Shade Guide Optimization—A Novel Shade Arrangement Principle for both Ceramic and Composite Shade Guides When Identifying Composite Test Objects

NIELS ØSTERVEMB, ••*
JETTE NEDERGAARD JØRGENSEN, DDS†
PREBEN HØRSTED BINDSLEV, DDS‡

ABSTRACT

Statement of Problem: The most widely used shade guide for composite materials is made of ceramic and arranged according to a non-proven method. There is a need for a composite shade guide using a scientifically based arrangement principle.

Purpose: To compare the shade tab arrangement of the Vitapan Classical shade guide and an individually made composite shade guide using both the originally proposed arrangement principle and arranged according to ΔE2000 values with hue group division.

Materials and Methods: An individual composite shade guide made from Filtek Supreme XT body colors was compared to the Vitapan Classical shade guide. Twenty-five students matched color samples made from Filtek Supreme XT body colors using the two shade guides arranged after the two proposed principles—four shade guides in total. Age, sequence, gender, time, and number of correct matches was recorded.

Results: The proposed visually optimal composite shade guide was both fastest and had the highest number of correct matches. Gender was significantly associated with time used for color sampling but not regarding the number of correct shade matches.

Conclusion: A composite shade guide is superior compared to the ceramic Vitapan classical guide when using composite test objects. A rearrangement of the shade guide according to hue, subdivided according to ΔE2000, significantly reduces the time needed to take a color sample and increases the number of correct shade matches.

CLINICAL SIGNIFICANCE

Total color difference in relation to the lightest tab with hue group division is recommended as a possible and universally applicable mode of tab arrangement in dental color standards. Moreover, a shade guide made of the composite materials itself is to be preferred as both a faster and more accurate method of determining color.

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*Scholarstipendiate, Department of Dental Pathology, Operative Dentistry and Endodontics, Aarhus School of Dentistry, Denmark
†Clinical Instructor, Department of Dental Pathology, Operative Dentistry and Endodontics, Aarhus School of Dentistry, Denmark
‡Head of School, Aarhus School of Dentistry, Denmark

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INTRODUCTION

The Vitapan Classical shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) is one of the most used in the world and, consequently, many companies develop their composite systems according to its design. However, Hall's statement from 1991 emphasis the complex of problems that emerges by doing so:

Shade guides of all dental restorative materials are based on the long established porcelain shade guides who evolved to represent the available shades of porcelain teeth. The shades developed by a process of popular selection by which shades perceived to be nearer tooth color were added and the least popular eliminated. This concept has not changed since the introduction of porcelain over two hundred years ago.[1]

Furthermore, the majority of dentists in a survey indicated a need for development of a systematic shade guide.[2] Newer research projects have also found that the same range of teeth could be covered with fewer tabs, or more teeth could be matched with the same number of shade tabs.[3] Currently, the color range of the Vitapan Classical shade guide to natural teeth only covers about 6–11%.[1,4] This means the range of shades in the shade guide is not consistent with natural teeth. Consequently, an error is introduced when you approximate to the nearest shade.[5,6] Furthermore, surrounding tissues (gingival, perioral) and background (oral cavity), together with the small and curved surface of the tooth, complicates shade matching even more.[7]

When a color is perceived, it is an interaction between (1) a light source, (2) an object, and (3) the human visual system. All three are possible to alter. The optimum light source and object is discussed later in the article. Despite research and opinions that color training and enhancement of our visual system is useful for improving one's shade-matching ability,[8] it has not yet become a mandatory part of dental education. So far, two extensive color training experiments have been conducted, both showing improvements in shade-matching abilities.[9,10]

The long-established Munsell color ordering system uses three coordinates to define a color:[11]

1. Value (lightness): 0 is black and 10 is white.
2. Chroma (saturation): open-ended scale from zero (achromatic colors) to a maximum dependant on the hue.
3. Hue: the color as it is perceived, as determined by the dominant wavelength of the light.

