shades (XL/Inc) in 180- and 1000-grit polishing groups.

Tables 3, 4 and 5 show results of EQ, CM and B2 resin composites compared with each of the L*a*b* values of different shades in different polishing groups measured with the SCI and SCE modes over white and black backgrounds. The influence of polishing on each of L*a*b* values differed among resin composites, shades, background colors and specular component modes.

For EQ (Table 3) over the white background for all

Table 2 Influence of final grit size of SiC polishing paper and composite shade to the surface roughness of resin composites

Resin Composite	Polishing (grit size)	Regular Shade	Roughness (Ra: μm)		Opaque Shade	Roughness (Ra: μm)		Enamel Shade	Roughness (Ra: μm)	
EQ	180-grit	A2	1.41 ± 0.23	A, a	OA2	1.93 ± 0.44	A, a	CE	1.86 ± 0.18	A, a
EQ	1000-grit	A2	0.90 ± 0.21	B, a	OA2	1.55 ± 0.23	B, a	CE	0.71 ± 0.10	B, a
EQ	3000-grit	A2	0.32 ± 0.04	C, a	OA2	1.52 ± 0.29	B, a	CE	0.30 ± 0.03	C, a
CM	180-grit	A2	6.24 ± 0.51	A, b	OA2	6.10 ± 0.44	A, b	XL	6.45 ± 0.75	A, c
CM	1000-grit	A2	4.56 ± 0.26	B, b	OA2	4.65 ± 0.12	B, b	XL	5.10 ± 0.27	B, c
CM	3000-grit	A2	5.01 ± 0.32	B, b	OA2	4.89 ± 0.49	B, b	XL	4.64 ± 0.67	B, b
B2	180-grit	A2	5.99 ± 0.51	A, b	A2O	6.00 ± 0.48	A, b	Inc	5.59 ± 0.43	A, b
B2	1000-grit	A2	4.68 ± 0.42	B, b	A2O	4.76 ± 0.27	B, b	Inc	4.70 ± 0.25	B, b
B2	3000-grit	A2	4.63 ± 0.32	B, b	A2O	4.77 ± 0.49	B, b	Inc	4.55 ± 0.58	B, b

For each composite shade in the same resin composite, different alphabetic capital letters (A, B, C) among different grit polishing represents statistical significance ($P < 0.05$).
For each composite shade with the same grit polishing, different alphabetic letters (a, b, c) among different resin composites represent statistical significance ($P < 0.05$).

Table 3 Estelite Σ Quick: L*,a*,b* values of all shades measured with SCI and SCE modes over white and black background

