Assessment of Color Parameters of Composite Resin Shade Guides Using Digital Imaging versus Colorimeter

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ABSTRACT

Purpose: This study evaluated the color parameters of resin composite shade guides determined using a colorimeter and digital imaging method.

Materials and Methods: Four composite shade guides, namely: two nanohybrid (Grandio [Voco GmbH, Cuxhaven, Germany]; Premise [KerrHawe SA, Bioggio, Switzerland]) and two hybrid (Charisma [Heraeus Kulzer, GmbH & Co. KG, Hanau, Germany]; Filtek Z250 [3M ESPE, Seefeld, Germany]) were evaluated. Ten shade tabs were selected (A1, A2, A3, A3,5, A4, B1, B2, B3, C2, C3) from each shade guide. CIE *Lab* values were obtained using digital imaging and a colorimeter (ShadeEye NCC Dental Chroma Meter, Shofu Inc., Kyoto, Japan). The data were analyzed using two-way analysis of variance and Bonferroni post hoc test.

Results: Overall, the mean ΔE values from different composite pairs demonstrated statistically significant differences when evaluated with the colorimeter ($p < 0.001$) but there was no significant difference with the digital imaging method ($p = 0.099$). With both measurement methods in total, 80% of the shade guide pairs from different composites (97/120) showed color differences greater than 3.7 (moderately perceptible mismatch), and 49% (59/120) had obvious mismatch ($\Delta E > 6.8$). For all shade pairs evaluated, the most significant shade mismatches were obtained between Grandio-Filtek Z250 ($p = 0.021$) and Filtek Z250-Premise ($p = 0.01$) regarding ΔE mean values, whereas the best shade match was between Grandio-Charisma ($p = 0.255$) regardless of the measurement method.

Conclusion: The best color match (mean ΔE values) was recorded for A1, A2, and A3 shade pairs in both methods. When proper object-camera distance, digital camera settings, and suitable illumination conditions are provided, digital imaging method could be used in the assessment of color parameters. Interchanging use of shade guides from different composite systems should be avoided during color selection.

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CLINICAL SIGNIFICANCE

The shade guides of nanohybrid and hybrid composites do not give consistent color match with exception of A1, A2, and A3 shade pairs.

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INTRODUCTION

The phenomenon of color is a psycho-physical response to the physical interaction of light energy with an object and the subjective experience of an individual observer.[1,2] Compared with the ceramics, especially for single anterior restorations, the success of a composite restoration from the esthetic aspect depends highly on the operator's decision on color. When better proximal margins and contours need to be achieved, composite restorations could be made indirectly by a dental technician. In this case, communication on color with the dental laboratory is important. However, often right shade selection cannot be met either because of lack of objectivity or availability of color space required in the shade guides.[3–7]

The viewing conditions are very important during color matching. The variables such as light source, time of day, surrounding conditions, and the angle of the tooth may all affect the apparent tooth color.[3–5,7] Several standard illuminants have been used to measure the color of dental materials. Standard illuminant D65 represents a phase of daylight with a correlated color temperature of approximately 6,500 Kelvin (K); illuminant A represents light from the full radiator at absolute color temperature of 2,856 K; and illuminant F2 represents light from a fluorescent lamp of medium color temperature of 4,230 K.[8]

Tooth color is measured by various methods such as visual assessment using a shade guide, spectrophotometer, colorimeter, computer analysis of digital images, or film-based photography.[1,3,8–10] Among all these methods, dental shade guides are frequently used in order to identify and communicate on the color. Yet, these shade guides have the main limitation that the range of shades is not consistent with natural teeth.[8] Therefore, the likelihood of an error in shade selection is high because many tooth colors must be defined by making an approximation to the nearest shade of the guide.[8,11–13] In a recent survey, the majority of dentists expressed the need for the development of a systematic shade guide.[5] On the other hand, during the last two decades, the colorimeters have been rapidly developed in dentistry. Such devices offer potential objective and quantitative assessment of tooth color, independent of the examiner's experience and the environmental conditions.[7,12,14–16] Spectrophotometric color measurements may show variations depending on the measuring geometry and the illuminant.[17] Therefore, when color measurements are made with such instruments, measured color values are sensitive to the methods employed. As an alternative to colorimeters, computer analysis of digital images was also reported to be a reliable method in tooth color quantification.[18] In this method, the images produced via a digital camera are analyzed using appropriate imaging software, enabling the collection of color values from the images. This is a much cheaper process than the use of spectrophotometers or colorimeters. However, their reliability for different composite shade guides is not known to date.