However, the Commision Internationale de l'Eclairage (CIE) refined color space in 1976 (Figure 1).[12] This three-dimensional space enables us to measure changes not only to the tooth, but also to the composite. For instance, it is possible to measure that, with age, there is a tendency for composite to become more yellowish because L^* and a^* declines while b^* increases.[13]

The Vitapan Classical shade tabs are divided into four groups based on hue. According to the manufacturer, group A is reddish-brown, group B is reddish-yellow, group C is gray, and group D is reddish-gray. Within the groups, the tabs are arranged according to increasing chroma—the higher the number, the higher the chroma and the lesser the value. However, others concluded that the visual distinction between Vita Lumin shade tabs was primarily due to a difference in brightness or luminance.[14]

Regarding teeth, the more translucent enamel plays a lesser role, through scattering of wavelengths in the blue range, when you compare it to the dentin.[15] The tubules are the predominant cause of light scattering in dentin, whereas the hydroxyapatite crystals contribute significantly to scattering in the enamel.[16] This means that the apparent color is a result

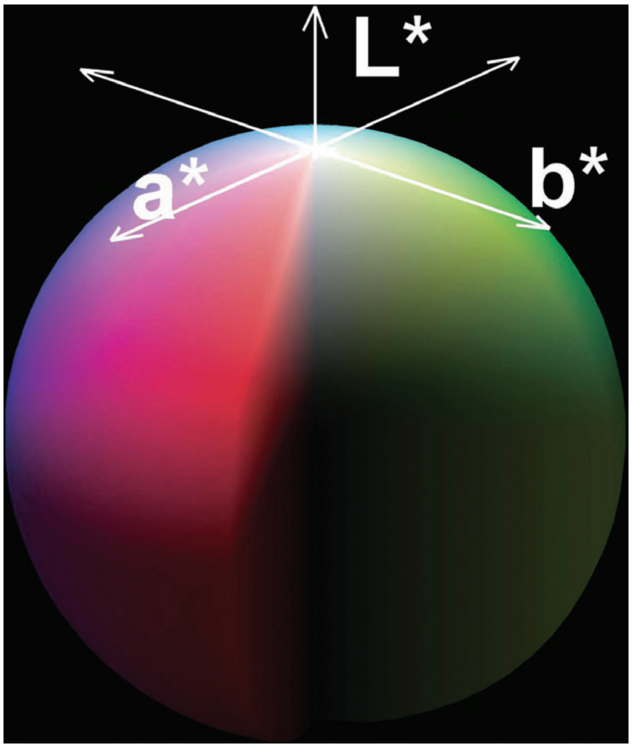

Figure 1. A three-dimensional representation of the CIE color space. L* *is a measure of the lightness of an object, such that perfect black has a value of 0 and a perfect white has a value of 100. CIE* a* *is a measure of redness (positive value) or green (negative value), and* b* *is a measure of yellowness (positive value) or blueness (negative value).*

of reflectance from the dentin modified by scattering, absorption, and thickness of the enamel. This diffuse reflectance from the inner dentin through the outer more translucent enamel layer is called the double-layer effect.[17]

Regarding threshold levels for color differences that can be visually perceived, various data have been published. The threshold for acceptable color difference was 1.7 ΔE^*_{ab} regardless of the shade,[18] whereas 3.3 ΔE^*_{ab} was considered as an acceptable threshold for composite resins.[19] The two aforementioned thresholds were determined under optimal in vitro conditions. The rating judged a clinical perfect match by the US Public Health service criteria was 3.7 ΔE^*_{ab} for composite resin veneer restorations and their comparison teeth.[20]

As stated previously, the structure of current shade guides is largely without any rational use of color distribution or ordering.[21,22] Instead, the arrangement of shade tabs according to color difference from light to dark provides a one-dimensional color order system.[23] Furthermore, hue group division should favor the most used colors. Our null-hypotheses are:

1. There is no difference in using a ceramic or a composite shade guide when judging composite colors of the same shade designation; and
2. Rearranging the shade guide according to ΔE2000 (from light to dark) with hue group division does not improve the number of correct shade matches, nor minimizes the time used.

MATERIALS AND METHODS

A silicone mould (Elastosil RT 601 A + B, Wacker Chemi, Munich, Germany) was made of one of the porcelain shade tabs (Figure 2). Individual composite shade tabs were then made from Filtek supreme XT (colors A1B, A2B, A3B, A3.5B, A4B, B1B, B2B, B3B, C1B, C2B, C3B, D2B) using the mould. Polymerization through the mould for 40 seconds from each side, followed by removal of the shade tab and another 40 seconds polymerization from each side. The L.E.Demetron 1 lamp (Kerr

Figure 2. Top: Composite shade guide made of Filtek Supreme XT. Bottom: Vitapan Classical shade guide. Both divided into two groups according to hue and subdivided according to ΔE2000. Picture taken under D65 illumination using MASTER TL-D 90 Graphica 58W/950 SLV light tubes from Philips and a Kodak Gray Card (18%).

