©Operative Dentistry, 2018, **43-6**, 642-655

Color and Translucency of Resin-based Composites: Comparison of A-shade Specimens Within Various Product Lines

D Kim • S-H Park

Clinical Relevance

Color and translucency of resin-based composites (RBCs) vary among the different shades within each product line. These differences do not always follow the order of the shade numbers. Clinicians should be aware of the optical characteristics of individual RBC products to achieve predictable results.

SUMMARY

Objectives: The purpose of this study was to examine and compare the color and translucency of currently available resin-based composites (RBCs) with respect to the shade numbers within each product line.

Methods and Materials: Four A-shades (A1, A2, A3, and A3.5) of nine RBC products (Beautifil II, Ceram-X One, Estelite Sigma Quick, Esthet-X HD, Filtek Z250, Filtek Z350 XT, Gradia Direct, Herculite Precis, and Tetric N-Ceram) were investigated. Ten disk-shaped specimens of two different thicknesses (1 and 2 mm) were prepared for each shade of the RBCs. The maximum blue light irradiance (I_{max}) through the specimen was recorded using a digital optometer. The color measurements were made according to the CIELAB color scale (quantifying L*, a*, and b*) using a colorimeter, and the translucency parameter (TP) was calculated. The L*, a*, b*, TP, and I_{max} values were compared among the different shades and thicknesses of each product using one-way analysis of variance followed by Tukey's *post hoc* test.

Results: There were significant differences in the color and translucency among the shades and thicknesses within each product line ($p<0.001$). The L*, I_{max}, and TP of the 1-mm specimens were higher than those of the 2-mm specimens. The specimens showed equal or lower L* and I_{max} for higher shade numbers. The a* values differed only slightly among the shades, whereas the b* values were distributed over a relatively wide range. The TP values were independent of the order of shade numbers.

Dohyun Kim, DDS, PhD, clinical assistant professor, Department of Conservative Dentistry and Oral Science Research Center, Yonsei University College of Dentistry, Seoul, Republic of Korea

*Sung-Ho Park, DDS, PhD, professor, Department of Conservative Dentistry and Oral Science Research Center, Yonsei University College of Dentistry, Seoul, Republic of Korea

*Corresponding author: 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Republic of Korea; e-mail: sunghopark@yuhs.ac

DOI: 10.2341/17-228-L

Conclusions: Within the limitations of this study, the RBCs became darker and yellowish as the shade number increased. The blue light irradiance decreased in increasing order of the shade numbers. Changes in the translucency demonstrated different trends among the shades, depending on the product line.

INTRODUCTION

Resin-based composites (RBCs) have been widely used as direct esthetic restorative materials in dental clinics. There are various kinds of RBC products supplied by different manufacturers, and each of them has its own color and optical characteristics. To satisfy increasing esthetic demands, it is a challenge for clinicians to select an appropriate product and technique that can best reproduce the color and overall appearance of the patient's teeth.

The color of an RBC is generally described as a "shade" based on the Munsell color system, which consists of three primary color attributes: hue, lightness, and chroma.[1] Currently, most of the manufacturers follow the VITA classical shade system (VITA Zahnfabrik, Säckingen, Germany) (Figure 1), where each RBC is labeled as a match to one of 16 shade tabs.[2] The shades are classified by the hue (represented by letters, eg, A, B, C, and D) and by the lightness (represented by numbers, eg, 1, 2, 3, and 4).

In addition to the primary color attributes, there are other subtle optical properties to be considered, such as translucency, opacity, opalescence, iridescence, surface gloss, and fluorescence.[3] Among these, translucency is regarded as one of the most important factors influencing the esthetics of restorations.[4] Translucency is the ability of a layer of a colored substance to allow an underlying background to show through.[5] RBCs are optically translucent materials because of their structure, which is composed of a highly transparent matrix and small filler particles. Incident light undergoes reflection, absorption, scattering, and transmission within the RBC material, and the translucency is expressed as a consequence of the interactions of these phenomena.[6]

Several authors have shown that the color and translucency of RBCs depend on the manufacturer and the shade classification.[7-12] Schmeling and others[13] reported that RBCs with a high lightness were more translucent than medium- and low-lightness materials within the same product line (4 Seasons, Ivoclar Vivadent, Schaan, Liechtenstein). In a recent study, the A3 shade showed the highest translucency among the A1, A2, A3, and A3.5 shades in another RBC product (Filtek Supreme XTE, 3M ESPE, St Paul, MN, USA).[14] These results suggest that the translucency of RBCs can differ, depending on the lightness, represented by the shade number, even within the same product line. Although each of these studies investigated only a single RBC product, their findings should be considered carefully by clinicians providing esthetic restorations. Yu and Lee[15] evaluated the relationship between the color parameters and the translucency of various shades of RBCs and reported that the lightness and translucency showed a weak positive correlation (r=0.117, p<0.05). However, they calculated only the overall correlations between various brands and shades of RBCs thoroughly; therefore, the color and translucency of each shade and product need to be reported and compared individually. In this regard, there is a need for studies that cover a wide range of currently available RBC products, evaluating the

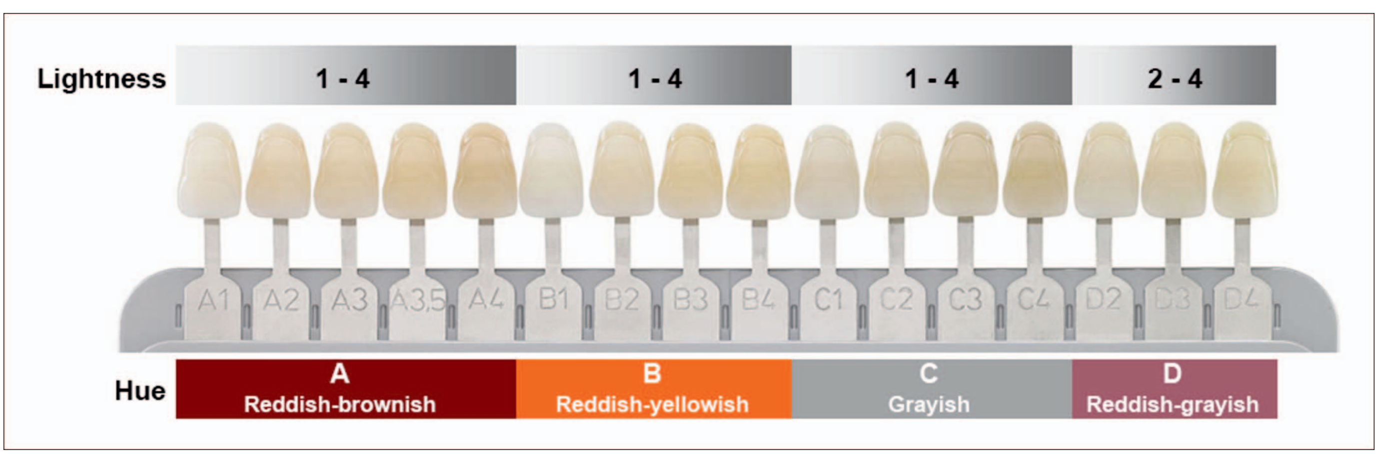

Figure 1. *VITA Classical shade system (VITA Zahnfabrik, Säckingen, Germany) (from manufacturer's instructions).*

Table 1: *Resin-Based Composites Used in the Study*

Code	Manufacturer	Product Name	Shades/Lot Numbers			
	A1	A2	A3	A3.5		
BF	Shofu Inc (Kyoto, Japan)	Beautifil II	121476	011596	051520	051590
CX	Dentsply (Konstanz, Germany)	Ceram-X One	1501000396	1503000560	1503000817	1501000306
ES	Tokuyama Dental (Tokyo, Japan)	Estelite Sigma Quick	129E85	138EY4	158EY4	123E45
EX	Dentsply (Milford, DE, USA)	Esthet-X HD	131002	1310023	131029	1412101
F2	3M ESPE (St Paul, MN, USA)	Filtek Z250	N683493	N651172	N699362	N676563
F3	3M ESPE	Filtek Z350 XT	N676527	N617414	N676525	N670694
GD	GC Corporation (Tokyo, Japan)	Gradia Direct	1409043	1409021	1406262	1509101
HC	Kerr (Orange, CA, USA)	Herculite Precis	4944388	5552574	5552583	5518416
TC	Ivoclar Vivadent (Schaan, Liechtenstein)	Tetric N-Ceram	U28046	U29443	U26780	U13046

color and translucency of RBCs with respect to the shade numbers.