			< White Color Backing >						< Black Color Backing >					
Mode	**Shade**	**Polishing**	**L***		**a***		**b***		**L***		**a***		**b***	
SCI	A2	180-grit	66.4 ± 0.3	a, 1	2.38 ± 0.15	a, 1	21.5 ± 0.1	b, 1	61.2 ± 0.4	a, 1	-0.85 ± 0.03	a, 1	14.4 ± 0.3	b, 1
		1000-grit	66.6 ± 0.1	a, 1	2.57 ± 0.01	a, 2	22.7 ± 0.2	a, 1	61.0 ± 0.1	a, b, 1	-0.86 ± 0.1	a, 1	15.0 ± 0.3	a, 1
		3000-grit	66.3 ± 0.4	a, 1	2.38 ± 0.14	a, 1	22.4 ± 0.7	a, 1	60.6 ± 0.1	b, 1	-0.95 ± 0.04	a, 1	14.7 ± 0.4	a, b, 1
SCE	A2	180-grit	65.6 ± 0.5	a, 1	2.43 ± 0.14	a, 1	21.8 ± 0.2	b, 1	60.3 ± 0.6	a, 1	-0.86 ± 0.1	a, 1	14.6 ± 0.3	a, 1
		1000-grit	65.4 ± 0.5	a, b, 2	2.61 ± 0.02	a, 1	23.1 ± 0.4	a, 1	59.6 ± 0.6	a, 2	-0.91 ± 0.04	a, 1	15.2 ± 0.4	a, 1
		3000-grit	64.3 ± 0.7	b, 2	2.46 ± 0.11	a, 1	23.1 ± 0.5	a, 1	58.3 ± 0.6	b, 2	-1.06 ± 0.06	b, 1	15.1 ± 0.2	a, 1
SCI	OA2	180-grit	69.7 ± 0.4	a, 1	2.17 ± 0.23	a, 1	15.9 ± 0.05	c, 1	66.7 ± 0.3	a, 1	-0.36 ± 0.13	a, 1	11.6 ± 0.2	b, 1
		1000-grit	69.5 ± 0.1	a, 1	2.26 ± 0.05	a, 1	16.8 ± 0.2	b, 1	66.4 ± 0.03	a, b, 1	-0.37 ± 0.01	a, 1	12.3 ± 0.2	a, 1
		3000-grit	69.8 ± 0.05	a, 1	2.33 ± 0.07	a, 1	17.3 ± 0.2	a, 1	66.2 ± 0.1	b, 1	-0.38 ± 0.03	a, 1	12.4 ± 0.1	a, 1
SCE	OA2	180-grit	69.1 ± 0.8	a, 1	2.21 ± 0.2	a, 1	16.0 ± 0.1	c, 1	66.0 ± 0.7	a, 1	-0.35 ± 0.02	a, 1	11.6 ± 0.2	b, 1
		1000-grit	67.9 ± 0.4	b, 2	2.33 ± 0.03	a, 1	17.2 ± 0.1	b, 1	64.6 ± 0.4	b, 2	-0.40 ± 0.02	a, 1	12.5 ± 0.1	a, 1
		3000-grit	67.8 ± 0.3	b, 2	2.41 ± 0.1	a, 1	17.7 ± 0.2	a, 1	64.1 ± 0.2	b, 2	-0.44 ± 0.02	a, 2	12.5 ± 0.1	a, 1
SCI	CE	180-grit	69.4 ± 0.5	b, 1	-3.02 ± 0.04	a, 1	12.1 ± 0.2	b, 1	60.0 ± 0.2	b, 1	-3.43 ± 0.02	a, 1	3.73 ± 0.1	b, 1
		1000-grit	70.1 ± 0.1	a, 1	-3.14 ± 0.07	b, 1	12.8 ± 0.3	a, 1	60.4 ± 0.1	a, 1	-3.50 ± 0.06	a, 1	4.38 ± 0.1	a, 1
		3000-grit	69.6 ± 0.1	b, 1	-3.06 ± 0.04	a,b, 1	12.7 ± 0.1	a, 1	60.0 ± 0.1	b, 1	-3.43 ± 0.03	a, 1	4.18 ± 0.03	a, 1
SCE	CE	180-grit	68.6 ± 0.8	a, 1	-3.05 ± 0.02	a, 1	12.1 ± 0.2	b, 1	59.0 ± 0.6	a, 1	-3.51 ± 0.04	a, 2	3.56 ± 0.1	c, 2
		1000-grit	68.6 ± 0.4	a, 2	-3.26 ± 0.05	b, 1	12.9 ± 0.2	a, 1	58.5 ± 0.4	a, 2	-3.70 ± 0.04	b, 2	4.14 ± 0.2	a, 1
		3000-grit	67.8 ± 0.1	a, 2	-3.22 ± 0.04	b, 2	12.7 ± 0.1	a, 1	57.6 ± 0.1	b, 2	-3.69 ± 0.04	b, 2	3.80 ± 0.1	b, 2

For each mode and each shade in each color backing, different alphabetic designators among different grit polishing papers represent statistical significant difference at $P < 0.05$.
For the same shade polished with the same grit polishing paper, different numerical designator between SCI and SCE modes represents statistical significant difference at $P < 0.05$.

shades both with the SCI and SCE modes, b* value of 180-grit group was significantly lower than those of 1000- and 3000-grit groups. For OA2 shade the order of b* value was 180- < 1000- < 3000-grit with significant differences among the groups. For the black background for all shades both with the SCI and SCE modes, L* value for 3000-grit group was significantly lower than those for 3000-grit groups, except for CE shade with the SCI mode.