Figure 3. The silicone mould used to fabricate the composite shade specimens.

Corporation, West Collins, ••, 3
USA), with a proven high intensity[24] that was checked prior to polymerization, was used.

High-gloss polishing was carried out using Sof-lex disc (30 μm followed by 3 μm) (3 M ESPE, St.
Paul, ••, USA), diamond polish 4
paste (SHINY A 3 μm, SHINY B μm) (HFO MICERIUM, Avegno, Italy), aluminum oxide paste (HFO Micerium, Avegno, Italy), and a dry cotton brush.[25] Finally, the composite specimens were polymerized for an additional 2 minutes to increase the degree of polymerization and achieve the hardest possible surface.[26] The individual shade tabs were fixed to the metal pins from a conventional Vitapan Classical shade guide, giving two similar shade guides—one composite and one ceramic (Figure 3). The composite specimens were made in the exact same way, using the same colors, giving a total of 12 tab-shaped specimens.

A MASTER TL-D 90 Graphica 58W/950 SLV light tube (Philips, Amsterdam, the Netherlands), with specifications according to the current recommendations listed as follows, was used.[27,28]

1. CCT (correlated color temperature) of 5,300 K
2. CRI (color-rendering index) of 98

3. Light with 1,500 lx (140fc)—checked using Hagner EC1 luxometer (B.Hagner AB, Solna, Sweden)
4. Using a neutral grey background with 18% reflectance (Kodak Gray cards, Kodak, New York, NY, USA)

The shade tab arrangements were made using the CIEDE2000 formulation and visual inspection and confirmation. The CIEDE2000 formula used to calculate ΔE_{2000} values is depicted as follows.[17]

$$\Delta E_{2000} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'ab}{k_C S_C}\right)^2 + \left(\frac{\Delta H'ab}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'ab}{k_C S_C}\right)\left(\frac{\Delta H'ab}{k_H S_H}\right)}$$

It was possible to find CIElab data for the Vitapan Classical shade guide.[29] However, CIElab data for Filtek Supreme XT was regarded as a company secret. Therefore, measurements were made that could be confirmed with precalculated ΔE2000 values obtained from 3 M ESPE. In order to avoid any difference due to different measurement methods, the ceramic shade guide was also measured and the data submitted to Vita Zahnfabrik, Bad Sackingen, Germany, for confirmation.

TABLE 1. FINAL SHADE TAB ARRANGEMENT FOR THE VITA CLASSICAL AND THE INDIVIDUAL FILTEK SUPREME XT SHADE GUIDE.

Vital classical		Composite	
Number	Color	Number	Color
11	B1	31	B1
12	A1	32	A1
13	B2	33	A2
14	A2	34	B2
15	B3	35	A3
16	A3	36	B3
17	A3.5	37	A3.5
18	A4	38	A4
21	C1	41	C1
22	D2	42	D2
23	C2	43	C2
24	C3	44	C3

Measurement was made using the Vita Easy shade (Vita Zahnfabrik, Bad Sackingen, Germany) on the middle third of the composite and ceramic shade guide tabs. Ten measurements were made on each shade tab, and the average was calculated. The ranking was visually confirmed by the chief ceramist and a clinical instructor from the School of Dentistry, Aarhus University. No changes were made. The shade tabs were then divided into two groups according to hue—group AB (A and B colors) and group CD (C and D colors). Table 1 and Figure 2 show the arrangement used. SG1 is the composite shade guide arranged according to the Vitapan classical guide. SG2 is the composite shade guide arranged according to hue subdivided according to ΔE2000. SG3 is the Vitapan Classical shade guide arranged according to the Vitapan Classical principle. SG4 is the Vitapan Classical shade guide arranged according to hue subdivided according to ΔE2000.

Sample size analysis was performed using G*Power 3.0.10 (Franz Faul, University of Kiel, Germany). Twenty-five dental students with at least 1 year of clinical experience participated. Initially, they were administered the Isicharas color blindness test,[30] but none were found to be color blind. They were given the same information, and the color determination sequence was randomized. Age, clinical experience, gender, time used, and shade tab chosen were recorded. After the recommended 1-minute adaptation period,[31] by observing the gray card, the observers began the shade matching procedure.