Color and translucency affect the esthetics of a restoration as well as the polymerization of the RBC itself, as light needs to penetrate to a sufficient depth in the material in order to activate the photoinitiators. Adequate polymerization of RBCs depends on the available light energy; the materials cannot be completely polymerized with insufficient light energy.[16] While the esthetics depends on the overall translucency of RBC material, the effect of translucency on the polymerization may be different to that considering the esthetics, as most photoinitiators absorb light over a certain range of wavelengths. For example, camphorquinone, the most widely used photoinitiator, absorbs light at wavelengths between 460 and 480 nm;[17] thus, a transmittance confined to the blue light range would be a decisive factor for the polymerization of RBCs containing camphorquinone as a photoinitiator. Although some studies have reported that the light transmittance at blue wavelengths differed among the different shades and types of RBCs,[18-20] further systematic studies of the blue light transmittance of current RBC products are required.

Therefore, the purpose of this study was to examine and compare the color and translucency of RBCs with respect to the shade numbers within the same product line. We also aimed to evaluate the blue light transmittance of each RBC separately. We expect that these findings can provide clinically helpful information for using such RBCs in esthetic restorative treatments.

METHODS AND MATERIALS

RBC Materials

Four A-shade materials with different shade numbers (A1, A2, A3, and A3.5) of nine RBC products (Beautifil II [BF], Ceram-X One [CX], Estelite Sigma Quick [ES], Esthet-X HD [EX], Filtek Z250 [F2], Filtek Z350 XT [F3], Gradia Direct [GD], Herculite Precis [HC], and Tetric N-Ceram [TC]) were selected for the present study (as detailed in Table 1). The characteristics and compositions of the RBCs are summarized in Table 2.

Specimen Preparation

Ten disk-shaped specimens with two different thicknesses (1 and 2 mm) were prepared for each shade of the nine RBC products, according to the International Organization for Standardization (ISO) 4049[21] with a slight modification (Figure 2). A custom-made stainless-steel mold (6 mm in diameter) was placed on a transparent film on a glass slide. RBC material was packed into the mold and covered with a transparent film and a flat stainless-steel cylinder. Then the mold was pressed to displace excess material and to produce a disk of uniform thickness. The glass slide and the cylinder were removed, and the RBC was light cured for 40 seconds using a light curing unit (Bluephase, Ivoclar Vivadent) placed directly on the surface of the material. After polymerization, the specimen was removed, and a digital caliper (500-181, Mitutoyo, Tokyo, Japan) was used to measure the thicknesses with a precision of 0.05 mm. The surface was examined by visual inspection, and the specimen

Table 2: *Compositions and Characteristics of the Resin-Based Composite Materials (From Manufacturer's Instructions)*

Code	Type	Composition		Filler Size (μm)	Filler Content (wt%/vol%)
		Matrix	Filler		
BF	Nanohybrid	Bis-GMA TEGDMA	Surface prereacted glass ionomer Multifunctional glass filler Nanofiller	0.01-4.0/mean 0.8 0.01-0.02	83.3/68.6
CX	Nanohybrid	Dimethacrylate based	Methacrylate modified polysiloxane Barium-aluminum-borosilicate glass Silica nanofiller	[a]	[a]
ES	Suprananofill	Bis-GMA TEGDMA	Silica/zirconia filler Composite filler Spherical submicron filler	0.1-0.3/mean 0.2	82/71
EX	Nanohybrid	Bis-GMA Bis-EMA TEGDMA	Barium fluoroborosilicate glass Silica nanofiller	<1.0 0.04	77/60
F2	Microhybrid	Bis-GMA UDMA Bis-EMA	Silica/zirconia filler	0.01-3.5	78/60
F3	Nanofill	Bis-GMA UDMA TEGDMA PEGDMA Bis-EMA	Nonaggregated silica/zirconia filler Aggregated silica/zirconia cluster	Silica 0.02/zirconia 0.004-0.011 0.6-20	78.5/63.3
GD	Microhybrid	UDMA	Microhybrid filler (no barium glass)	Mean 0.85	73/64
HC	Nanohybrid	Bis-GMA TEGDMA	Prepolymerized filler Silica nanofiller Hybrid filler (barium glass)	30-50 0.02-0.05 Mean 0.4	78/59
TC	Nanohybrid	Bis-GMA UDMA	Barium glass Ytterbium trifluoride Mixed oxide and copolymers	0.04-3.0	80-81/55-57

Abbreviations: wt%, weight percentage; vol%, volume percentage; Bis-GMA, bisphenol-A-glycidyl dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, ethoxylated bisphenol-A-dimethacrylate; UDMA, urethane dimethacrylate.
[a] No information is available about the filler size and content of Ceram-X One.

was rejected if there were any defects or irregularities. Each specimen was stored in distilled water for 24 hours.

Measurement of Blue Light Irradiance

During specimen preparation, prior to light curing, the mold was placed at the entry of an integrating sphere (UMBB-150, Gigahertz-Optik, Turkenfeld, Germany) to measure the blue light irradiance. The mold was custom designed and made for mounting on this integrating sphere. During the curing time, a digital optometer device (P-9710, Gigahertz-Optik) was connected to the integrating sphere and used to measure the transmitted irradiance through the bottom of the specimen in real time (Figure 2). The maximum irradiance during the curing time (I_{max}; mW/cm^2) was recorded for each specimen. The light intensity of the curing unit, the irradiance measured without any specimen, was 1405 mW/cm^2.

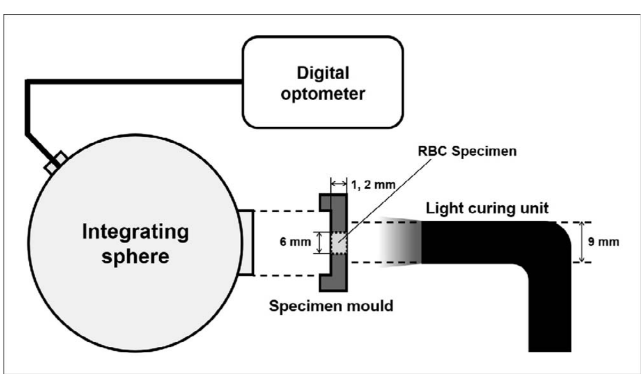

Figure 2. *Schematic diagram of the apparatus for the specimen preparation and the blue light irradiance measurement.*

Measurement of Color and Translucency

The color measurements were made according to the Commission Internationale de l'Eclairage CIELAB color scale[22] using a colorimeter (CR-321, Minolta, Osaka, Japan). L* indicates lightness (0 to 100), and a* and b* indicate levels of red (+a*), green (–a*), yellow (+b*), and blue (–b*) (–60 to 60). The L*, a*, and b* values of each specimen were recorded relative to the standard illuminant D65 against black (L^*=1.38, a^*=0.00, b^*=0.06) and white (L^*=94.44, a^*=0.26, b^*=1.69) reflectance standards (Spectralon, Labsphere, North Sutton, NH, USA). The aperture diameter of the colorimeter was 3 mm, and each specimen was measured in triplicate. The color difference between the specimens (ΔE) was determined using the formula

$$\Delta E = \left[(L_x^* - L_y^*)^2 + (a_x^* - a_y^*)^2 + (b_x^* - b_y^*)^2\right]^{1/2}$$

where the L^*, a^*, and b^* values were measured against the white standard. The subscripts "x" and "y" refer to the shades (eg, A1, A2, A3, and A3.5). A value of $\Delta E \geq 3.3$ was used as the threshold for a clinically perceivable color difference.[23]

The translucency parameter (TP) of each specimen was obtained by calculating the color difference of the specimen against the black and white standards according to the formula[5]

$$TP = \left[(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2\right]^{1/2}$$

where L^*_B, a^*_B, and b^*_B were measured against the black background and L^*_W, a^*_W, and b^*_W were measured against the white background. The difference in TP (ΔTP) was calculated by

$$\Delta TP = |TP_x - TP_y|$$

where the subscripts "x" and "y" refer to the shades (eg, A1, A2, A3, and A3.5). A value of $\Delta TP \geq 2.0$ was used as the threshold for a clinically perceivable translucency difference.[24]

Statistical Analysis

The color parameters measured against the white background (L^*, a^*, and b^*), TP, and I_{max} were compared among the different shades and thicknesses within each RBC product line using one-way analysis of variance followed by Tukey's *post hoc* test. All statistical analyses were performed under a 95% confidence level using the SPSS 23 (IBM Corp, Somers, NY, USA) software program.