Surface characterization of composite materials revealed that the outer covering layer is mainly the resin matrix itself.[19] It can be anticipated that this would eliminate the type and amount of fillers offsetting the color difference between the shade guides of nanohybrid and hybrid composites. The objectives of this study were therefore twofold, namely: (1) to

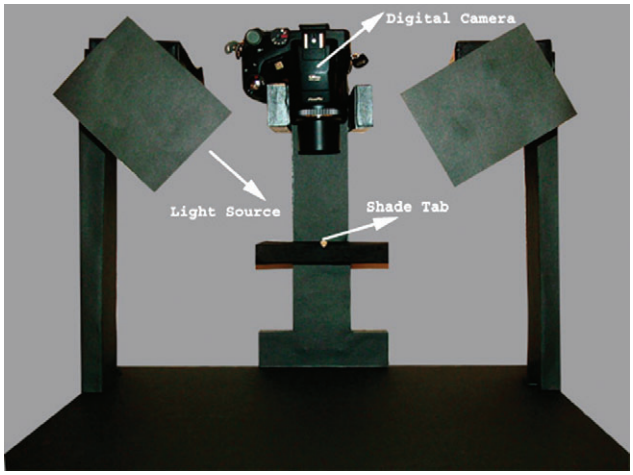

Figure 1. Tailor-made photo stand for the digital color measurement. Note the standard distance between the lens and the shade tab (10 cm) and standard reflecting angle of the lamps (45°).

compare the digital imaging method with a colorimeter for color parameters of resin composite shade guides; and (2) to evaluate the cross-comparison of shade guides from different composite types. The null hypotheses tested were that the digital imaging method would correlate well with that of a colorimeter and composite shade guides would present similar color parameters regardless of the type of composites.

MATERIALS AND METHODS

Color Measurement

Four composite shade guides, namely: two nanohybrid (Grandio [Voco GmbH, Cuxhaven, Germany]; Premise [KerrHawe SA, Bioggio, Switzerland]) and two hybrid (Charisma [Heraeus Kulzer, GmbH & Co. KG, Hanau, Germany]; Filtek Z250 [3M ESPE, Seefeld, Germany]) were evaluated. Ten shade tabs were selected (A1, A2, A3, A3,5, A4, B1, B2, B3, C2, C3) from each shade guide.

For the digital imaging method, four fluorescent tubes were mounted on a tailor made photostand with tubes perpendicular to the front plane, being 20 cm away from the specimen and illuminating at an angle of 45° (Figure 1). The shade tab was placed 15 cm higher than the stand plane. From each shade tab, three digital images were obtained using a digital camera (Fuji S20 Pro, Fujifilm, Tokyo, Japan) with a fourth generation charge-coupled device sensor having 6.2 million effective pixels. Images were taken at an object-lens distance of 10 cm. The camera was set to macro mode using manual settings (aperture f/11, shutter speed 1/80 s). Two 6,500-K fluorescent tubes (Philips PL-C 18W/865, Koninklijke Philips Electronics N.V., Eindhoven, the Netherlands) were placed in the lower sockets and were combined with two 2,700 K (Philips PL-C 18W/827) fluorescent tubes placed in the upper sockets.