Observers were given the 12 ($N = 12$) tab-shaped specimens one at a time. Shade matching time was measured as the time from when they were handed the shade tab until they stated what they had determined. There were no breaks between shade matching trials, except the time it took to give the observers the next shade tab to identify. They were allowed to determine the shades as they would normally do, meaning observer geometry and shade matching reflected the clinical environment with a natural variation.

TABLE 2. NUMBER OF CORRECT SHADE MATCHES.

Gender	Female	Men	Both
SG1	8.4	8.5	8.4*
SG2	10.3	10.3	10.3*
SG3	4.4	4.5	4.4*
SG4	5.9	5.0	5.5*
Average	7.2	7.1	7.2

(*$p < 0.05$).

STATISTICAL EVALUATION

Statistical analysis was performed with the aid of Statistix (Analytical Software, Tallahassee, FL, USA). For comparison between the number of correct shade matches using SG1, SG2, SG3, or SG4 and time of date, years of experience, and sequence of the shade guides, a paired *t*-test was used. For comparison between gender and time used and number of correct matches, the one-sample *t*-test was used. A significance of $p \leq 0.05$ was chosen.

RESULTS

The composite shade guide significantly increased the probability of a correct color match compared to the ceramic shade guide (Table 2). Furthermore, the rearrangement of both the composite and the ceramic shade guide also increased the number of correct matches (Table 2).

It was calculated that the order in which the students tested the shade guides did not statistically affect the number of correct answers. Neither did the date or the time of day influence this. The age of the test persons varied between 23 and 33 years (average 25.5 years), but was not found to have any significant effect.

The capability of selecting the correct tooth shade was not found to be gender dependent. However, the time used was significantly less for men compared to women—on average, women used 21% more time on their color decision protocol (Table 3).

The colors with the least percentage of correct matches, all on average below 50%, were B2, C1, C2, and A1 (Table 4). Furthermore, Table 5 shows that despite the corresponding ceramic and composite colors and that they should have the same ΔE2000 value, a large difference was found between them.

When using the composite shade guide there was a clear tendency to choose colors with a very similar ΔE2000 value. When using the ceramic shade guide, there was a larger variation and, often, a color with a very different ΔE2000 value was chosen (Tables 6 and 7)

DISCUSSION

The Vitapan Classical shade guide is divided into groups according to hue, and within the groups according to saturation. The rearrangement principle proposed is made according to CIEDE2000 calculations, and current knowledge about human vision and color distribution. Consequently, the shade guides was divided into two groups according to hue—the AB group and the CD group—and arranged in each group according to ΔE2000. This was done because as much as 80% of all fillings may be made using A and B colors. This

TABLE 3. TIME USED.

Gender	Women (seconds)	Men (seconds)	Both (seconds)
SG1	636	531	591
SG2	397	362	382
SG3	757	585	684
SG4	581	473	534
Total time	2,371*	1,952*	2,191

(* $p < 0.05$).

TABLE 4. PERCENTAGE OF CORRECT SHADE MATCHES ACCORDING TO SHADE GUIDE USED AND COLOUR.

Color	SG1 (%)	SG2 (%)	SG3 (%)	SG4 (%)	Average (%)
A1	64.29	85.71	21.43	21.43	48.21
A2	64.29	78.57	78.57	85.71	76.79
A3	71.43	92.86	57.14	64.29	71.43
A3.5	71.43	78.57	28.57	42.86	55.36
A4	100.00	92.86	100.00	100.00	98.21
B1	64.29	100.00	28.57	64.29	64.29
B2	57.14	57.14	7.14	0.00	30.36
B3	85.71	100.00	35.71	42.86	66.07
C1	50.00	92.86	0.00	7.14	37.50
C2	78.57	71.43	0.00	7.14	39.29
C3	71.43	78.57	35.71	64.29	62.50
D2	100.00	100.00	50.00	42.86	73.21
Average	62.76*	73.47*	31.63*	38.78*	

(* $p < 0.05$).

was shown in a large Chinese study with 15,836 metal ceramic crowns comparing the selected color of the crown with the adjacent teeth.[32] They found that 64.47% of the restorations were matched by Vita A, 15.85% by Vita B, and 19.68% by Vita C and D. The five most used colors (A2, A3, B2, A1, and A3.5) alone covered 73.85%. Another study evaluating the selected shades for 2,500 metal ceramic crown showed that 43% of the selected shades were in the A hue range and 25% in the B hue range.[33] Furthermore, it has been shown that the standard of judgment for color discrimination was made first in terms of hue, second in terms of value, and third in terms of chroma,[34] which supports the concept of having two groups according to hue. Therefore, systems that help improve the accuracy of selecting, especially those shades that closely correspond to natural teeth, would be beneficial.