RESULTS

The mean and standard deviation of the L^*, a^*, b^*, TP, and I_{max} values of each shade of the RBCs are presented in Table 3 and Figure 3. All variables showed significant differences among the different shades and sample thicknesses within each product line ($p<0.05$). The ΔE and ΔTP values between the shades are presented in Table 4, and clinically perceivable differences are indicated in Figure 3; it can be seen that these parameters also differed depending on the product line. The colors of all four shades of each RBC product are indicated in the three-dimensional CIELAB color space in Figure 4.

Color

For all RBC products, the 1-mm specimens showed higher L^* values than the 2-mm specimens. Most specimens showed equal or lower L^* values for higher shade numbers. Only in the case of the 2-mm specimen of EX was a higher L^* value observed for the A3 shade compared to the A2 shade. Significant decreases in L^* were observed for the CX and GD samples as a function of increasing shade number. In the ES and HC product lines, there was no significant difference in L^* values between the A3 and A3.5 shades. For the EX, F2, and TC samples, the A2 and A3 shades showed no difference in L^*, while in the BF, F3, and HC product lines, the L^* values of A1 and A2 shades showed no significant difference (Table 3; Figure 3).

The a^* values varied only slightly among the shades and thicknesses, whereas the b^* values were distributed over a relatively wide range with respect to the shade numbers and RBC products. The a^* values increased with increasing shade number for the BF, CX, F2, F3, and HC samples. In the ES product line, the A3 shade showed the highest a^* value among the four shades, while the EX samples showed almost equal a^* values for all shades. The GD and TC samples showed no correlation between the a^* values and the shade numbers. All of the RBCs demonstrated an increase in b^* with increasing shade number (Table 3; Figure 3).

Regardless of the significant differences in the L^*, a^*, and b^* values, there were some shades whose color differences were not clinically perceivable ($\Delta E<3.3$) within every product line except EX, which showed distinct color differences ($\Delta E\geq3.3$) among all shades (Table 4; Figure 3). For the 1-mm specimens, between the A1 and A2 shades, F2 showed relatively distinct color differences ($\Delta E=7.6$) compared to the other products, and the BF and HC samples showed color differences that were clinically unperceivable ($\Delta E<3.3$). Between the A2 and A3 shades, the color differences were only slightly different among the products, where the CX, F2, and TC samples showed ΔE values less than 3.3. Between the A3 and A3.5 shades, the EX showed a maximum ΔE of 9.3, and four out of the

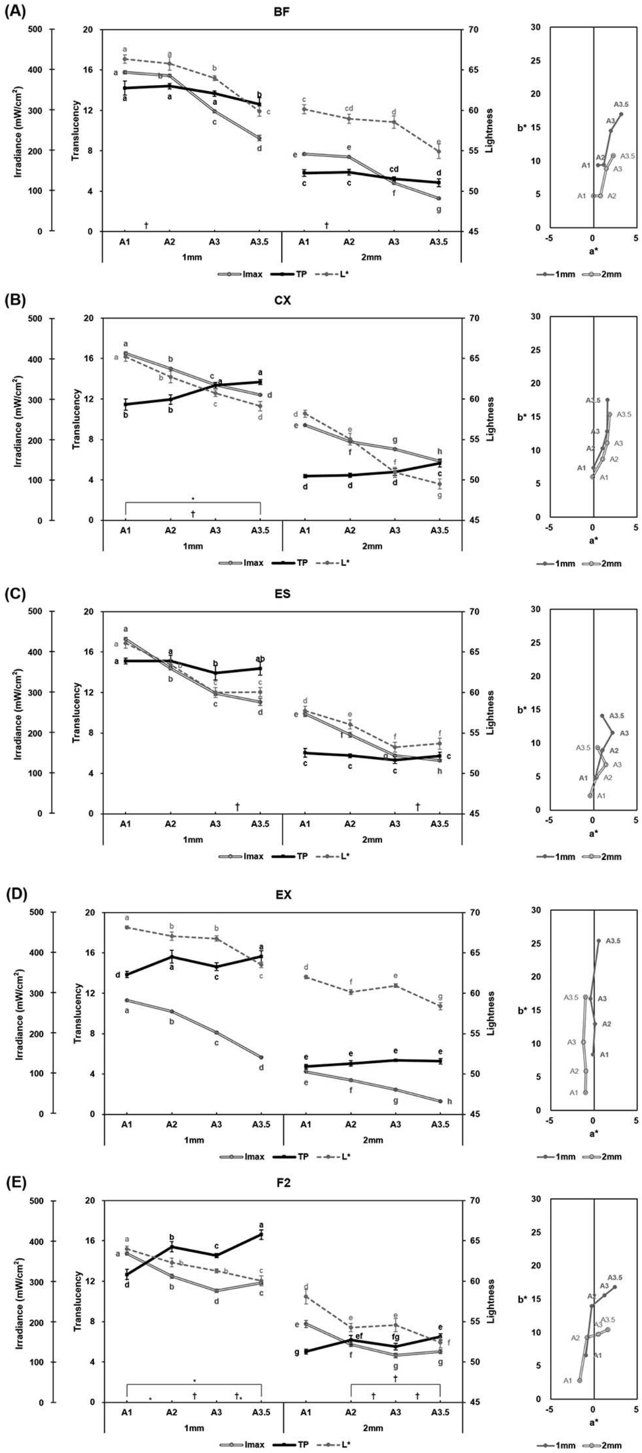

Figure 3. *Mean L*, a*, b*, TP, and I_{max} values of each shade of the RBC products. (A): Beautifil II (BF). (B): Ceram-X One (CX). (C): Estelite Sigma Quick (ES). (D): Esthet-X HD (EX). (E): Filtek Z250 (F2). (F): Filtek Z350 XT (F3). (G): Gradia Direct (GD). (H): Herculite Precis (HC). (I): Tetric N-Ceram (TC). Different letters denote significant differences among the specimens within each RBC product line* ($p<0.05$). *† Color difference that is clinically unperceivable ($\Delta E<3.3$). * Translucency difference that is clinically perceivable ($\Delta TP\geq 2.0$).*

