Fluorescence of Layered Resin Composites

YONG-KEUN LEE, DDS, PhD*
HUAN LU, DDS, PhD†
JOHN M. POWERS, PhD‡

ABSTRACT

Background: Fluorescence is the absorption of light by a substance and the spontaneous emission of light in a longer wavelength within 10^{-8} seconds of activation.

Purpose: The purpose of this study was to determine the differences in fluorescence among layered resin composites with a color-measuring spectrophotometer.

Materials and Methods: Spectral reflectance and color of five brands of resin composites were measured over a white standard tile according to the Commission Internationale de l'Eclairage (CIE) CIELAB color scale relative to the standard illuminant D65. Human dentin was used as a control; five specimens were made for each group and each specimen was measured three times. An ultraviolet (UV) filter was inserted or removed to exclude or include the UV component of illumination. From the spectral reflectance values, subtraction spectrum by the inclusion and exclusion of the UV component was calculated.

Results: Dentin showed a fluorescence peak around 440 to 450 nm. Three of the five resin composites showed fluorescence peaks, and the peak wavelength was 440 to 450 nm. Peak height and peak area varied by the composite. Changes in color (ΔE^*_{ab}) caused by the UV component were 1.58 to 2.35, and Δb^* values were from −2.20 to −1.49 in composites that showed fluorescence peaks.

CLINICAL SIGNIFICANCE

Since the UV component of light can brighten a fluorescent substance such as human dentin, color differences between human dentin and nonfluorescent composites might be more apparent when viewed under UV light. Some commercial composites were found to exhibit fluorescence.

(*J Esthet Restor Dent* 17:93–101, 2005)

Luminescence is a general term that describes any process in which energy is emitted from a substance at a different wavelength from that at which it is absorbed. It covers fluorescence, phosphorescence, and triboluminescence. Fluorescence by definition is the absorption of light by a substance and the spontaneous emission of light in a longer wavelength within 10^{-8} seconds of activation.[1] In dentistry it has been traditionally assumed that fluorescence is the absorption by a substance of ultraviolet (UV) light (black light) and the emission of visible light in the bluish spectrum. Substances could also absorb

*Associate professor, Department of Dental Biomaterials Science, College of Dentistry, Seoul National University, Seoul, Korea
†Assistant professor of Oral Biomaterials, Department of Restorative Dentistry and Biomaterials, Houston Biomaterials Research Center, The University of Texas Dental Branch at Houston, Houston, TX, USA
‡Professor, Department of Restorative Dentistry and Biomaterials, and director, Houston Biomaterials Research Center, The University of Texas Dental Branch at Houston, Houston, TX, USA

shorter-wavelength visible light and emit it as longer-wavelength visible light. Thus, many forms of fluorescence are possible.[2]

Natural teeth emit a strong blue fluorescence under the action of UV light. This property makes teeth whiter and brighter in daylight. In human enamel three distinct luminescence peaks have been found in the region of 350 to 360, 405 to 410, and 440 to 450 nm.[3] The fluorescence spectrum of natural enamel has the shape of a wide band whose maximum is at 450 nm and slowly decreases to 680 nm.[4] When human dentin was irradiated with 365 nm light, blue fluorescence was observed with a peak at 440 ± 10 nm.[5]

Ideal restorative materials should have similar properties of light reflection, scattering, and fluorescence as those of natural teeth. If they are absent, the esthetic qualities of the restorations suffer under UV illumination. The fluorescence spectrum of anterior restorative materials has been found to vary by material.[6] Many of the porcelain teeth and powders have strikingly different luminescence characteristics from those of natural teeth.[7] Fluorescence has been detected in some white standard tiles intended for the calibration of spectrophotometers.[8]

Recently the use of resin composites for the restoration of large defects in anterior teeth has been increasing, and layered resin composites with opaque dentin and translucent enamel shades are widely promoted for this purpose. These resin composites are used in direct restorative techniques that use layering to mimic the natural layering of dentin and enamel.[9] Since these composites are used for the restoration of large areas, fluorescent properties are important, as in dental ceramics.