The light source, as well as the environment, influences the quality and the intensity of light.[21,35] Daylight was initially found to be just as good as artificial lightning sources for color matching,[36] but is now disregarded due to its inconstant color characteristics. The color temperature of daylight varies between 1,000 K on a dusty sunset to more than 20,000 K when the sky is blue. The spectral energy distribution also varies, with a greater intensity at blue wavelengths when the sky is blue to a greater intensity in the red-orange wavelengths at sunset. Furthermore, the relative intensity also fluctuates depending on the degree of clouds from below 1,000 lx, meaning as little as 200–300 lx inside to more than 100,000 lx on a sunny day.[37] However, the MASTER TL-D 90 Graphica 58W/950 SLV light tube (Philips) combined with the neutral grey background with 18% reflectance (Kodak Gray cards, Kodak) should have given the participants optimum conditions for shade matching.

The CIEDE2000 formula is an approximation and is, therefore, not accurate enough to be used alone. In addition, 50% of people cannot tell a difference between

TABLE 5. ΔE2000 DATA FOR THE VITA CLASSICAL SHADE GUIDE AND THE INDIVIDUAL COMPOSITE SHADE GUIDE MADE OF FILTEK SUPREME XT.

Vita classical guide		Composite guide	
Color	ΔE2000	Color	ΔE2000
B1	0.0	B1	0.0
A1	1.6	A1	2.9
C1	3.3	A2	5.2
B2	3.3	B2	6.0
A2	5.2	C1	7.6
D2	5.7	A3	7.8
C2	6.5	B3	9.7
B3	8.2	D2	10.2
A3	8.6	C2	10.5
C3	9.1	A3.5	11.6
A3.5	9.1	C3	12.9
A4	12.0	A4	14.5

TABLE 6. DISTRIBUTION OF SHADE MATCHES SUMMARIZED FOR SG1 AND SG2.

Color	B1B	A1B	A2B	B2B	C1B	A3B	B3B	D2B	C2B	A3.5B	C3B	A4B
B1B	36	10		1								
A1B	7	40										
A2B			33	18	5	4		1				
B2B			12	27	1	1						
C1B			1		32		2				1	
A3B				3	6	40	2		4	4		
B3B	7				2		45				7	
D2B					1			46				
C2B				1	3	3		2	35	5		
A3.5B						2	1		7	38	2	2
C3B								1	1		39	
A4B									3	3	1	48

two colors if the ΔE2000 value between them is less than one,[38] alternatively two,[18] depending on which study you look at. This means you can get an overall picture of the arrangement, but it has to be visually confirmed. Furthermore, the manufacturer of the existing shade guides did not originally use the proposed arrangement principle. Therefore, the advantages of the proposed arrangement can only fully be observed and judged using a new standard designed according to this model.

The capability of selecting the correct tooth shade has been considered gender dependent.[39] Furthermore, is has been stated women have fewer color vision deficiencies.[8] This could not be confirmed in the present study. Instead, the shade matching abilities were nearly equal. This is supported by other studies showing that dental shade color discrimination is nearly equal between genders.[40]

Studies have shown, that with age, the cornea and the lens becomes yellowed,[41] affecting refraction of the lens for red (increases) and blue light (decreases) in many individuals from around 40 to 50 years of age.[42] However, this does not seem to have any significant effect.[28,43] Age was in the present study found not to be significant, but the age range of the tested men and women was only 23 to 33 years.

The colors B2, C1, C2 and A1 all on average had below 50% correct matches. Other studies have confirmed this problem with identifying the Vita C colors.[28] This, and the fact that you are more prone to select a color with a large difference in ΔE2000 value, when using a ceramic shade guide, should be taken into consideration when choosing color.

CIElab values are measured spectrophotometrically; however, there

TABLE 7. DISTRIBUTION OF SHADE MATCHES SUMMARIZED FOR SG3 AND SG4.