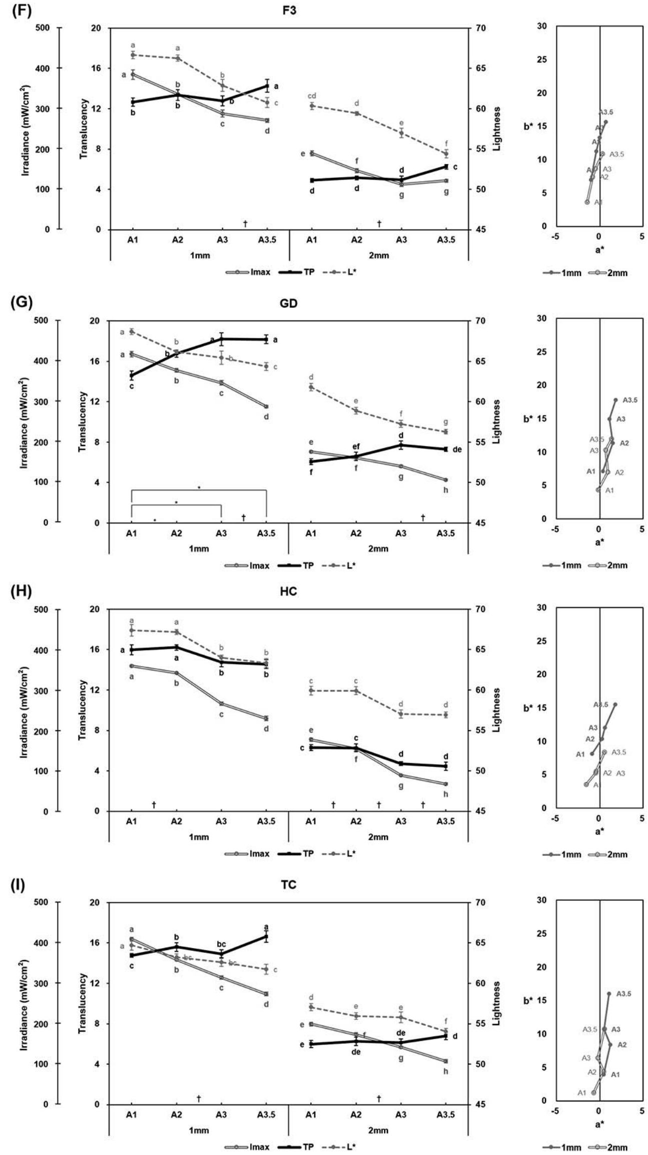

Figure 3. *Continued.*

nine products (ES, F2, F3, and GD) showed clinically unperceivable color differences ($\Delta E<3.3$). Between the A1 and A3, A1 and A3.5, and A2 and A3.5 shades, all specimens showed color differences that were clinically perceivable ($\Delta E\geq 3.3$); the greatest color difference was observed between the A1 and A3.5 shades of the EX product ($\Delta E=17.68$). For the 2-mm specimens, the BF, ES, EX, GD, and TC samples demonstrated similar color difference patterns among the shades compared to those of the 1-mm specimens. CX showed ΔE values of more than 3.3 among all shades. In the F2 product, there was no distinct color difference even between the A2 and A3.5 shades ($\Delta E=3.27$). The HC product showed clinically unperceivable color differences

Table 3: *L*, a*, b*, TP, and I_{max} Values of Each Shade of the Resin-Based Composites*[a]

Code	Thickness	Shade	L*			a*			b*			TP			I_{max}		
			Mean	SD		Mean	SD		Mean	SD		Mean	SD		Mean	SD	
BF	1 mm	A1	66.35	0.49	A	0.48	0.07	G	9.38	0.21	D	14.22	0.69	A	394.20	4.17	A
		A2	65.79	0.82	A	1.18	0.08	E	9.45	0.34	D	14.41	0.27	A	385.99	3.19	B
		A3	64.00	0.30	B	1.96	0.03	C	14.53	0.12	B	13.66	0.27	A	297.37	3.68	C
		A3.5	59.90	0.61	C	3.17	0.11	A	17.01	0.47	A	12.61	0.66	B	231.65	6.82	D
	2 mm	A1	60.14	0.58	C	−0.03	0.14	H	4.81	0.14	E	5.81	0.32	C	191.74	2.88	E
		A2	58.99	0.56	CD	0.77	0.08	F	4.81	0.25	E	5.88	0.29	C	184.98	2.55	E
		A3	58.57	0.78	D	1.44	0.12	D	8.85	0.34	D	5.23	0.20	CD	120.53	3.05	F
		A3.5	54.93	0.91	E	2.25	0.15	B	10.79	0.68	C	4.85	0.39	D	82.10	2.30	G
CX	1 mm	A1	65.23	0.55	A	−0.03	0.02	D	7.40	0.08	G	11.45	0.55	B	412.63	3.75	A
		A2	62.70	0.72	B	1.03	0.03	C	10.31	0.20	E	11.94	0.47	B	374.88	2.25	B
		A3	60.73	0.41	C	1.54	0.03	B	12.88	0.11	C	13.34	0.29	A	335.03	2.27	C
		A3.5	59.11	0.59	D	1.62	0.04	B	17.54	0.25	A	13.68	0.25	A	310.20	2.29	D
	2 mm	A1	58.19	0.44	D	−0.11	0.11	D	6.00	0.26	H	4.37	0.17	D	235.32	1.43	E
		A2	55.02	0.72	E	1.04	0.12	C	8.71	0.25	F	4.47	0.21	D	194.11	1.18	F
		A3	50.93	0.61	F	1.55	0.02	B	11.09	0.16	D	4.78	0.31	D	175.77	2.21	G
		A3.5	49.51	0.63	G	1.84	0.09	A	15.40	0.36	B	5.65	0.38	C	146.18	1.76	H
ES	1 mm	A1	66.08	0.60	A	0.19	0.14	E	4.82	0.23	E	15.12	0.29	A	432.76	3.77	A
		A2	63.42	0.66	B	1.00	0.08	C	8.94	0.14	C	15.13	0.58	A	359.41	4.12	B
		A3	60.01	0.63	C	2.19	0.09	A	11.54	0.27	B	13.94	0.73	B	297.70	5.15	C
		A3.5	60.06	0.57	C	0.97	0.11	C	14.13	0.47	A	14.36	0.66	AB	276.73	8.61	D
	2 mm	A1	57.72	0.59	D	−0.42	0.08	F	2.15	0.34	F	6.03	0.42	C	247.28	6.69	E
		A2	56.08	0.56	E	0.32	0.11	DE	4.92	0.43	E	5.76	0.19	C	195.87	6.16	F
		A3	53.26	0.62	F	1.40	0.12	B	6.80	0.31	D	5.32	0.34	C	144.07	2.47	G
		A3.5	53.67	0.70	F	0.47	0.10	D	9.36	0.45	C	5.73	0.37	C	131.79	2.94	H
EX	1 mm	A1	68.16	0.17	A	−0.14	0.05	C	8.40	0.14	E	13.86	0.32	D	282.74	2.26	A
		A2	67.07	0.51	B	0.12	0.06	B	12.96	0.45	C	15.62	0.64	A	255.37	1.90	B
		A3	66.79	0.35	B	−0.39	0.09	D	16.75	0.34	B	14.64	0.39	C	202.92	3.10	C
		A3.5	63.52	0.32	C	0.53	0.08	A	25.45	0.83	A	15.65	0.59	A	141.32	1.42	D
	2 mm	A1	62.01	0.22	D	−0.97	0.10	E	2.69	0.19	G	4.74	0.23	E	105.25	2.52	E
		A2	60.15	0.32	F	−0.93	0.10	E	5.91	0.22	F	5.05	0.26	E	84.81	1.96	F
		A3	60.95	0.22	E	−1.24	0.04	F	10.25	0.05	D	5.34	0.10	E	60.90	1.59	G
		A3.5	58.40	0.43	G	−0.97	0.15	E	16.97	0.68	B	5.26	0.27	E	32.23	1.35	H
F2	1 mm	A1	63.97	0.36	A	−0.93	0.38	F	6.59	0.17	F	12.68	0.52	D	368.65	4.47	A
		A2	62.32	0.54	B	−0.25	0.11	E	13.98	1.12	C	15.41	0.51	B	312.23	4.98	B
		A3	61.28	0.27	B	1.20	0.08	C	15.55	0.11	B	14.54	0.21	C	276.27	4.19	D
		A3.5	60.07	0.62	C	2.42	0.09	A	16.79	0.27	A	16.62	0.47	A	296.26	4.23	C
	2 mm	A1	58.08	0.89	D	−1.67	0.08	G	2.83	0.17	G	5.02	0.24	G	193.89	8.22	E
		A2	54.27	0.51	E	−0.80	0.10	F	9.24	0.24	E	6.17	0.46	EF	143.15	4.66	F
		A3	54.55	0.81	E	0.48	0.13	D	9.73	0.39	DE	5.52	0.34	FG	116.11	5.49	G
		A3.5	52.41	0.68	F	1.60	0.14	B	10.46	0.55	D	6.49	0.31	E	125.83	5.09	G
F3	1 mm	A1	66.66	0.46	A	−1.03	0.06	F	6.99	0.26	E	12.64	0.41	B	384.86	11.61	A
		A2	66.28	0.40	A	−0.40	0.04	D	11.23	0.28	C	13.34	0.53	B	336.16	3.31	B
		A3	62.90	0.74	B	−0.02	0.06	C	13.30	0.33	B	12.78	0.50	B	288.12	8.87	C
		A3.5	60.76	0.62	C	0.69	0.05	A	15.68	0.23	A	14.26	0.64	A	271.23	4.69	D
	2 mm	A1	60.34	0.41	CD	−1.46	0.09	G	3.65	0.12	F	4.90	0.17	D	189.09	6.38	E
		A2	59.42	0.23	D	−0.83	0.06	E	7.44	0.18	E	5.14	0.20	D	146.14	5.34	F
		A3	57.00	0.58	E	−0.49	0.31	D	8.64	0.88	D	4.95	0.37	D	112.81	5.97	G
		A3.5	54.41	0.51	F	0.30	0.06	B	10.85	0.08	C	6.25	0.22	C	121.26	3.89	G