Although fluorescence of teeth and dental porcelain has been measured previously, there have been few trials to evaluate the fluorescence of resin composites. Some commercial resin composites are claimed by the manufacturers to have toothlike fluorescence. The purpose of this study was to determine the difference in fluorescence of layered resin composites with a color-measuring spectrophotometer and to compare the fluorescence with that of human dentin. The hypothesis was that the fluorescence of several commercial resin composites was the same as that of human dentin.

MATERIALS AND METHODS

Five layered resin composites with a total of nine shades were studied (Table 1). Specimens 10 mm in diameter and 2 mm thick were made with a polytetrafluoroethylene mold. Five specimens were made for each shade of composite. Five sound human dentin specimens were measured as controls. Spectral reflectance and color coordinates were measured according to Commission Internationale de l'Eclairage (CIE) CIELAB color scale relative to the standard illuminant D65 (Figure 1) over a white standard tile (Reference White Standard, Instrumental Serial No. 71060147K, GretagMecbeth Instruments Corp., Newburgh, NY, USA; CIE $L^* = 94.28$, $a^* = -0.40$, and $b^* = 1.34$) on a reflection spectrophotometer (Color-Eye 7000, GretagMecbeth Instruments Corp.). A UV filter was inserted or removed to exclude or include the UV component of illumination. The aperture size was 3 × 8 mm. Illuminating and viewing configurations were CIE diffuse/10° geometry.[10] Measurements were repeated three times for each specimen.

From the spectral reflectance values, the difference in reflectance by the inclusion and exclusion of the UV component was calculated. With the following calculations, subtraction spectra were obtained. Preliminary subtraction spectrum from 410 to 750 nm (ie, the reflectance spectrum obtained with the UV-excluded condition subtracted at each wavelength from the reflectance spectrum obtained with the UV-included condition) was obtained. To eliminate the bias in illumination by the inclusion or exclusion of the UV component, the difference in reflectance spectrum at each wavelength of the white standard tile by the inclusion or exclusion of the UV component was subtracted from the preliminary subtraction spectrum at each wavelength. Peak wavelength, height,

TABLE 1. MATERIALS USED IN THIS STUDY.

Product	Composition	Shade	Batch No.	Manufacturer
Filtek Supreme	58–60 vol% (78.5 wt%) filler of primary particle size of 5–20 nm	A2E	3AF	3M ESPE, St. Paul, MN, USA
		A2B	3AR	
		A2D	3AC	
		Gray translucent (GT)	2AA	
Gradia Direct	64–65 vol% filler	A2	0305132	GC America, Alsip, IL, USA
		AO2*	030421	
Simile	68 vol% filler	A2	77325	Pentron Clinical Technologies, Wallingford, CT, USA
Palfique Estelite	71 vol% (82 wt%) filler of 0.2 μm	A2	YE61192	Tokuyama Dental Corp., Tokyo, Japan
Vit-l-escence	58 vol% (75 wt%) filler of 0.7 μm	A2	56V4	Ultradent Products, South Jordan, UT, USA

vol = volume; wt = weight.
*AO shade is an incisal special shade.

and peak area (410–550 nm) were calculated. Differences in color (ΔE^*_{ab}) and color coordinates (ΔL^*, Δa^*, and Δb^*) by the inclusion or exclusion of the UV component were calculated, where ΔL^* is the change in lightness, Δa^* is the change in red-green parameter, and Δb^* is the change in yellow-blue parameter.

In the present study, dentin was used as the reference because dentin has shown a three times higher intensity of fluorescence than enamel, and the peak wavelength has been reported to be the same as that of enamel.[4] Practically, it was hard to make enamel specimens larger than 3 × 8 mm, and the thickness of enamel was reported to influence the fluorescence, which was similar to the report that the cementing medium affected the fluorescence of a ceramic prosthesis.[4]

Differences in the values by composite were analyzed by analysis of variance and Scheffe's multiple range test (SPSS 11.0, SPSS, Chicago, IL, USA; $p = .05$). Regression analyses were made between the difference in color and the difference in color coordinates by the inclusion or exclusion of the UV component, and between the peak area or peak height and differences in color and color coordinates by the inclusion or exclusion of the UV component ($p = .05$).