Digital images were transferred to a personal computer and *L**, *a**, *b** values were calculated using Adobe Photoshop CS2 (Adobe Systems Inc., San Jose, CA, USA). For standardized calculations, a measurement template was created in the middle third of the tab that consisted of a spherical area having 3.790 pixels. Color measurements were made using a histogram tool. The data were obtained in Photoshop Red, Green, and Blue (RGB). Mean values were converted from RGB to CIE-*Lab* (Commision Internationale de l'Eclairage, *L**, *a**, *b**) values with EasyRGB software (Logicol S.r.l., Trieste, Italy). CIE *L** value is a measure of the lightness of an object where a perfect black has a CIE *L** value of 0 and a perfect reflecting diffuser (white) has a CIE *L** value of 100. CIE *a** value is a measure of redness (positive value) or greenness (negative value), and CIE *b** value is a measure of yellowness (positive value) or blueness (negative value).[19–21]

Color measurements were made again from all tabs of the shade guides using a digital intraoral colorimeter (ShadeEye NCC Dental Chroma Meter, Shofu Inc., Kyoto, Japan). Before each measurement, the colorimeter was calibrated according to the manufacturer's recommendations. The ShadeEye NCC device contains a pulsed xenon lamp as an optical light source and a three-component silicon photocell as the optical sensor. The measurements were obtained from each tab by contacting the measurement tip on the middle third region of the shade tabs. Measurements were realized in the analysis mode that gives L^*, a^*, b^* values of the colorimeter.

ΔE values were then calculated using the equation $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ for both the digital imaging and the colorimetric measurements.

Statistical Analysis

The statistical analysis was performed with the SPSS software package (version 11.5; SPSS Inc., Chicago, IL, USA). The means of CIE L^*, a^*, b^* values of each group were analyzed using two-way analysis of variance and Bonferroni post hoc test ($\alpha = 0.05$).

RESULTS

Whereas the colorimetric assessment revealed L^* values ranging from 53.5 to 78.4, a^* values from −3.2 to −0.2, and b^* values from 2 to 17.5, the digital imaging assessment L^* values ranged from 63.0 to 85.6, a^* values from −6.1 to 3.0, and b^* values from 29.0 to 48.6 (Table 1).

Mean a^* values showed statistical differences between the digital imaging method ($p = 0.029$) and colorimetric measurement ($p = 0.013$), but no significant difference was observed within the groups except for Charisma ($p = 0.017$) (Table 2, Figure 2). Mean b^* values, on the other hand, showed no significant differences between the groups for both the digital imaging ($p = 0.487$) and colorimeter ($p = 0.096$), but all shade guides from all composites showed significant differences within the groups (Table 2). Mean L^* demonstrated significant differences between the measurement methods as well as within the groups.

For all shade pairs evaluated, the most significant shade mismatches were obtained between Grandio-Filtek Z250 and Filtek Z250-Premise regarding ΔE mean values, whereas the best shade match was between Grandio-Charisma regardless of the measurement method. Overall, the mean ΔE values from different composite pairs demonstrated statistically significant differences when evaluated with the colorimeter ($p < 0.001$), but there was no significant difference with the digital imaging method ($p = 0.099$) (Table 3).

Eighty percent of the shade guide pairs from different composites (97/120) showed color differences greater than 3.7 (moderately perceptible mismatch), and 49% (59/120) had obvious mismatch ($\Delta E > 6.8$) (Table 4). The best color match (mean ΔE values) was recorded for A1, A2, and A3 shade pairs in both methods (Table 4). $Cab^* = (a^{*2} + b^{*2})^{1/2}$ versus CIE L^* values for representative A1, A2, A3, A3,5 composite shade tabs are presented in Figure 3A,B.

DISCUSSION

Resin composites are commonly used in various disciplines of dentistry. However, no standardization has been supplied regarding the color aspect of their shade guides. In a previous study, color differences among 11 resin composite brands of identical shade designation were found to be visually perceptible and authors pointed out the need for improved standardization of resin composite shades.[6] Because composites with new formulations are being produced and frequently used in daily practice, this study was undertaken to compare the shade guides of two nanohybrid and two hybrid composites with the aid of two color measurement methods.