For CM (Table 4), both with white and black backgrounds for all the shades with the SCI and SCE modes, L* value of 180-grit group was significantly higher than those of 1000- and 3000-grit groups. The order of the L* values

Table 4 Clearfil Majesty: L*,a*,b* values of all shades measured with SCI and SCE modes over white and black background

			White Color Backing			Black Color Backing		
Mode	Shade	Polishing	L*	a*	b*	L*	a*	b*
SCI	A2	180-grit	69.8 ± 0.1 a, 1	0.89 ± 0.04 a, 1	11.5 ± 0.3 a, 1	64.5 ± 0.2 a, 1	-2.00 ± 0.03 a, 1	3.96 ± 0.1 a, 1
		1000-grit	68.9 ± 0.2 b, 1	0.90 ± 0.07 a, 1	12.7 ± 0.1 b, 1	63.3 ± 0.1 b, 1	-2.11 ± 0.03 b, 1	4.92 ± 0.3 b, 1
		3000-grit	68.6 ± 0.3 b, 1	0.86 ± 0.05 a, 1	13.1 ± 0.1 b, 1	62.9 ± 0.01 c, 1	-2.10 ± 0.04 b, 1	5.29 ± 0.3 b, 1
SCE	A2	180-grit	65.6 ± 0.5 a, 1	0.92 ± 0.08 a, 1	11.4 ± 0.3 a, 1	64.3 ± 0.2 a, 1	-1.96 ± 0.02 a, 1	3.90 ± 0.3 a, 1
		1000-grit	68.6 ± 0.1 b, 2	0.93 ± 0.07 a, 1	12.7 ± 0.1 b, 1	63.1 ± 0.2 b, 2	-2.10 ± 0.04 b, 1	4.85 ± 0.1 b, 1
		3000-grit	67.3 ± 0.4 c, 2	0.87 ± 0.06 a, 1	13.3 ± 0.2 c, 1	61.5 ± 0.3 c, 2	-2.18 ± 0.05 c, 1	5.19 ± 0.4 b, 1
SCI	OA2	180-grit	74.5 ± 0.2 a, 1	0.54 ± 0.04 a, 1	13.0 ± 0.1 a, 1	70.1 ± 0.1 a, 1	-2.24 ± 0.03 a, 1	6.46 ± 0.1 a, 1
		1000-grit	73.8 ± 0.1 b, 1	0.44 ± 0.07 a, 1	13.7 ± 0.4 b, 1	69.3 ± 0.1 b, 1	-2.44 ± 0.07 b, 1	7.11 ± 0.4 b, 1
		3000-grit	73.5 ± 0.2 b, 1	0.43 ± 0.07 a, 1	13.7 ± 0.3 b, 1	69.0 ± 0.1 c, 1	-2.40 ± 0.02 b, 1	7.13 ± 0.2 b, 1
SCE	OA2	180-grit	74.4 ± 0.2 a, 1	0.58 ± 0.04 a, 1	12.9 ± 0.2 a, 1	69.9 ± 0.1 a, 1	-2.21 ± 0.03 a, 1	6.40 ± 0.1 a, 1
		1000-grit	73.5 ± 0.2 b, 2	0.47 ± 0.07 a, b, 1	13.7 ± 0.4 b, 1	69.0 ± 0.04 b, 2	-2.42 ± 0.08 b, 1	7.05 ± 0.4 b, 1
		3000-grit	72.3 ± 0.2 c, 2	0.43 ± 0.07 b, 1	13.9 ± 0.4 b, 1	67.6 ± 0.2 c, 2	-2.50 ± 0.03 b, 2	7.08 ± 0.3 b, 1
SCI	XL	180-grit	72.9 ± 0.2 a, 1	-2.96 ± 0.05 a, 1	10.0 ± 0.4 a, 1	66.5 ± 0.3 a, 1	-4.34 ± 0.1 a, 1	1.72 ± 0.3 a, 1
		1000-grit	72.6 ± 0.2 a, b, 1	-3.11 ± 0.03 b, 1	10.7 ± 0.2 b, 1	65.6 ± 0.1 b, 1	-4.51 ± 0.01 b, 1	1.90 ± 0.1 a, 1
		3000-grit	72.2 ± 0.2 b, 1	-3.08 ± 0.05 b, 1	10.5 ± 0.2 a, b, 1	65.5 ± 0.2 b, 1	-4.49 ± 0.1 b, 1	1.89 ± 0.1 a, 1
SCE	XL	180-grit	72.7 ± 0.3 a, 1	-2.93 ± 0.06 a, 1	9.9 ± 0.4 a, 1	66.3 ± 0.3 a, 1	-4.31 ± 0.1 a, 1	1.65 ± 0.4 a, 1
		1000-grit	72.2 ± 0.2 a, 1	-3.11 ± 0.03 b, 1	10.6 ± 0.2 b, 1	65.2 ± 0.1 b, 2	-4.53 ± 0.01 b, 1	1.80 ± 0.1 a, 1
		3000-grit	71.1 ± 0.3 b, 2	-3.17 ± 0.04 b, 1	10.5 ± 0.1 a, b, 1	64.1 ± 0.1 c, 2	-4.66 ± 0.1 c, 2	1.66 ± 0.2 a, 1