RESULTS

Subtraction spectra of the white standard tile and human dentin caused by the UV filter are shown in Figure 2. For the white tile, differences in spectra were negligible in visible light range, whereas dentin showed a clear peak around 440 to 450 nm.

Subtraction spectra of resin composites are shown in Figure 3. Four of nine specimens showed peaks, and the peak wavelength was observed at 440 to 450 nm. Properties of the measured fluorescence peaks are listed in Table 2. Vit-l-escence (VIT) showed the largest peak height followed by Gradia Direct (GRA)-AO2, GRA-A2, and Simile

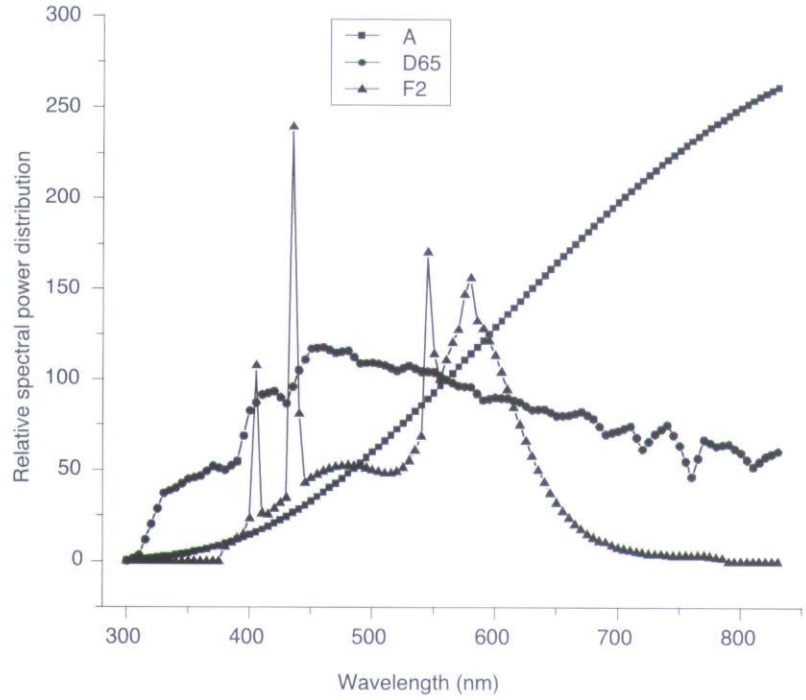

Figure 1. Relative spectral power distribution of Commission Internationale de l'Eclairage (CIE) standard illuminants D65, A, and F2.

(SIM) ($p < .05$). VIT showed the largest peak area followed by GRA-AO2, GRA-A2, and SIM ($p < .05$). Subtraction spectra of resin composites without fluorescence peaks are shown in Figure 4. The pattern was similar in Filtek Supreme (FSP) composites, regardless of the difference in shade designations.

Changes in color (ΔE^*_{ab}) and the CIE b* value are shown in Figure 5. In dentin the ΔE^*_{ab} value was 0.73 $\pm$ 0.04 and the Δb^* value was -0.10 $\pm$ 0.03. In composites that showed peaks, ΔE^*_{ab} values were 1.58 to 2.35 and Δb^* values were from -2.20 to -1.49. In composites that did not show a peak, ΔE^*_{ab} values were 0.15 to 0.78 and Δb^* values were from -0.10 to 0.15. ΔE^*_{ab} values of VIT and GRA were significantly higher than those of FSP and Palfique Estelite (PAE), and Δb^* values of VIT and GRA were significantly lower than those of FSP and PAE ($p < .05$). The correlation coefficient between two values of ΔE^*_{ab} and Δb^* was -0.77 in composites that showed peaks ($p < .05$). ΔE^*_{ab} and Δb^* values were very small in composites that did not show fluorescence peaks.