Table 3: *L*, a*, b*, TP, and I_{max} Values of Each Shade of the Resin-Based Composites[a] (cont.)*

Code	Thickness	Shade	L*			a*			b*			TP			I_{max}		
			Mean	SD		Mean	SD		Mean	SD		Mean	SD		Mean	SD	
GD	1 mm	A1	68.68	0.34	A	0.36	0.11	E	7.14	0.31	F	14.59	0.44	C	417.72	6.90	A
		A2	66.18	0.23	B	1.49	0.08	B	11.36	0.20	D	16.77	0.37	B	377.58	4.61	B
		A3	65.43	0.81	B	1.10	0.13	C	14.95	0.24	B	18.19	0.64	A	346.75	5.56	C
		A3.5	64.36	0.49	C	1.82	0.08	A	17.82	0.22	A	18.18	0.44	A	288.12	2.72	D
	2 mm	A1	61.81	0.48	D	−0.17	0.12	F	4.34	0.23	G	6.07	0.30	F	176.24	2.60	E
		A2	58.89	0.43	E	0.94	0.10	C	7.00	0.33	F	6.60	0.39	EF	161.12	1.47	F
		A3	57.27	0.45	F	0.70	0.06	D	10.29	0.25	E	7.70	0.40	D	140.48	3.26	G
		A3.5	56.30	0.27	G	1.34	0.13	B	11.95	0.28	C	7.30	0.22	DE	106.86	1.98	H
HC	1 mm	A1	67.37	0.71	A	−0.86	0.10	E	8.13	0.38	D	15.98	0.50	A	359.41	3.53	A
		A2	67.18	0.31	A	0.24	0.07	C	10.39	0.18	C	16.22	0.26	A	342.48	1.67	B
		A3	63.97	0.35	B	0.59	0.11	B	12.07	0.29	B	14.74	0.44	B	266.05	3.77	C
		A3.5	63.35	0.52	B	1.80	0.08	A	15.53	0.46	A	14.56	0.42	B	229.70	5.69	D
	2 mm	A1	59.91	0.54	C	−1.55	0.08	F	3.54	0.35	F	6.29	0.30	C	177.31	4.24	E
		A2	59.91	0.48	C	−0.44	0.14	D	5.30	0.25	E	6.28	0.40	C	154.25	4.84	F
		A3	57.03	0.53	D	−0.40	0.34	D	5.54	1.17	E	4.71	0.18	D	89.12	1.33	G
		A3.5	56.92	0.37	D	0.55	0.11	B	8.39	0.26	D	4.45	0.41	D	67.68	2.79	H
TC	1 mm	A1	64.69	0.59	A	0.47	0.17	B	3.94	0.25	E	14.77	0.19	C	409.27	4.88	A
		A2	63.23	0.41	BC	1.23	0.09	A	8.43	0.17	C	15.59	0.44	B	358.76	3.20	B
		A3	62.60	0.49	BC	0.51	0.14	B	10.71	0.20	B	14.92	0.39	BC	314.84	4.13	C
		A3.5	61.74	0.63	C	1.09	0.13	A	16.04	0.54	A	16.63	0.57	A	273.74	4.57	D
	2 mm	A1	57.05	0.43	D	−0.70	0.05	D	1.23	0.31	F	5.99	0.35	E	199.25	4.38	E
		A2	55.96	0.42	E	0.46	0.14	B	4.35	0.20	E	6.26	0.42	DE	172.45	5.25	F
		A3	55.80	0.65	E	−0.22	0.10	C	6.43	0.32	D	6.12	0.37	DE	141.74	2.88	G
		A3.5	54.08	0.34	F	0.54	0.07	B	10.74	0.52	B	6.80	0.36	D	107.55	3.97	H

[a] *Different letters denote significant differences among the specimens within each resin-based composite product ($p<0.05$).*

between the A1 and A2, A2 and A3, and A3 and A3.5 shades ($\Delta E<3.3$). The greatest color difference was observed between the A1 and A3.5 shades of the EX product ($\Delta E=14.73$).

Translucency

The translucency properties varied depending on the RBC product line. The TP values of BF and ES samples were similar for all four shades. In addition, the HC line showed TP values confined within a narrow range, even though there were significant differences between A1/A2 and A3/A3.5. On the contrary, CX, F3, GD, and TC samples showed equal or higher TP values for higher shade numbers. For the EX and F2 samples, the TP values increased according to A1 < A3 < A2 < A3.5, ie, no correlation. The correlations between the translucency and the shade were the same for both the 1-mm and the 2-mm specimens, where the 1-mm specimens showed higher TP values than the 2-mm specimens for every RBC product line (Table 3; Figure 3).

Unlike the TP value, I_{max} decreased when the shade number increased for all nine RBC products except the 1-mm F2 specimen, which showed a higher I_{max} value for the A3.5 shade compared to the A3 shade (Table 3; Figure 3).

The ΔTP values of the different shades also differed with respect to the product line. For the 1-mm specimens, the BF, ES, EX, F3, HC, and TC samples showed a maximum ΔTP less than 2.0, which is regarded as clinically unperceivable. The CX samples showed a maximum ΔTP of 2.3 between the A1 and A3.5 shades. The F2 and GD product lines showed relatively clear differences in TP among the shades, where the maximum ΔTP was more than 3.5. For the 2-mm specimens, none of the RBC products showed a perceivable ΔTP among the shades (Table 4; Figure 3).

DISCUSSION

In the present study, the color and translucency of four different shades (A1, A2, A3, and A3.5) of nine RBC products were compared within each product

Table 4: *ΔE and ΔTP Among the Four Shades of Each Resin-Based Composite*[a]