For each mode and each shade in each color backing, different alphabetic designators among different grit polishing papers represent statistical significant difference at $P < 0.05$.
For the same shade polished with the same grit polishing paper, different numerical designator between SCI and SCE modes represents statistical significant difference at $P < 0.05$.

Table 5 Beautifil II: L*,a*,b* values of all shades measured with SCI and SCE modes over white and black background

			< White Color Backing >			< Black Color Backing >		
Mode	Shade	Polishing	L*	a*	b*	L*	a*	b*
SCI	A2	180-grit	72.2 ± 0.2 a, 1	2.41 ± 0.01 b, 2	13.5 ± 0.3 a, 1	67.1 ± 0.2 a, 1	-0.51 ± 0.01 b, 2	6.63 ± 0.2 a, 1
		1000-grit	71.8 ± 0.1 b, 1	2.45 ± 0.04 b, 1	13.2 ± 0.2 a, b, 1	66.7 ± 0.2 b, 1	-0.44 ± 0.03 b, 1	6.29 ± 0.1 a, b, 1
		3000-grit	71.7 ± 0.1 b, 1	2.71 ± 0.01 a, 2	13.0 ± 0.2 b, 1	66.6 ± 0.1 b, 1	-0.25 ± 0.01 a, 1	6.05 ± 0.2 b, 1
SCE	A2	180-grit	72.1 ± 0.2 a, 1	2.45 ± 0.01 b, 1	13.5 ± 0.3 a, 1	67.0 ± 0.2 a, 1	-0.47 ± 0.01 c, 1	6.58 ± 0.2 a, 1
		1000-grit	71.6 ± 0.1 b, 2	2.49 ± 0.01 b, 1	13.2 ± 0.2 a, b, 1	66.5 ± 0.2 b, 1	-0.41 ± 0.01 b, 1	6.24 ± 0.1 a, b, 1
		3000-grit	71.2 ± 0.03 b, 2	2.75 ± 0.01 a, 1	13.0 ± 0.2 b, 1	66.0 ± 0.05 c, 2	-0.24 ± 0.03 a, 1	5.95 ± 0.2 b, 1
SCI	A2O	180-grit	76.4 ± 0.1 b, 1	3.75 ± 0.11 b, 1	16.1 ± 0.8 a, 1	73.5 ± 0.1 a, 1	0.76 ± 0.15 b, 1	11.4 ± 0.8 b, 1
		1000-grit	76.6 ± 0.1 a, 2	3.69 ± 0.07 b, 1	16.6 ± 0.3 a, 1	73.3 ± 0.1 b, 1	0.70 ± 0.09 b, 1	11.8 ± 0.3 a, 1
		3000-grit	76.2 ± 0.03 c, 1	4.00 ± 0.06 a, 1	15.7 ± 0.1 b, 1	73.1 ± 0.1 c, 1	0.98 ± 0.04 a, 1	11.0 ± 0.1 c, 1
SCE	A2O	180-grit	76.4 ± 0.1 a, 1	3.78 ± 0.1 b, 1	16.0 ± 0.8 a, b, 1	73.4 ± 0.1 a, 1	0.80 ± 0.1 b, 1	11.3 ± 0.8 a,b, 1
		1000-grit	76.2 ± 0.1 b, 1	3.72 ± 0.1 b, 1	16.5 ± 0.3 a, 1	73.1 ± 0.1 b, 2	0.74 ± 0.1 b, 1	11.8 ± 0.3 a, 1
		3000-grit	75.6 ± 0.1 c, 2	4.04 ± 0.1 a, 1	15.7 ± 0.1 b, 1	72.6 ± 0.1 c, 2	1.00 ± 0.05 a, 1	11.0 ± 0.04 b, 1
SCI	Inc	180-grit	70.3 ± 0.1 a, 1	-1.96 ± 0.03 b, 1	0.75 ± 0.2 b, 1	61.3 ± 0.03 a, 1	-2.37 ± 0.01 b, 2	-7.10 ± 0.2 b, 1