From regression analysis of composites that showed fluorescence peaks, the correlation coefficient between the peak area and peak

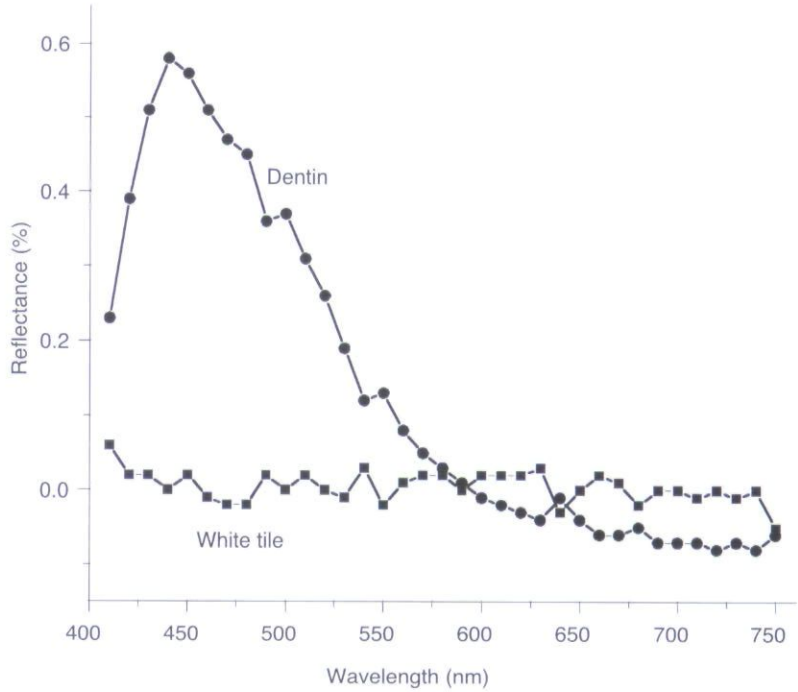

Figure 2. Subtraction spectra of white tile and dentin by the inclusion or exclusion of the ultraviolet component (100% reflectance means total reflectance).

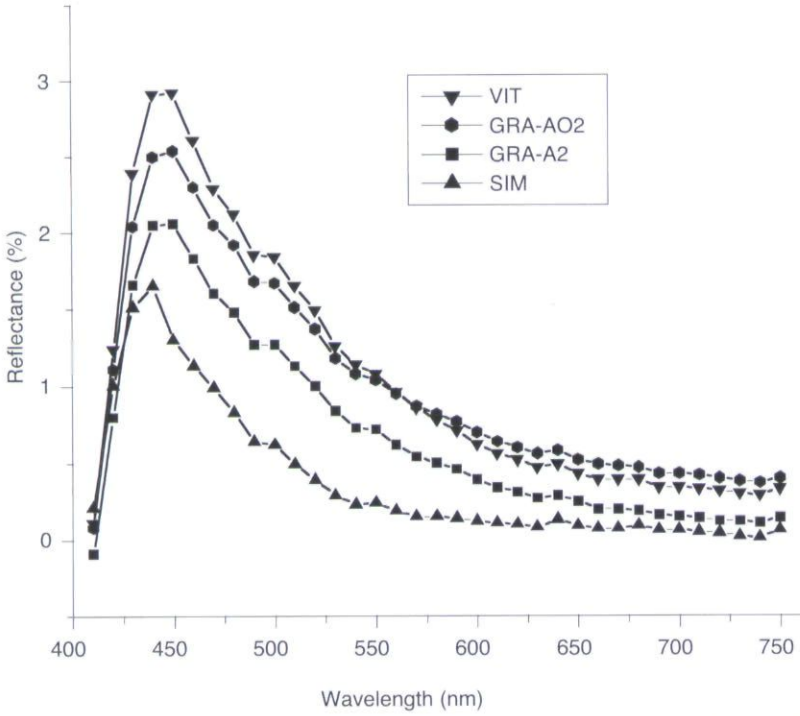

Figure 3. Subtraction spectra of resin composites by the inclusion or exclusion of the ultraviolet component (100% reflectance means total reflectance). GRA = Gradia Direct; SIM = Simile; VIT = Vit-l-escence.

height was 0.97 ($p < .05$). The correlation coefficient between the peak area and the ΔE^*_{ab} value was 0.81, and that between the peak area and the Δb^* value was 0.72 ($p < .05$). The correlation coefficient between the peak height and the ΔE^*_{ab} value was 0.89, and that between the peak height and Δb^* value was 0.83 ($p < .05$).