Code	Thickness	1 mm				2 mm			
	Shade	A1	A2	A3	A3.5	A1	A2	A3	A3.5
BF	A1		0.90[b]	5.85	10.34		1.40[b]	4.58	8.25
	A2	*0.19*		5.45	9.79	*0.07*		4.11	7.37
	A3	*0.55*	*0.75*		4.94	*0.59*	*0.65*		4.20
	A3.5	*1.61*	*1.80*	*1.06*		*0.97*	*1.03*	*0.38*	
CX	A1		4.00	7.26	11.96		4.32	9.02	12.94
	A2	*0.49*		3.27[b]	8.10	*0.10*		4.76	8.70
	A3	*1.89*	*1.40*		4.94	*0.42*	*0.31*		4.55
	A3.5	*2.23*[c]	*1.74*	*0.35*		*1.29*	*1.18*	*0.87*	
ES	A1		4.98	9.28	11.11		3.31	6.70	8.32
	A2	*0.02*		4.45	6.18	*0.27*		3.55	5.05
	A3	*1.17*	*1.19*		2.86[b]	*0.71*	*0.44*		2.75[b]
	A3.5	*0.75*	*0.77*	*0.42*		*0.30*	*0.03*	*0.41*	
EX	A1		4.70	8.46	17.68		3.71	7.63	14.73
	A2	*1.76*		3.83	12.98	*0.31*		4.42	11.20
	A3	*0.78*	*0.98*		9.34	*0.61*	*0.29*		7.20
	A3.5	*1.78*	*0.02*	*1.01*		*0.53*	*0.21*	*0.08*	
F2	A1		7.61	9.59	11.42		7.51	8.04	10.06
	A2	*2.74*[c]		2.37[b]	4.48	*1.15*		1.39[b]	3.27[b]
	A3	*1.87*	*0.87*		2.12[b]	*0.50*	*0.65*		2.53[b]
	A3.5	*3.95*[c]	*1.21*	*2.08*[c]		*1.48*	*0.32*	*0.97*	
F3	A1		4.31	7.42	10.64		3.95	6.08	9.49
	A2	*0.70*		3.98	7.17	*0.24*		2.72[b]	6.17
	A3	*0.14*	*0.56*		3.27[b]	*0.06*	*0.18*		3.49
	A3.5	*1.62*	*0.92*	*1.48*		*1.36*	*1.12*	*1.30*	
GD	A1		5.03	8.49	11.61		4.11	7.54	9.52
	A2	*2.18*[c]		3.69	6.72	*0.54*		3.68	5.60
	A3	*3.60*[c]	*1.42*		3.15[b]	*1.63*	*1.10*		2.02[b]
	A3.5	*3.59*[c]	*1.41*	*0.01*		*1.23*	*0.70*	*0.40*	
HC	A1		2.52[b]	5.40	8.83		2.09[b]	3.69	6.08
	A2	*0.23*		3.64	6.60	*0.02*		2.89[b]	4.41
	A3	*1.25*	*1.48*		3.71	*1.58*	*1.57*		3.01[b]
	A3.5	*1.42*	*1.66*	*0.18*		*1.85*	*1.83*	*0.26*	
TC	A1		4.78	7.08	12.47		3.51	5.37	10.04
	A2	*0.83*		2.47[b]	7.75	*0.27*		2.20[b]	6.66
	A3	*0.15*	*0.68*		5.43	*0.13*	*0.14*		4.70
	A3.5	*1.86*	*1.04*	*1.71*		*0.81*	*0.54*	*0.68*	

[a] *Values in roman text indicate ΔE between the shades. Values in italic text indicate ΔTP between the shades.*
[b] *Color difference that is clinically unperceivable (ΔE<3.3).*
[c] *Translucency difference that is clinically perceivable (ΔTP≥2.0).*

line. The A shade was selected according to Paravina and others,[25] who reported that most human teeth match the A shade of the VITA classical shade system. Although there have been a number of studies that evaluated the color and translucency of RBCs,[7-14] only few studies analyzed different shades of various RBC products in numerical order. In this regard, the results of this study are expected to provide relevant information for the clinical use of contemporary RBC products.

There were significant differences in L*, a*, and b* values among the different shades of each RBC product line (Table 3; Figure 3). The L* values of the specimens tended to decrease as the shade number increased, which is consistent with the shade number indicating the lightness of the material. In

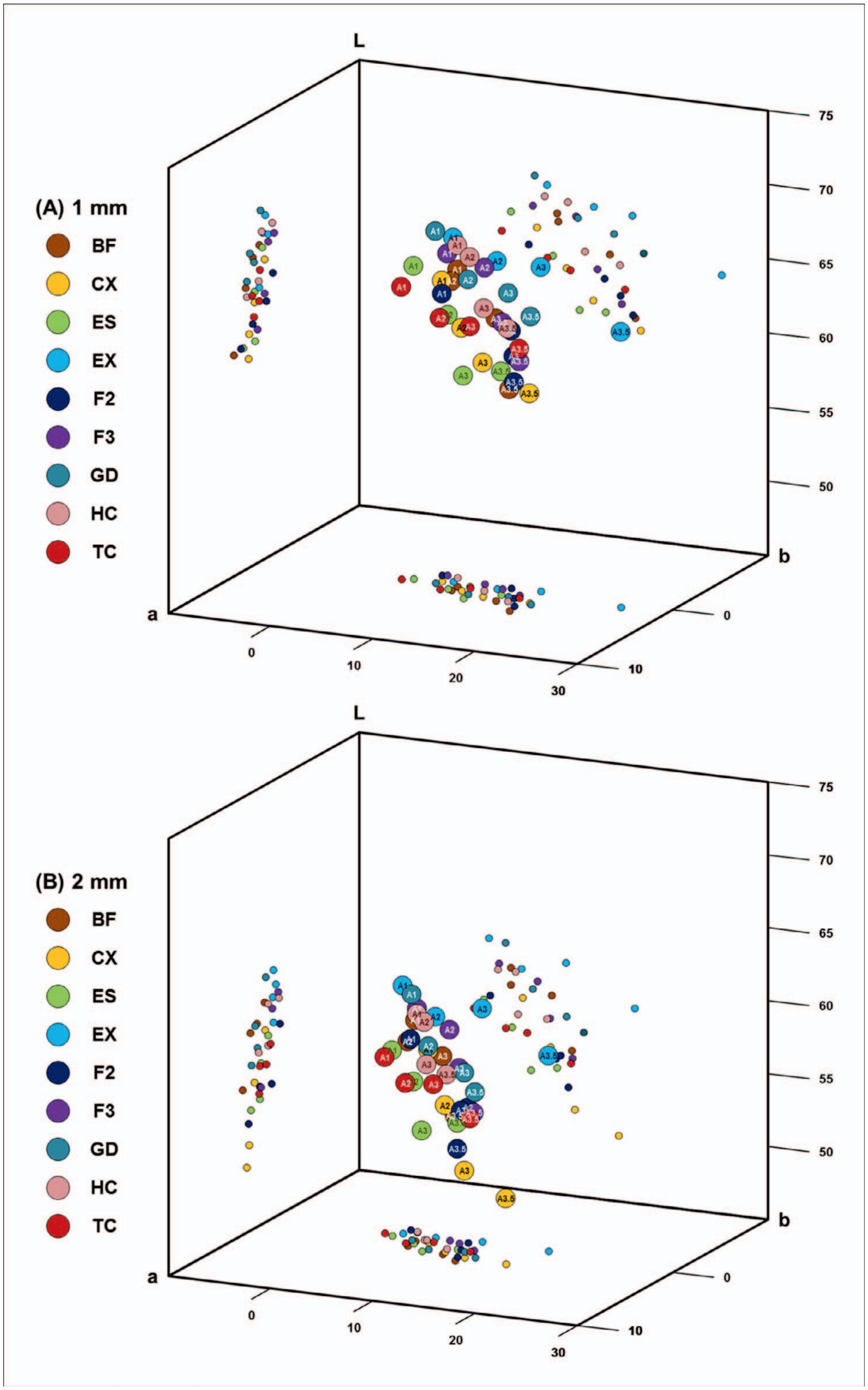

Figure 4. *The color distribution of each shade of the RBC products in the CIELAB color space. (A): 1-mm specimens. (B): 2-mm specimens.*

the CIELAB color space, as the a* and b* values increase, the chroma of the color increases. In this study, the RBCs showed various patterns of color distribution with respect to the shade and product line. This implies that the shade number includes information about the hue and chroma in addition to the lightness, consistent with the VITA classical shade system.[26] Overall, the a* values did not vary much among the shades, whereas the b* values covered a relatively wide range and gradually increased with increasing shade number. From these results, it is concluded that the RBC becomes darker and yellowish when the shade number increases.

When the thickness of the specimen increased from 1 mm to 2 mm, the L* and b* values decreased significantly, whereas the a* values were either unchanged or slightly increased for all products (Table 3; Figure 3). In other words, the RBCs became darker and bluish when they were thicker. Therefore, for the restoration of a deep cavity, layering the RBC using a slightly lighter-colored material could be a way of avoiding it from looking dark. When the restoration is thought to be slightly lighter than the adjacent tooth structure in the final layering step near the surface layer, we can use a higher shade number to reduce the lightness and increase the yellowish hue.