		1000-grit	69.9 ± 0.1 b, 1	-1.89 ± 0.01 b, 2	0.39 ± 0.2 c, 1	60.7 ± 0.1 b, 1	-2.36 ± 0.03 b, 1	-7.56 ± 0.2 c, 1
		3000-grit	69.8 ± 0.1 b, 1	-1.62 ± 0.10 a, 1	1.12 ± 0.1 a, 1	60.7 ± 0.1 b, 1	-2.17 ± 0.07 a, 1	-6.97 ± 0.1 a, 1
SCE	Inc	180-grit	70.1 ± 0.02 a, 2	-1.93 ± 0.03 b, 1	0.70 ± 0.2 a, 1	61.2 ± 0.05 a, 2	-2.34 ± 0.02 b, 1	-7.15 ± 0.2 a, 1
		1000-grit	69.7 ± 0.1 b, 2	-1.87 ± 0.01 b, 1	0.32 ± 0.2 b, 1	60.5 ± 0.1 b, 1	-2.34 ± 0.02 b, 1	-7.66 ± 0.2 b, 1
		3000-grit	69.2 ± 0.2 c, 2	-1.64 ± 0.1 a, 1	0.96 ± 0.1 a, 1	60.0 ± 0.3 c, 2	-2.21 ± 0.05 a, 1	-7.27 ± 0.1 a, 2

For each mode and each shade in each color backing, different alphabetic designators among different grit polishing papers represent statistical significant difference at $P < 0.05$.
For the same shade polished with the same grit polishing paper, different numerical designator between SCI and SCE modes represents statistical significant difference at $P < 0.05$.

with black background was 180- > 1000- > 3000-grit with significant differences among the groups, except for XL shade with the SCI mode. For A2 and OA2 shades with the SCI and SCE modes, b* value of 180-grit was significantly lower than those of 1000- or 3000-grit groups. For black background and all the shades, a* value of 180-

grit group was significantly higher than those of 1000- and 3000-grit groups with the SCI mode. However, for white background, a* value of 180-grit group was significantly higher than those of 1000- and 3000-grit groups only for XL shade both with the SCI and SCE modes.

For B2 (Table 5) both with white and black backgrounds for all the shades both with the SCI and SCE modes, L* value of 180-grit group was significantly higher than those of 1000- and 3000-grit groups except for A20 shade with the SCI mode over a white background. The order of L* values with the SCE mode was 180- > 1000- > 3000-grit with significant differences among the groups, except for A2 shade over a white background. With both white and black backgrounds for all the shades with the SCI and SCE modes, a* value of 3000-grit group was significantly higher than those of 1000- and 180-grit groups.