DISCUSSION

Standard illuminant D65 represents average daylight with a correlated color temperature of approximately 6,500 K.[11] Illuminant D65 contains a strong emission in the UV range compared with standard illuminant A or F2 (see Figure 1). The difference in reflection spectra of teeth was measured between two illuminants (A and D65), and the influence of the UV component of D65 illumination on the color of teeth was found to be insignificant.[12] Color differences of resin composites between the values measured under the standard illuminants A and D65, or A and C, were larger than those between D65 and C.[13] In previous studies exact measurement of fluorescence was impossible because spectral distributions of illuminants were

TABLE 2. PEAK WAVELENGTH, HEIGHT, AND AREA.

Product	Shade	Peak Wavelength (nm)	Peak Height in Arbitrary Units	Peak Area in Arbitrary Units* (SD)
Filtek Supreme	A2E	ND	ND	18.6 (1.5)
	A2B	ND	ND	4.6 (12.9)
	A2D	ND	ND	14.6 (44.4)
	GT	ND	ND	6.4 (36.3)
Gradia Direct	A2	450	2.06 (0.20)	183.7 (30.6)
	AO2	450	2.54 (0.20)	240.4 (28.9)
Simile	A2	440	1.65 (0.39)	115.2 (33.0)
Palfique Estelite	A2	ND	ND	15.8 (25.6)
Vit-l-escence	A2	450	3.04 (0.31)	285.4 (42.8)

ND = not detectable.
*Peak area from 410 to 550 nm.