The TP and I_{max} values were measured separately for evaluating the translucency considering two different aspects: esthetics and polymerization. Both TP and I_{max} differed significantly among the shade numbers within each RBC product investigated in this study (Table 3; Figure 3). The I_{max} decreased with increasing shade number for all RBC product lines, whereas the TP did not always follow the order of the shade number. This implies that a specimen with a higher shade number may need a longer light curing time for complete polymerization; however, it may not be directly related to the overall translucency of the specimen. The blue light irradiance is thought to be influenced mainly by the L* and b* values of the specimen, which make it consistently darker and yellowish when the shade number increases.

The BF, ES, and HC product lines showed almost no differences in TP values among the shades despite distinguishable color differences. Hence, restorations using these products would have similar translucency regardless of the shade within the same product line. Although the constant translucency may be convenient and predictable for clinicians, we should consider the additional use of either translucent or opaque composites to reproduce a varied translucency in a natural tooth. In CX, F3, GD, and TC samples, the TP values increased with increasing shade number. For these products, light restorations would appear to be more opaque than dark restorations. When we use the A1 or A2 shades of these RBCs, especially in anterior regions, we need to accompany it with a translucent shade to obtain proper translucency of the restoration. The EX and F2 samples showed no correlation between the TP and shade number (A1<A3<A2<A3.5); hence, these products should be used with caution.

Several authors have investigated the effect of the matrix and fillers on the color and translucency of RBCs, such as the composition and distribution of the matrix and fillers,[27-30] size and shape of filler particles,[19,31] and refractive indices (RIs).[32,33] The amount of Bis-GMA in the matrix had a significant effect on the translucency of RBCs,[27] and the translucency of Bis-GMA–based RBCs were much higher than TEGDMA/UDMA-based RBCs.[28] The translucency was shown to decrease as the amount of filler increased.[29] The lightness was highly correlated with the amount of filler, whereas the hue and chroma were only moderately affected.[30] The translucency decreased with a greater mismatch between the RIs of the matrix and filler, as light is scattered at the matrix-filler interfaces when it passes through the RBCs.[32] Ota and others[33] reported that the L* and a* values increased and TP decreased with increasing RI mismatch. The development of filler technology makes it possible to produce higher-translucency RBC materials; nano-sized (smaller than 100 nm) filler particles do not scatter light, as they are below the wavelength range of visible light (380 to 780 nm).[34] In addition to the effect of the matrix and fillers, the color and translucency of RBCs also depend on additives such as dyes and other chemicals.[35] Small amounts of inorganic oxides are often added to change the color and opacity of RBCs.[36] The coloring material or pigments absorb various wavelengths of visible light, allowing other wavelengths to scatter out of the object.[6] When many internal particles are present in the RBCs, the light is likely to be scattered and the translucency decreased.[15] White or high-lightness gray pigments can be used to increase the lightness while reducing the translucency.[37]

The exact reason for the different translucency behavior among the products is uncertain; as the RBCs were compared within the same product line, all compositions were probably very similar. The optical properties of RBCs may depend on the specific manufacturing process, which is confidential information. Nevertheless, it is worth noting that the RBC products with similar characteristics showed comparable translucency trends. The BF and HC products include unique large fillers, prereacted glass ionomer and prepolymerized fillers, respectively. The ES materials have relatively uniform filler shapes and sizes and spherical fillers with a size of 0.1 to 0.3 μm. The CX, EX, F2, F3, GD, and TC products contain small hybrid filler particles.

In this study, we used $\Delta E \geq 3.3$ as a threshold for clinically visible color changes.[23] We observed that some specimens demonstrated ΔE values less than 3.3, even though they demonstrated significant differences in either L*, a*, or b*. In particular, between the A1 and A2 shades of BF and HC, between the A2 and A3 shades of F2 and TC, and between the A3 and A3.5 shades of ES, F2, and GD, there were no perceivable differences in TP regardless of thickness; these shades could be used without differentiation in clinics. A perception threshold for ΔTP has only recently been suggested; Lee[24] proposed a ΔTP value of 2.0 as the perception threshold of translucency, and this was applied in the present study. However, this was calculated based only on the threshold of the contrast ratio.[38] Further investigations should be carried out regarding the clinically perceivable difference of translucency.

Although color and translucency of natural teeth should be the reference for restorative materials, little information is available regarding the optical properties of human teeth. The enamel and dentin layers have natural variations among individuals, tooth types, and sites on particular teeth. Hasegawa and others[39] evaluated the color and translucency of human central incisors and found that the a* and b* values of natural teeth tended to increase from incisal to cervical, whereas the lightness and translucency decreased. Yu and others[40] reported that the mean TPs of 1-mm human enamel and dentin were 18.7 and 16.4, respectively, using a spectrophotometer. They also mentioned that enamel showed lower a* and b* values than dentin, which means dentin is more reddish and yellowish in color. Pop-Ciutrila and others[41] evaluated the color and translucency of 2-mm specimens of human dentin. The mean TP of dentin specimens from anterior teeth was 6.85 as measured using a spectrophotometer. In our study, the TP of 1-mm specimens of RBC ranged from 11.45 (A1 shade of CX) to 18.19 (A3 shade of GD) and that of 2-mm specimens ranged from 4.37 (A1 shade of CX) to 7.70 (A3 shade of GD). Even though the data from different studies are not directly comparable due to differences in measuring instruments and methods, we can assume that the translucency of currently used RBCs is appropriate for replacing natural tooth structures. A recent case report showed that highly acceptable esthetic results could be obtained clinically by combining two body shades, without the use of opaque or translucent RBCs.[42]

The color and translucency of teeth changes during aging.[43] Over time, the enamel gets thinner due to abrasion, and the dentin becomes thicker by lifelong deposition and shrinkage of pulp. This makes the overall color tone of a tooth yellowish. Meanwhile, dentin sclerosis proceeds inside the dentinal tubules, which makes dentin become more homogeneous.[44] In this respect, for the restorative treatment of relatively old patients, it seems to be reasonable to use a single shade of an RBC product whose translucency increases with higher shade numbers. However, from a different viewpoint, the opposite also could be reasonable. For example, when restoring a large anterior class IV cavity, clinicians may use the layering technique (a dark opaque shade for the inner dentin layer and a light transparent shade for the outer enamel layer). In this situation, it could be more favorable if the translucency is inversely proportional to the shade number.

Yu and Lee[45] reported that the stability of the optical properties of RBCs varied depending on their type, brand, and shade. Considering the long-term clinical aspects that the restoration is exposed directly to the oral environment and the material undergoes aging, the long-term stability of the color and translucency of RBCs is another important aspect to be considered. Further research related to the stability of RBC products should be undertaken.

The optical properties of RBCs are the result of complicated interactions of various factors, and detailed knowledge is still lacking. For predictable clinical applications, further detailed investigations should be performed considering the color and optical properties of the RBCs as well as their stability considering the light source, surface morphology, background color, and storage medium and period. When clinicians perform restorative treatments with high esthetic demands, such as anterior class III or IV lesions, they should be aware of the color and translucency characteristics of the individual RBC product in order to successfully reproduce the appearance of natural teeth. The combination of layers with different shade and translucency values could be considered for this purpose, which would provide more possibilities if several types of RBC products were prepared in the clinic.

CONCLUSIONS

Within the limitations of this study, we observed significant differences in the color and translucency among the different shade numbers within each RBC product line. Overall, the RBCs became darker and yellowish as the shade number increased. The variations in the translucency were not correlated with the order of the shade numbers. On the contrary, the blue light transmittance consistently decreased with increasing shade numbers for all RBC types.