Comparison of the shade values between the SCI and SCE modes, for EQ and CM (Table 3 and 4) and for all the shades both with white and black backgrounds, L* values with SCI were significantly higher than those with SCE in 1000- and 3000-grit groups except for XL shade of CM in 1000-grit group over a white background. For all the shades in all the polishing groups, both with white and black backgrounds, there was no significant difference of b* values between SCI and SCE modes except for CE shade of EQ in 180- and 3000-grit groups over a white background. The a* values differed between EQ and CM and among shades and backgrounds. For B2 (Table 5) for all the shades and both with white and black backgrounds, L* values with SCI were significantly higher than those with SCE in 3000-grit group. The a* value differed among the polishing groups, shades and background colors. For all the shades in all the polishing groups measured both with white and black backgrounds, there was no significant difference of b* values between SCI and SCE modes except for incisal shade (Inc) in 3000-grit group over a black background.

Table 6 compares the color differences between 3000- and 1000-grit, and 3000- and 180-grit polishing groups for each of the shades. For all the shades of all resin composites in all polishing groups against both a white and a black background, the ΔE*ab values with SCE mode were higher than those with SCI mode, except for OA2 shade in 1000-grit group of EQ resin composite over a white background. The color factor most influencing the ΔE*ab value was ΔL*, followed by Δb*. Comparing the ΔE*ab values among different resin composites, both with the SCI and SCE modes and with white and black backgrounds, the order for many shades in many polishing groups was CM > EQ > B2.

Discussion

Generally, a spectrophotometer with an integrating sphere can measure the color both in the transmittance and reflectance modes, and reflectance can be measured in both with SCE and SCI geometries. The spectrophotometer used for *in vivo* measurement, such as tooth color or skin color, has a fiber-optic head and can directly touch and measure the object color but can only measure the reflectance. Normally, this type of spectrophotometer has a light-trap or filter to exclude the specular component and can be used with SCE geometry. Although it is unclear which geometry reflects clinical situations, the SCE geometry may be preferable at the present time. However, for studies comparing the correlations between the color and gloss or surface roughness of resin composites, the SCI geometry might be useful.

Reflection of light from surfaces can be classified into two broad categories. The diffuse component results from light penetration to the surface, undergoing multiple reflections and refractions, and reemerging again at the surface. The specular component is a surface phenomenon, and it can be expressed as a function of the incidence angle and the refractive index of the material, the surface roughness, and a geometrical shadowing function (18).

Most color-measuring spectrophotometers cannot separate or compensate for several types of residual or confounding differences between instruments. The sources of these differences include specular effects, non-uniformities in integrating sphere illumination, nonlinearities in the photometric scale, and the translucent blurring effect found in translucent materials (19). In this study, the influence of the specular component mode (SCE and SCI) on the color of polished resin composites was determined with the use of a single instrument.

Many previous studies have reported the influence of the surface roughness of resin composites to discoloration after acceleration tests or soaking in dye solutions. These studies measured the ΔL* and/or ΔE*ab before and after a discoloration test. Very few studies have reported the influence of surface roughness on the L*a*b* color factors of resin composites. One of them (20) showed that, in general, polished composites tended to appear lighter, whiter, and less glossy than the corresponding Mylar-covered surface. In the present study, comparing the L*, a* and b* values with the SCI and SCE modes over white and black backgrounds, influence of polishing to each of the L*a*b* values was differed among resin composites, shades, background colors and specular components of the SCI or SCE mode (Table 3-5). Generally, the L* value with SCI mode was higher than that with SCE mode (7,21,22). For all shades measured both with white and black

Table 6 Color differences between 3000- and 1000-grit, and 3000- and 180-grit polishing groups for each of shades