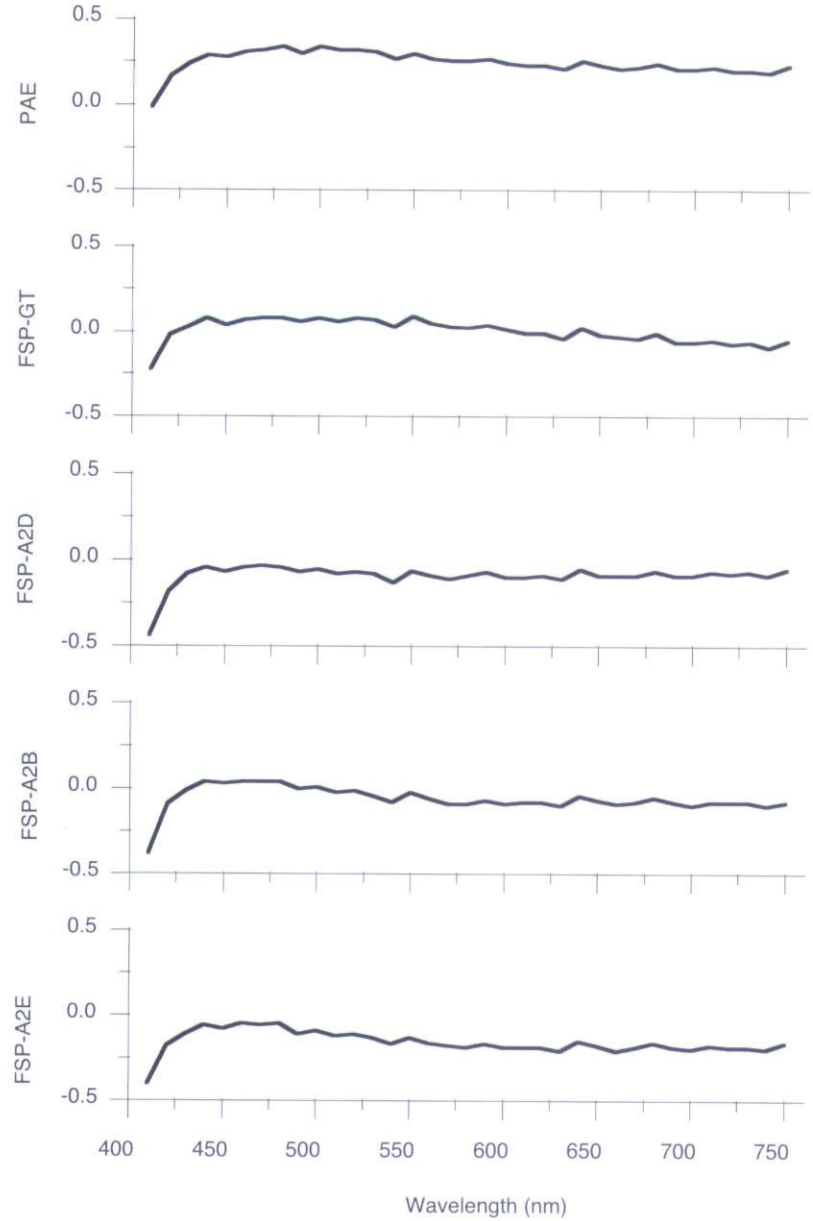

Figure 4. Subtraction spectra of resin composites by the inclusion or exclusion of the ultraviolet component (unit of y-axis = Δreflectance [%]). FSP = Filtek Supreme; PAE = Palfique Estelite.

different in visible range as well as in UV range.

Previous studies used fluorescence spectrophotometers to measure the fluorescence. They usually used single wavelength for the emission of fluorescence. However, since the ambient light is not a monochromatic light, the use of the UV component of the standard illuminant D65 has clinical relevance. The technique used in the present study was a new technique for fluorescence measurement of dental materials, which used a spectrophotometer with an adjustable UV filter.

The difference in spectral reflectance can be regarded as the fluorescence of substance excited by the UV component of the standard illuminant D65. Illuminant D65 contains relative spectral power of 37 to 69% in the wavelength range of 330 to 395 nm.[14] To induce fluorescence of dentin, UV light of 365 nm (or 363.8 nm) has generally been employed.[4,5] Therefore, the UV light emitted from the illuminant D65 can excite the fluorescence of dentin. After excitation, dentin showed blue fluorescence in a peak at 440 ± 10 nm,[5] or 430 nm.[4] In the present study, dentin showed peak intensity at 440 nm, and the subtraction spectrum (fluorescence) had a wide band form, which is similar to those of previous studies. Subtraction spectrum of white standard tile showed negligible values (−0.03–0.06% in wavelengths > 410 nm). Therefore the white tile of the present study showed no fluorescence despite the fact that some white standard tiles showed fluorescence.[8]

The difference in reflection spectra of tooth between the values measured under illuminations A and D65 showed no evidence of a contribution of fluorescence to tooth color in spectra or color coordinates.[12] Since standard illuminant A is different from D65 in visible

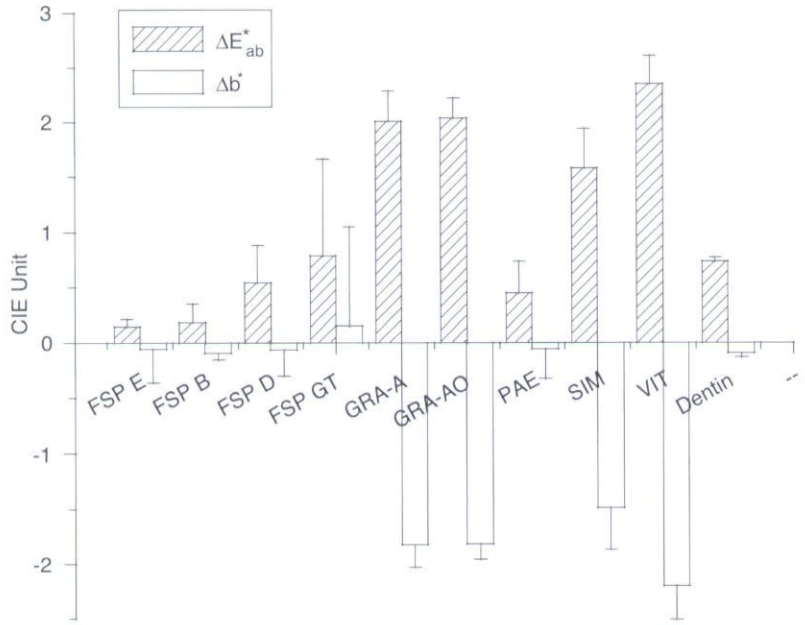

Figure 5. Values of ΔE^*_{ab} and Δb^* by the inclusion or exclusion of the ultraviolet component. CIE = Commission Internationale de l'Eclairage; FSP = Filtek Supreme; GRA = Gradia Direct; PAE = Palfique Estelite; SIM = Simile; VIT = Vit-l-escence.