Acknowledgments

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (grant number: HI17C1719).
The authors thank 3M Korea, Dentsply Sirona Korea, Ivoclar Vivadent Korea, Midong, and Shinhung for providing the materials for this research.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 14 October 2017)

REFERENCES

1. Munsell AH (1905) *A Color Notation* GH Ellis Company.
2. Browning WD, Contreras-Bulnes R, Brackett MG, & Brackett WW (2009) Color differences: Polymerized composite and corresponding Vitapan Classical shade tab *Journal of Dentistry* **37(Supplement 1)** e34-e39.
3. Terry DA, Geller W, Tric O, Anderson MJ, Tourville M, & Kobashigawa A (2002) Anatomical form defines color: Function, form, and aesthetics *Practical Procedures and Aesthetic Dentistry* **14(1)** 59-67; quiz 68.
4. Winter R (1993) Visualizing the natural dentition *Journal of Esthetic Dentistry* **5(3)** 102-117.
5. Johnston WM, Ma T, & Kienle BH (1995) Translucency parameter of colorants for maxillofacial prostheses *International Journal of Prosthodontics* **8(1)** 79-86.
6. Lee YK (2007) Influence of scattering/absorption characteristics on the color of resin composites *Dental Materials* **23(1)** 124-131.
7. Ryan EA, Tam LE, & McComb D (2010) Comparative translucency of esthetic composite resin restorative materials *Journal of the Canadian Dental Association* **76** a84.
8. Kim DH, & Park SH (2013) Evaluation of resin composite translucency by two different methods *Operative Dentistry* **38(3)** E1-E15.
9. Yu B, & Lee YK (2008) Translucency of varied brand and shade of resin composites *American Journal of Dentistry* **21(4)** 229-232.
10. Kim SJ, Son HH, Cho BH, Lee IB, & Um CM (2009) Translucency and masking ability of various opaque-shade composite resins *Journal of Dentistry* **37(2)** 102-107.
11. Mikhail SS, Schricker SR, Azer SS, Brantley WA, & Johnston WM (2013) Optical characteristics of contemporary dental composite resin materials *Journal of Dentistry* **41(9)** 771-778.
12. Perez MM, Ghinea R, Ugarte-Alvan LI, Pulgar R, & Paravina RD (2010) Color and translucency in silorane-based resin composite compared to universal and nanofilled composites *Journal of Dentistry* **38(Supplement 2)** e110-e116.
13. Schmeling M, DE Andrada MA, Maia HP, & DE Araujo EM (2012) Translucency of value resin composites used to replace enamel in stratified composite restoration techniques *Journal of Esthetic and Restorative Dentistry* **24(1)** 53-58.
14. Pecho OE, Ghinea R, do Amaral EA, Cardona JC, Della Bona A, & Perez MM (2016) Relevant optical properties for direct restorative materials *Dental Materials* **32(5)** e105-e112.
15. Yu B, & Lee YK (2008) Influence of color parameters of resin composites on their translucency *Dental Materials* **24(9)** 1236-1242.
16. Calheiros FC, Daronch M, Rueggeberg FA, & Braga RR (2008) Influence of irradiant energy on degree of conversion, polymerization rate and shrinkage stress in an experimental resin composite system *Dental Materials* **24(9)** 1164-1168.
17. Stansbury JW (2000) Curing dental resins and composites by photopolymerization *Journal of Esthetic Dentistry* **12(6)** 300-308.
18. Bucuta S, & Ilie N (2014) Light transmittance and micromechanical properties of bulk fill vs. conventional resin based composites *Clinical Oral Investigations* **18(8)** 1991-2000.
19. dos Santos GB, Alto RV, Filho HR, da Silva EM, & Fellows CE (2008) Light transmission on dental resin composites *Dental Materials* **24(5)** 571-576.
20. Masotti AS, Onofrio AB, Conceicao EN, & Spohr AM (2007) UV-vis spectrophotometric direct transmittance analysis of composite resins *Dental Materials* **23(6)** 724-730.
21. International Organization for Standardization (2009) ISO 4049 Dentistry—Polymer-based restorative materials Geneva: International Organization for Standardization.
22. Commission Internationale de l'Eclairage (2004) *Colorimetry: Technical Report* Central Bureau of the CIE, Vienna.
23. Ruyter IE, Nilner K, & Moller B (1987) Color stability of dental composite resin materials for crown and bridge veneers *Dental Materials* **3(5)** 246-251.
24. Lee YK (2016) Criteria for clinical translucency evaluation of direct esthetic restorative materials *Restorative Dentistry and Endodontics* **41(3)** 159-166.
25. Paravina RD, Majkic G, Imai FH, & Powers JM (2007) Optimization of tooth color and shade guide design *Journal of Prosthodontics* **16(4)** 269-276.
26. Paravina RD, Powers JM, & Fay RM (2002) Color comparison of two shade guides *International Journal of Prosthodontics* **15(1)** 73-78.

27. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, & van Noort R (2009) Effect of resin matrix composition on the translucency of experimental dental composite resins *Dental Materials* **25(12)** 1564-1568.

28. Manojlovic D, Dramicanin MD, Lezaja M, Pongprueksa P, Van Meerbeek B, & Miletic V (2016) Effect of resin and photoinitiator on color, translucency and color stability of conventional and low-shrinkage model composites *Dental Materials* **32(2)** 183-191.

29. Lee YK (2008) Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites *Dental Materials* **24(9)** 1243-1247.

30. Lim YK, Lee YK, Lim BS, Rhee SH, & Yang HC (2008) Influence of filler distribution on the color parameters of experimental resin composites *Dental Materials* **24(1)** 67-73.

31. Arikawa H, Kanie T, Fujii K, Takahashi H, & Ban S (2007) Effect of filler properties in composite resins on light transmittance characteristics and color *Dental Materials Journal* **26(1)** 38-44.

32. Shortall AC, Palin WM, & Burtscher P (2008) Refractive index mismatch and monomer reactivity influence composite curing depth *Journal of Dental Research* **87(1)** 84-88.

33. Ota M, Ando S, Endo H, Ogura Y, Miyazaki M, & Hosoya Y (2012) Influence of refractive index on optical parameters of experimental resin composites *Acta Odontologica Scandinavica* **70(5)** 362-367.

34. Mitra SB, Wu D, & Holmes BN (2003) An application of nanotechnology in advanced dental materials *Journal of the American Dental Association* **134(10)** 1382-1390.

35. Johnston WM, & Reisbick MH (1997) Color and translucency changes during and after curing of esthetic restorative materials *Dental Materials* **13(2)** 89-97.

36. Klapdohr S, & Moszner N (2005) New inorganic components for dental filling composites *Monatshefte für Chemie* **136(1)** 21-45.

37. Miller L (1987) Organizing color in dentistry *Journal of the American Dental Association* **Special No** 26E-40E.

38. Liu MC, Aquilino SA, Lund PS, Vargas MA, Diaz-Arnold AM, Gratton DG, & Qian F (2010) Human perception of dental porcelain translucency correlated to spectrophotometric measurements *Journal of Prosthodontics* **19(3)** 187-193.

39. Hasegawa A, Ikeda I, & Kawaguchi S (2000) Color and translucency of in vivo natural central incisors *Journal of Prosthetic Dentistry* **83(4)** 418-423.

40. Yu B, Ahn JS, & Lee YK (2009) Measurement of translucency of tooth enamel and dentin *Acta Odontologica Scandinavica* **67(1)** 57-64.

41. Pop-Ciutrila IS, Ghinea R, Colosi HA, & Dudea D (2016) Dentin translucency and color evaluation in human incisors, canines, and molars *Journal of Prosthetic Dentistry* **115(4)** 475-481.

42. Romero MF, Haddock FJ, Freites AG, Brackett WW, & Brackett MG (2016) Restorative technique selection in class IV direct composite restorations: A simplified method *Operative Dentistry* **41(3)** 243-248.

43. Goodkind RJ, & Schwabacher WB (1987) Use of a fiber-optic colorimeter for in vivo color measurements of 2830 anterior teeth *Journal of Prosthetic Dentistry* **58(5)** 535-542.

44. Vasiliadis L, Darling AI, & Levers BG (1983) The histology of sclerotic human root dentine *Archives of Oral Biology* **28(8)** 693-700.

45. Yu B, & Lee YK (2013) Comparison of stabilities in translucency, fluorescence and opalescence of direct and indirect composite resins *European Journal of Esthetic Dentistry* **8(2)** 214-225.