			<white color backing>				<black color backing>			
Resin	**Shade**	**Polishing**	**ΔL***	**Δa***	**Δb***	**ΔE*ab**	**ΔL***	**Δa***	**Δb***	**ΔE*ab**
Estelite Σ	**< SCI Mode >**									
Quick	A2	1000-grit	0.31	0.19	0.34	0.50	0.37	0.09	0.32	0.50
	A2	180-grit	0.05	-0.03	-0.82	0.82	0.55	0.1	-0.31	0.64
	OA2	1000-grit	-0.23	-0.07	-0.43	0.49	0.11	0.03	-0.06	0.13
	OA2	180-grit	-0.07	-0.17	-1.33	1.34	0.41	0.03	-0.75	0.86
	CE	1000-grit	0.58	-0.18	0.18	0.63	0.66	-0.08	0.22	0.70
	CE	180-grit	-0.11	-0.07	-0.56	0.57	0.22	-0.01	-0.45	0.50
	< SCE Mode >									
	A2	1000-grit	1.09	0.17	-0.11	1.11	1.29	0.16	0.02	1.30
	A2	180-grit	1.28	-0.01	-1.35	1.86	1.99	0.21	-0.57	2.08
	OA2	1000-grit	0.12	-0.11	-0.46	0.49	0.51	0.05	-0.02	0.51
	OA2	180-grit	1.35	-0.23	-1.68	2.17	1.98	0.11	-0.91	2.18
	CE	1000-grit	0.78	-0.03	0.24	0.82	0.94	0	0.34	1.00
	CE	180-grit	0.81	0.18	-0.58	1.01	1.45	0.17	-0.25	1.48
Clearfil	**< SCI Mode >**									
Majesty	A2	1000-grit	0.29	-0.01	-0.40	0.49	0.36	-0.01	-0.36	0.51
	A2	180-grit	1.26	0.03	-1.67	2.09	1.53	0.09	1.33	2.03
	OA2	1000-grit	0.25	0.00	-0.01	0.25	0.29	-0.02	-0.02	0.29
	OA2	180-grit	0.98	0.09	-0.76	1.24	1.07	0.17	-0.66	1.27
	XL	1000-grit	0.33	-0.05	0.2	0.39	0.13	0.01	0.00	0.13
	XL	180-grit	0.67	0.11	-0.47	0.83	0.98	0.19	-0.18	1.01
	< SCE Mode >									
	A2	1000-grit	1.34	0.07	-0.60	1.47	1.56	0.09	-0.34	1.60
	A2	180-grit	2.38	0.09	-1.87	3.03	2.82	0.22	-1.29	3.11
	OA2	1000-grit	1.26	0.06	-0.20	1.28	1.43	0.07	-0.04	1.43
	OA2	180-grit	2.07	0.18	-0.96	2.29	2.30	0.29	-0.68	2.42
	XL	1000-grit	1.12	0.02	0.17	1.13	0.94	0.12	0.14	1.11
	XL	180-grit	1.64	0.21	-0.52	1.73	2.16	0.34	0.00	2.19
Beautifil II	**< SCI Mode >**									
	A2	1000-grit	0.07	-0.26	0.21	0.34	0.09	-0.19	0.25	0.33
	A2	180-grit	0.48	-0.31	0.50	0.76	0.53	-0.29	0.59	0.84
	A2O	1000-grit	0.09	-0.27	-0.72	0.77	0.11	0.03	-0.06	0.13
	A2O	180-grit	0.46	-0.36	-0.36	0.69	-0.02	-0.17	-0.61	0.63
	Inc	1000-grit	0.24	-0.32	0.89	0.98	0.22	-0.31	0.81	0.89
	Inc	180-grit	0.41	-0.24	0.42	0.63	0.41	-0.24	0.36	0.60
	< SCE Mode >									
	A2	1000-grit	0.37	-0.24	0.19	0.48	0.44	-0.18	0.29	0.56
	A2	180-grit	0.87	-0.25	0.49	1.03	0.96	-0.23	0.63	1.17
	A2O	1000-grit	0.53	-0.22	-0.64	0.86	0.53	-0.18	-0.38	0.68
	A2O	180-grit	0.96	-0.26	-0.27	1.03	1.21	-0.18	0.12	1.23
	Inc	1000-grit	0.58	-0.33	0.85	1.08	0.59	-0.27	0.79	1.02
	Inc	180-grit	0.78	-0.28	0.36	0.90	0.80	-0.19	0.34	0.89