range as well as UV range, the result of a previous study may not have measured fluorescence accurately. In the present study, color differences (ΔE^*_{ab}) of fluorescent resin composites were 1.6 to 2.4. Although these values are lower than the generally considered clinically perceptible limit of 3.3,[15] the characteristics of fluorescent emission may be different from those of visible light. The fluorescence of a tooth makes an important contribution to its appearance, even though it is not as apparent in daylight. Therefore, perceptibility of fluorescent emission under varied illumination conditions should be studied further.

Δb^* values were from −2.20 to −1.49 in composites that showed peaks. This means color of resin composites moved to the blue direction as a result of fluorescent emission. ΔE^*_{ab} and Δb^* values of dentin were low, and the magnitude was similar to those of nonfluorescent resin composites. Dentin showed fluorescence; however, the amount was lower than those of fluorescent resin composites (peak height: 0.58 vs 1.65–3.04). Therefore, the changes in color and b* values caused by the UV component were similar to those of nonfluorescent composite materials.

In fluorescent resin composites, the peak area and peak height had significant correlation, which means that wavelength of fluorescent emission of resin composites gathered around the peak. Color differences resulting from UV components were mainly caused by the fluorescent emission (peak area) (r = .81).

Fluorescence of anterior restorative materials was measured previously with a spectrophotometer with a fluorescent attachment.[6] The results varied for silicate cement, acrylic resin, and resin composites, and resin composites showed fluorescence peaks around 450 nm.[6] However, quantitative comparison with the results of the present study was impossible because the method was different.

Three of five resin composites tested showed fluorescence. Peak wavelengths were within the same range; however, peak heights and areas were different among the composites. These composites showed higher peak heights than that of dentin. Although there have been quantitative studies on the sequential changes of autofluorescence of dentin,[5,16] there have been few studies on the quantity of fluorescence of dental materials. In dental porcelain a fluorescent material called luminary is used to brighten dark teeth without negatively affecting the translucency.[2] Resin composites with higher fluorescence may be used to mask the darkness of tooth. In this aspect, resin composites with higher fluorescence have clinical merit.

From the present study, the fluorescence of resin composites was measured with a color-measuring

spectrophotometer using a new technique. Some commercial resin composites showed fluorescence, and the others did not. The influence of surface sealants and the addition of new fluorescent substances into materials on the change of fluorescence should be studied further.