TABLE 1. MEAN CIE *L, *a**, AND *b** VALUES OBTAINED FROM THE DIGITAL IMAGING METHOD AND COLORIMETER.**

Shade	Filtek Z250 digital imaging			Filtek Z250 colorimeter			Shade	Premise digital imaging			Premise colorimeter		
	*L**	*a**	*b**	*L**	*a**	*b**		*L**	*a**	*b**	*L**	*a**	*b**
A1	82.1	–2.4	32.6	67.3	–2.3	3.0	A1	77.5	–2.4	35.7	60.1	–1.7	2.0
A2	80.4	–0.8	39.7	70.1	–1.3	9.2	A2	77.0	–1.2	38.7	62.8	–1.8	5.8
A3	79.8	1.4	40.0	70.6	–0.6	11.8	A3	76.3	–1.4	41.9	63.0	–1.7	8.8
A3,5	75.1	3.0	45.6	66.2	–0.9	16.8	A3,5	66.8	1.1	44.0	56.6	–0.6	10.3
A4	73.0	1.6	47.8	64.8	–0.5	14.8	A4	67.1	0.7	43.3	57.7	–1.5	10.5
B1	85.6	–4.3	29.0	78.4	–1.5	2.4	B1	82.7	–5.2	35.4	68.7	–2.7	3.4
B2	80.6	–2.3	38.7	69.8	–1.9	7.0	B2	82.6	–6.1	41.4	69.2	–3.2	7.7
B3	78.0	0.8	48.6	69.3	–0.5	17.5	B3	73.0	1.4	41.2	61.4	–1.9	7.9
C2	75.3	0.5	44.7	66.4	–0.8	13.7	C2	73.6	–0.5	43.5	60.2	–1.5	8.0
C3	71.7	1.4	44.3	64.3	–0.4	13.1	C3	71.0	–0.4	42.2	57.9	–1.6	7.8
Shade	**Charisma digital imaging**			**Charisma colorimeter**			**Shade**	**Grandio digital imaging**			**Grandio colorimeter**		
	*L**	*a**	*b**	*L**	*a**	*b**		*L**	*a**	*b**	*L**	*a**	*b**
A1	78.5	–4.4	36.5	66.3	2.2	3.9	A1	75.6	–2.3	32.1	65.3	–2.7	4.0
A2	74.4	–4.8	38.9	64.8	–1.3	4.6	A2	76.2	–1.6	39.6	60.1	–1.9	6.4
A3	73.0	–1.2	40.2	62.1	–1.1	7.8	A3	72.4	–0.6	40.0	60.6	–1.7	7.8
A3,5	74.2	–1.0	45.8	64.4	–1.6	15.0	A3.5	69.8	1.0	42.2	55.7	–1.1	10.5
A4	70.9	1.2	40.6	60.8	–0.2	9.8	A4	63.0	–2.4	45.1	53.5	–1.2	11.2
B1	79.9	–6.1	36.3	71.8	–2.5	5.4	B1	78.0	–3.3	30.0	64.7	–2.5	2.2
B2	76.5	–4.1	47.1	66.3	–1.9	12.4	B2	74.5	–6.0	37.4	62.5	–3.2	5.0
B3	76.0	–3.1	47.0	68.2	–2.2	17.5	B3	72.6	–1.6	42.7	58.0	–2.1	8.1
C2	76.1	–3.9	41.6	65.3	1.7	8.0	C2	68.0	–3.3	37.2	55.3	–1.7	7.1
C3	75.8	–3.8	43.2	62.8	1.9	10.5	C3	66.4	–3.7	39.9	53.9	–1.7	6.9

With the intraoral colorimeters, errors may occur in absolute color values as measurements suffer from edge loss.[22,23] Also, it is not possible to position the tip in a consistent position on the tooth.[23] Thus, they may be inaccurate and not repeatable especially when used with polychromatic, translucent specimens such as natural teeth. There are, however, controversial reports revealing that accurate, repeatable quantitative color measurements would still be possible using colorimeters.[2,9,15,21,24,25] Nevertheless, the colorimeter used in this study (ShadeEye NCC Chroma Meter) was chosen based on previous favorable results where the device was found to be more reliable than visual color selection especially in uncomplicated cases.[7] In another study, no significant difference was noted in the results of shade selection whether it is performed by experienced specialists or with the colorimeter.[14] In fact, the colorimeters are basically designed for flat surfaces rather than curved ones.