backgrounds, the result was similar in 1000- and 3000-grit polishing groups for EQ and CM resin composites, except for XL shade of CM resin composite over white background. The results for B2 resin composite differed among shades. However, in 180-grit groups, there were no significant differences of the L* between the SCI and SCE modes for all resin composites (Table 3-5) except for Inc shade of B2 (Table 5). Strong diffused reflection on the highly rough-surfaced resin composite in 180-grit polishing group might be one reason of no significant difference of the L* between SCI and SCE modes. CM and B2 are irregularly-filled resin composites, whereas EQ is a spherical-filled composite (Table 1). In all polishing groups, surface roughness of EQ was significantly lower than those of CM and B2. The significantly lower roughness of EQ may be the result of spherical silica-zirconia fillers (23) in EQ. However with regard to L* values, EQ and CM showed similar results, whereas B2 was different (Table 2). Glass-ionomer-oriented S-PRG fillers loaded in B2 might cause a different type of diffused reflection and influence the lightness and color of B2.

Each of the L*, a*, b* and ΔE*ab values for the same objects differed by the many different factors such as differences of measuring machine, background color, illumination, and object size. In the present study, values of ΔE*ab of SCE were higher than those of SCI for all shades in all polishing groups, regardless of the resin composites and background color, except for OA2 shade in 1000-grit EQ group, over a white background in agreement with previous studies (13-15,24) (Table 6).

With white and black backgrounds, differences of ΔE*ab values measured with SCE and SCI modes of ΔE*ab between 3000- and 180-grit groups were higher than those of ΔE*ab between 3000- and 1000- grit groups for EQ and CM, especially the EQ. However for B2, the differences of ΔE*ab values between the SCE and SCI modes of the ΔE*ab 3000- and 180-grit groups and 3000- and 1000-grit groups were slight (Table 6). As visible light interacts with small filler particles in EQ, the light is much more scattered than with the large particles in CM and B2. However, light scattering (diffuse reflection) also differs between spherical fillers and irregularly-shaped fillers. In comparison with EQ and B2, CM contains bigger and more irregular fillers, and the influence of diffuse reflection caused by these fillers might be stronger than that caused by differences in surface roughness among the different polishing groups. For EQ, spherical nano-fillers created a lot more scatter than large-particle fillers. Thus the influence of diffuse reflection or scattering by fillers might be stronger than that for CM and B2. These differences of reflection and scattering caused by differences in the size, shape and ingredients of fillers could mostly influence the L* value in each of L*a*b* values. These effects could be one reason for the higher L* values obtained with the SCI mode compared with the SCE mode.

There has been some debate about the threshold value of color differences (ΔE*ab) that are visually perceptible. Previously reported values were 1.1 for red-varying shades and 2.1 for yellow-varying shades (25), 3.7 for clinical acceptable (26), and 3.3 (27) for the value 50% of observers considered unacceptable. In the present study, color differences between 3000- and 180- grit groups of each shade with SCE for the B2 resin composite ranged from 0.89 (CE, black backed) to 1.23 (0A2, black backed) and were imperceptible by naked eye. Those for EQ resin composite ranged from 1.01 (CE, white backed) to 2.18 (OA2, black backed) and those for CM resin composite ranged from 1.73 (XL, white backed) to 3.11 (A2, black backed), color differences of many shades, especially for CM, were visually perceptible (Table 6). The color and optical properties of resin composites are determined by many factors such as resin matrix composition, filler composition and content, pigment and other chemical additives (28-30). Comparison between EQ and CM resin composites suggested that the lower ΔE*ab of B2 resin composite might be caused not only by S-PRG fillers and MF glass fillers but also by pigments in B2. For each of all resin composites used in this study, the main components among different shades are the same, except for the pigments. Thus the differences of ΔE*ab values among different shades of CM and EQ might be mainly caused by the differences in the pigments.

Within the limitations of this study, it was shown that the effects of specular component modes and final polishing grit size of SiC paper on each of L*, a*, b* and ΔE*ab differed among resin composites and shades. Thus for the color measurement of esthetic dental materials, the specular component mode employed should be stated.

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