Color	B1B	A1B	A2B	B2B	C1B	A3B	B3B	D2B	C2B	A3.5B	C3B	A4B
B1B	23	23								1	1	
A1B	24	12		1	1						1	
A2B		15	3					1		1		
B2B				4	4			2				
C1B			20	43	41	5		1	5			
A3B			6		1	23						
B3B			3			2	4	2	1			
D2B	3		1					23	2	1		
C2B			16	2	3	7	9	3	30		2	
A3.5B			1			4	4			24		
C3B						5	14	18	4	11	20	
A4B						4	19		8	12	26	50

is a sensitivity toward the method used.[44] Two standard illuminants are recommended,[45,46]but it has been reported that the changes in optical properties of composite resins relative to the varied illuminants were different from those of dentin.[47] The most appropriate choice depends upon application,[47] and D65 is recommended as the preferred reference illuminant.[48] ISO also uses D65 for all colorimetric calculations requiring representative daylight.[45] Vita Easyshade complies with these recommendations.

The characteristic of the surface and the shape of the objects being used as controls could represent a problem. The influence of tab and disk design on shade matching of dental porcelain shade guides has shown that the shape of the object does not play a major role.[49] Nevertheless, the tab-shaped specimens and the individual composite guide were made with the help of a silicone impression in order to eliminate any possible effects. Regarding surface characteristics, a study has shown an effect of finishing and polishing of resin composites, with a tendency for the composite samples to become lighter after polishing.[50] This study also suggested a custom-made shade guide based on the polishing and finishing regimen that each individual dentist uses, due to the fact that the mean color difference after polishing were significantly greater ($p \leq 0.01$) than for the controls, ranging from 1.08 to 8.15 ΔE units.

It could represent a problem that the Vitapan Classical shade guide uses multiple colors and layers. However, the middle part of the shade tab should still represent the color indicated on each shade tab. Nevertheless, a study have examined 25 Vitapan Classical shade guides and concluded that "*this large variation in what are claimed as identical shade tabs is deemed of clinical importance, and therefore, the shade guides should not be considered interchangeable*".[51] Therefore, composite with different batch numbers were used in the present study in order to avoid any effect of varying differences in the color composition of the composite. Using a single color should also minimize any differences due to layering. However, further studies need to be undertaken, especially clinical studies using real teeth.

Previous studies matching the shade tabs from 2 Vitapan Classical shade guides to each other have shown results varying from 69%,[17] 48%,[52] to 46%.[39] When comparing the two composite guides to each other an average of 63% (Table 4) was obtained when using the same arrangement principle as in the Vitapan Classical shade guide. This value is comparable to the values obtained with the two Vitapan Classical shade guides further emphasizing the importance of the shade guide and restorative material being made of the same material.

Due to the choice of colors, excluding B4, C3, D3, and D4, and that only Filtek Supreme XT® was tested the arrangement principle has to be evaluated using other shade guides and other composite materials. Nevertheless, one must assume that the same theoretical arrangement principle would apply to other shade guides.

CONCLUSION

1. A composite shade guide is more predictable compared to the Vitapan classical shade guide concerning composite test objects. Therefore, if using composite, a shade guide fabricated of the composite itself is recommended.
2. A rearrangement of the shade guide according to hue, subdivided according to ΔE2000, significantly reduces the time needed to take a color sample.
3. Gender was only significantly associated with the time used.

CLINICAL IMPLICATIONS

Total color difference in relation to the lightest tab with hue group division is recommended as a possible and universally applicable mode of tab arrangement in dental color standards. Moreover, a shade guide made of the composite materials itself is to be preferred as both a faster and more accurate method of determining color. If not using a composite shade guide, it is advisable to use a composite mock-up to confirm the choice of color.

INTEREST

The shade guides was sponsored by VITA Zahnfabrik, Bad Sackingen, Germany and the composite (Filtek Supreme XT) was sponsored by 3 M ESPE, Glostrup, Denmark.

DISCLOSURE

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

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Reprint requests: Niels Østervemb, ••, Department of Dental Pathology, Operative Dentistry and Endodontics, Address: Aarhus School of Dentistry, Vennelyst Boulevard 9, 8000 Aarhus, Denmark; Tel: +45 28900237; Fax: +45 86202202; email: niels@composite-cosmetics.com

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