Because natural teeth are polychromatic, translucent, and have curved surfaces, instrumental color assessment of teeth is not free of errors. Furthermore, the thickness of shade tabs produced by different manufacturers varies substantially. These variations may affect color perception and matching.[25] For these reasons, digital imaging was considered as an alternative method. In this study, the mean ΔE values from different composite pairs demonstrated statistically significant differences when

TABLE 2. TWO-WAY ANALYSIS OF VARIANCE AND BONFERRONI POST HOC RESULTS FOR CIE *L, *a** AND *b** VALUES.**

		Charisma	Premise	Grandio	Filtek Z250	p*
*L**	Digital imaging	76 ± 2.6	75 ± 5.6	72 ± 4.8‡	78 ± 4.4	0.021
	Colorimeter	65 ± 3.2	62 ± 4.3‡	59 ± 4.4‡,§	69 ± 4.1	<0.001
	p†	<0.001	<0.001	<0.001	<0.001	
*a**	Digital imaging	−3 ± 2.2	−1.4 ± 2.5	−2.4 ± 1.9	−0.1 ± 2.3§	0.029
	Colorimeter	−1 ± 1.8	−1.8 ± 0.7§	−2 ± 0.7§	−1.1 ± 0.7	0.013
	p†	0.017¶	0.518	0.440	0.129	
*b**	Digital imaging	42 ± 4	41 ± 3.1	39 ± 4.7	41 ± 6.4	0.487
	Colorimeter	10 ± 4.5	7 ± 2.8	7 ± 2.8	11 ± 5.4	0.096
	p†	<0.001	<0.001	<0.001	<0.001	

*Comparison between groups.

†Comparison within groups.

‡Significant difference between Filtek Z250 group ($p < 0.05$).

§Significant difference between Charisma group ($p < 0.05$).

¶No statistically significant difference between digital imaging and colorimeter according to Bonferroni correction ($p = 0.0125$).

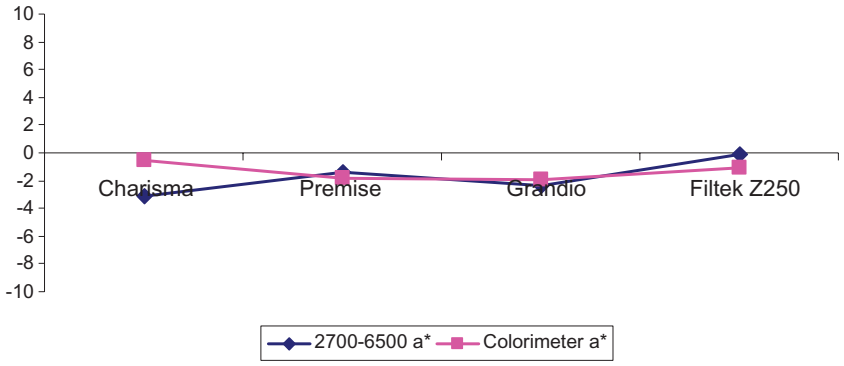

Figure 2. Mean a values obtained from both the digital imaging method and the colorimeter for each composite.*