DISCLOSURE

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

REFERENCES

1. Nassau K. Color for science, art and technology. New York: Elsevier, 1998.
2. McLaren EA. Luminescent veneers. J Esthet Dent 1997; 9:3–12.
3. Spitzer D, ten Bosch JJ. The total luminescence of bovine and human dental enamel. Calcif Tissue Res 1976; 20:201–208.
4. Monsenego G, Burdairon G, Clerjaud B. Fluorescence of dental porcelain. J Prosthet Dent 1993; 69:106–113.
5. Matsumoto H, Kitamura S, Araki T. Autofluorescence in human dentine in relation to age, tooth type and temperature measured by nanosecond time-resolved fluorescence microscopy. Arch Oral Biol 1999; 44:309–318.
6. Panzeri H, Fernandes LT, Minelli CJ. Spectral fluorescence of direct anterior restorative materials. Aust Dent J 1977; 22:458–461.
7. Wozniak WT, Moore BK. Luminescence spectra of dental porcelains. J Dent Res 1978; 57:971–974.
8. Pons A, Compos J. Spectrophotometric error in color coordinates introduced by fluorescence of white calibration tile. Color Res Appl 2004; 29:111–114.
9. Farah JW, Powers JM. Layered resin composites. Dental Advisor 2003; 20(7):1–4.
10. Brodbelt RH, O'Brien WJ, Fan PL, Frazer-Dib JG, Yu R. Translucency of human dental enamel. J Dent Res 1981; 60:1749–1753.
11. International Standardization Organization. CIE standard illuminant for colorimetry. Geneva: ISO, 1999. ISO 10526:1999(E), CIE S 005-1998.
12. ten Bosch JJ, Coops JC. Tooth color and reflectance as related to light scattering and enamel hardness. J Dent Res 1995; 74: 374–380.
13. Lee YK, Lim BS, Kim CW, Powers JM. Color characteristics of low-chroma and high translucency dental resin composites by different measuring modes. J Biomed Mater Res 2001; 58:613–621.
14. Commission Internationale de l'Eclairage. Colorimetry—technical report. 2nd Ed. (Corrected reprint 1996) Vienna: Bureau Central de la CIE, 1986. CIE Publication No.: 15.
15. Craig RG, Powers JM. Restorative dental materials. 11th Ed. St. Louis: Mosby, 2002.
16. Kvaal S, Solheim T. Fluorescence from dentin and cementum in human mandibular second premolars and its relation to age. Scand J Dent Res 1989; 97: 131–138.

Reprint requests: Yong-Keun Lee, DDS, PhD, Department of Dental Biomaterials Science, College of Dentistry, Seoul National University, 28 Yeongeon-dong, Jongro-gu, Seoul, Korea; e-mail: ykleedm@snu.ac.kr

COMMENTARY

FLUORESCENCE OF LAYERED RESIN COMPOSITES

Ralph DeLong, DDS, MS, PhD*

The whiteness, brightness, and vitality of natural teeth are often attributed to the fluorescence of dentin. Therefore, for maximum esthetics, it is generally accepted that a restorative material should duplicate this natural fluorescence. In this study, the authors investigated the fluorescence properties of five different resin composites using human dentin as the control. An object's color is highly dependent on the light source. To address this, the authors elected to use a standard D65 illuminant. This light source approximates the spectrum of average daylight, has a strong UV component, and is more clinically relevant than other standard light sources or monochrome UV light sources. The authors' method also differs from other methods in that they used a spectrophotometer with an adjustable UV filter to either include or remove the UV wavelengths from the D65 illuminant. This enabled them to calculate the fluorescence spectral reflectance and changes in CIELAB color coordinates by subtracting spectrums with and without the UV wavelengths.

Variations in the tested resin composites ranged from those with no fluorescence to those with high fluorescence. What is interesting is that if one accepts that changes in the CIELAB ΔE^* coordinate of < 3 are not clinically perceptible, then under a D65 light source, there is effectively no perceptible difference in any of the resin composites. In fact, the resin composites without fluorescence had CIELAB coordinates closer to those of natural dentin than did the resin composites with fluorescence. This raises the question of whether fluorescence really has any esthetic significance under natural light.

Change the light source, however, and you can have a totally different outcome. As an example, in my youth, while on a cave-touring excursion, I remember the guide saying that she was going to show the fluorescence of the rock formations using a black light, and that anyone with artificial teeth should keep their mouth closed because the black light would make their teeth glow. When she turned off the incandescent lights and turned on the black light, amongst the "oohs" and "aahs" I heard my mother yell at my dad to close his mouth. I turned to look, and saw this wonderful array of bright green teeth. Put in perspective, under a UV light source, which is not uncommon today, the resin composites examined in this study give one the choice of bright teeth with glowing restorations or bright teeth with dull or dark restorations. Neither provides an esthetic choice. At least my dad's Cheshire Cat grin was esthetically appealing from an artistic point of view.

This example only emphasizes the authors' concluding remarks that more investigation is needed. In fact, as a first step, we should understand what component of natural teeth is responsible for the fluorescence, and then try to mimic that component in the restorative material.

*Professor and chair, Department of Restorative Sciences, and director of the Minnesota Dental Research Center for Biomaterials and Biomechanics, University of Minnesota School of Dentistry, Minneapolis, MN, USA