evaluated with the colorimeter, but there was no significant difference with the digital imaging method. This could indicate that the digital imaging method could be an alternative to the colorimeter in assessing color if proper object-camera distance, digital camera settings, and suitable lighting conditions are provided. However, mean *L** demonstrated significant differences between the measurement methods as well as within the shade guides. This was followed by *b** and *a** values. Therefore, the first hypothesis could only be partially accepted. Whether ΔE values alone are sufficient for the justification of the use of digital images versus colorimeter needs to be verified in future investigations. According to Douglas and Brewer,[14] under intraoral conditions, the resolution of digital colorimeters is above that of a human eye. Therefore, photocolorimetric analysis was recommended in shade selection as an alternative to conventional visual shade selection. If this is really the case, shade selection could be made based on the digital photocolorimetric analysis, eliminating the art of shade selection *in vivo*. This may add to the chairside time initially but at the same time reduce the possibility of wrong shade selection to some extent. Nevertheless, under standard conditions of this study, even the information derived from digital colorimeters may not simulate the clinical conditions fully; the results could be beneficial in color measurement science in general.

TABLE 3. STATISTICAL COMPARISONS OF MEAN ΔE VALUES BETWEEN SHADE GUIDES FOR DIGITAL IMAGING AND COLORIMETER METHOD (TWO-WAY ANALYSIS OF VARIANCE, BONFERRONI).

	Grandio-Charisma	Grandio-Premise	Grandio-Filtek Z250	Filtek Z250-Charisma	Filtek Z250-Premise	Charisma-Premise	p*
Digital imaging	6.8 ± 3.1	5.3 ± 2.5	7.9 ± 2.0	6.7 ± 1.8	5.6 ± 2.4	5.3 ± 2.2	0.099
Colorimeter	8.0 ± 3.5‡	4.0 ± 1.7	10.9 ± 3.6‡,§,¶	5.6 ± 2.3	8.4 ± 2.9‡	5.8 ± 3.2	<0.001
p†	0.255	0.053	0.021¶	0.064	0.010**	0.608	

*Comparison between groups.

†Comparison within groups.

‡The difference between Grandio-Premise group is statistically significant ($p < 0.05$).

§The difference between Filtek Z250-Charisma group is statistically significant ($p < 0.01$).

¶The difference between Charisma-Premise group is statistically significant ($p < 0.01$).

**No significant difference between digital imaging and colorimeter according to Bonferroni correction ($p = 0.83$).

TABLE 4. ΔE VALUES PER COMPOSITE SHADE TAB OBTAINED FROM DIGITAL IMAGING AND COLORIMETRIC MEASUREMENT.

		A1	A2	A3	A3,5	A4	B1	B2	B3	C2	C3	Mean ΔE
Grandio-Charisma	Digital imaging	5.7	3.7	0.9	6.1	9.8	7.3	10.1	5.7	9.2	9.9	6.8
Grandio-Premise	Digital imaging	4.1	1.2	4.5	3.5	5.4	7.5	9.0	3.3	8.8	6.0	5.3
Grandio-Filtek Z250	Digital imaging	6.6	4.3	7.7	6.6	11.0	7.8	7.2	8.4	11.1	8.5	7.9
Filtek Z250-Charisma	Digital imaging	5.7	7.2	7.3	4.1	7.4	9.4	9.5	4.7	5.4	6.6	6.7
Filtek Z250-Premise	Digital imaging	5.6	3.5	4.8	8.7	7.4	7.0	5.0	9.0	2.3	2.9	5.6
Charisma-Premise	Digital imaging	2.4	4.4	3.7	7.9	4.7	3.0	8.6	7.9	4.7	6.0	5.3
	Mean ΔE	5.0	4.1	4.8	6.1	7.6	7.0	8.3	6.5	6.9	6.7	
Grandio-Charisma	Colorimeter	5.0	5.1	1.6	9.8	7.5	7.8	8.4	13.9	10.6	10.3	8.0
Grandio-Premise	Colorimeter	5.7	2.8	2.6	1.1	4.3	4.2	7.2	3.4	5.0	4.1	4.0
Grandio-Filtek Z250	Colorimeter	2.3	10.4	10.8	12.3	11.9	13.7	7.7	14.8	13.0	12.2	10.9
Filtek Z250-Charisma	Colorimeter	4.7	7.0	9.4	2.6	6.4	7.3	6.4	2.0	6.3	3.8	5.6
Filtek Z250-Premise	Colorimeter	7.3	8.1	8.2	11.6	8.4	9.8	1.6	12.5	8.5	8.4	8.4
Charisma-Premise	Colorimeter	7.6	2.4	1.5	9.2	3.4	3.7	5.7	11.8	6.0	6.6	5.8
	Mean ΔE	5.4	6.0	5.7	7.8	7.0	7.8	6.2	9.7	8.2	7.6	

Green = ΔE < 3.7 (acceptable match); Blue = 3.7 < ΔE < 6.8 (moderately perceptible mismatch); Red = ΔE > 6.8 (obvious mismatch).

It should also be noted that in this study, surfaces of the shade tabs were not flattened for close approximation to clinical conditions. Standardization was achieved primarily with the distance and the light source. The shade tabs have been placed 15 cm above the ground, and two light sources of different color temperature (2,700–6,500 K) were combined for the digital imaging method. Among many other factors, light source is the most critical factor in the selection of correct shades. Two standard illuminants are recommended for use in colorimetry.[8,23] Illuminant A should be used in all applications of colorimetry involving incandescent lighting, and D65 should be used in all colorimetric calculations requiring representative daylight. Regarding the color difference by the illuminant, it was reported that the changes in optical properties of composite resins relative to the

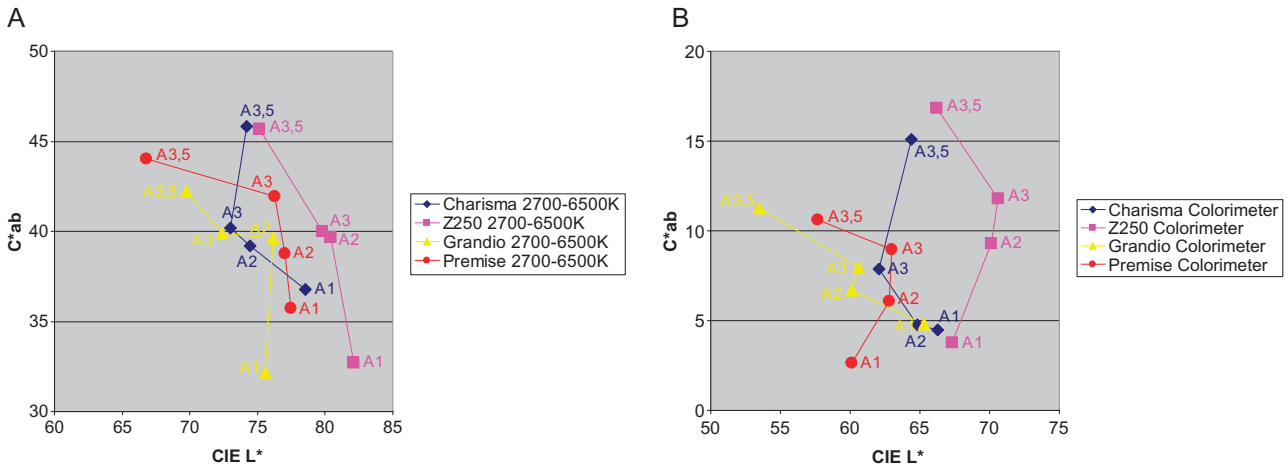

*Figure 3A–B. C*ab versus CIE L* for representative A1, A2, A3, and A3,5 shade tabs of the composites tested using* (A) *the digital imaging method at 2,700–6,500 K color temperature, and* (B) *the colorimeter.*

varied illuminants were different from those of dentin.[8,23] Metameric color difference can be minimized when a restoration is matched under a combination of light sources, which was found to provide the best-perceived match.[23] The colorimetric device used in this study contains a pulsed xenon lamp. A xenon arc lamp is a bright white light that closely mimics natural daylight (D65). Mean value differences in L^* and b^* values were probably observed because of the different power and color temperature of the light sources in the two methods. For reflectance spectrophotometry and colorimetry, two basic geometries are used; diffuse illumination and observation at 0° or illumination at 45° and observation at 0°. As access to the oral cavity is limited, only the 45°/0° geometry is a suitable method for clinical use. The accuracy and reliability of such devices have been demonstrated when photo table illuminants are placed at 45° and camera (observer) at 0° in the digital image method.[17] During color selection clinically, there should be no surface contact with the shade tab, and the oral cavity constitutes the background color that may affect the obtained results.[26,27]

Especially during layering, when several shades from different composite sets are to be used, shade matching becomes more complicated because of variations between the shade guides provided by many products. The majority of shade guides are manufactured from unfilled methacrylates rather than the actual composite material and do not accurately depict the true shade, translucency, or opacity of the resin composite after polymerization.[4] Filler shape strongly affects the color of composite resins, and other filler properties (such as filler particle size and filler content) exert significant influences as well.[28,29] Shade tabs of nanohybrid composites or hybrid composites showed no difference but nanohybrid–hybrid composites showed significant mismatches except for Grandio-Charisma. Therefore, the hypothesis was rejected. Whether the differences were related to the surface properties of the shade types or fillers were exposed to the surface and thereby affected the results needs further investigation. The manufacturers claimed that the shade guides studied were actually produced from the composite materials themselves. Although as a rule interchanging use of the shade tabs should be avoided, the best color compatibility based on ΔE values

was obtained for A1, A2, and A3 shade pairs in each method. These shades may be less prone to making an error in clinical practice. Paravina and colleagues reported the best color match for A2 shade pairs.[6] Only two of all shade pairs (4.2%) were below the limit of clinical acceptability.[5]

The average, casual viewer can notice the difference between two colors that are 5 to 6 ΔE apart.[13] On the other hand, a trained eye is capable of differentiating two colors that are closer to 3 to 4 ΔE apart. However, the human eye is very sensitive to changes away from achromatic tones (a^* and b^* values near 0). In this case, one can often notice a difference between two "shifted" grays that are as close as 0.5 ΔE apart.[13] In general, a $\Delta E = 0$ to 2 is considered imperceptible, a $\Delta E = 2$ to 3 just perceptible, a $\Delta E = 3$ to 8 moderately perceptible, and a $\Delta E > 8$ markedly perceptible.[13] When these ranges are taken into consideration, in the present study, 80% of the pairs had a color difference greater than 3.7 and only almost half of the pairs had obvious mismatch ($\Delta E > 6.8$). Paravina and colleagues[6] evaluated the color compatibility of six commercial resin composites and found 75% to have color differences that were above 3.7. It is difficult to compare the results of this study with that of Paravina and colleagues[6] because of the variations in the composite brands. Nonetheless, either 75 or 80% of obvious mismatch still carries 20% error possibility. In general, in color studies, ΔE values are considered for judging perceptibility. It should be noted that in this study, b^* values, the measure of yellowness, showed no significant difference between the measurement methods. Although yellowness alone is not sufficient for differentiating between shade guides, future studies may not only consider ΔE but also b^* values when color measurement methods are compared. When all color parameters show nonsignificant difference, only then could such methods be considered comparable.

CONCLUSIONS

From this study, the following could be concluded:

1. The mean ΔE values from different composite pairs demonstrated statistically significant differences when evaluated with the colorimeter, but there was no significant difference with the digital imaging method under standardized laboratory conditions
2. The best color match based on mean ΔE values was recorded for A1, A2, and A3 shade pairs in both methods. Interchanging use of shade guides from different composite systems should be avoided during color selection
3. The majority of the shade tab pairs of shade guides used in this study showed mismatch greater than 3.7, which is a moderately perceptible mismatch and almost half of them had obvious mismatch
4. Shade tabs of nanohybrid composites or hybrid composites showed no difference, but nanohybrid–hybrid composites showed significant mismatches except for Grandio-Charisma.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are included in this article.

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