DENTAL MATERIALS 34 (2018) 819–823

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

# The effect of ultraviolet induced fluorescence on visually perceived tooth color under normal light conditions

*Sascha Hein*[a,*], *Jaap J. ten Bosch*[b]

[a] *Private dental laboratory, Freiburg im Breisgau, Germany*
[b] *University of Groningen, The Netherlands*

ARTICLE INFO

*Article history:*
Received 20 January 2018
Accepted 19 February 2018

*Keywords:*
Tooth color
Fluorescence
Optical properties
Dental

ABSTRACT

*Objective.* Restorative and prosthetic materials should provide an appearance similar to natural teeth under all light conditions, including UV-rich environments and daylight. Various studies claim that UV-induced fluorescence makes teeth whiter and brighter in daylight. The aim of this paper is to determine experimentally the significance of tooth fluorescence in natural sunlight on perceived tooth color.

*Methods.* A total of 35 extracted, hydrated teeth without restorations or endodontic treatments were evaluated in an experimental setup. A UV/VIS spectrometer using a reflectance/backscattering probe was used to collect the reflected spectrum. Unfiltered and filtered sunlight was used for irradiation of the samples so as to use the combined ultraviolet and visible spectrum (UV/VIS) and the visible spectrum (VIS) exclusively. Color coordinates for each group were measured using the CIE $L^*a^*b^*$ 1976 system, averaged, and compared.

*Results.* The average color difference between both groups (UV/VIS and UV) was $\Delta E^*$ 0.527. The average tooth color for the VIS group was $L^*_{VIS}$ 72.21, $a^*_{VIS}$ −2.42, and $b^*_{VIS}$ 22.35, and for the UV/VIS group was $L^*_{UV/VIS}$ 72.00, $a^*_{UV/VIS}$ −2.47, and $b^*_{UV/VIS}$ 22.44.

*Significance.* UV induced fluorescence from sunlight does not make teeth whiter and brighter.



## Contents



* *Corresponding author at*: Rennweg 17, 79106 Freiburg i.Br., Germany.
E-mail address: saschachristianhein@me.com (S. Hein).

https://doi.org/10.1016/j.dental.2018.02.007
0109-5641/

## 1. Introduction

Fluorescence, by definition, is the absorption of light by a substance and the spontaneous emission of light in a longer wavelength, within $10^{-8}$ s of activation. After the absorption of a photon, an electron of the fluorophore is excited to a higher energy level. After a slight relaxation due to vibrational and rotational energy losses within the excited state, the electron falls to its ground state, thereby releasing a photon. The vibrational and rotational energy is released as heat. Thus, the photon has a slightly lower energy than that which caused the excitation [1].

There are 3 types of tooth fluorescence: blue fluorescence, which is excited in the near ultraviolet (UV) region; yellow/orange fluorescence, which is excited by the blue and green wavelengths; and fluorescence in the far red and near infrared [2,3]. Yellow–orange fluorescence can be used for the diagnosis of dental caries [4]. Blue fluorescence, which is excited by near ultraviolet radiation, is relevant in the optical appearance of teeth. This type of fluorescence is clearly visible under illumination that is relatively rich in ultraviolet radiation. It is therefore of importance to a large part of the general public who visit environments such as nightclubs and entertainment shows [5]. Accordingly, because restorative and prosthetic materials should provide an appearance similar to natural teeth, the fluorescence of such materials is also very important, and consequently much research has been devoted to this field [1].

There is a widespread belief that ultraviolet-induced fluorescence in daylight noticeably affects tooth color [6–12]. Although studies [1,14] using the standard illuminants A and D65 as defined by the International Commission on Illumination (Commission Internationale de'L'eclairage, or CIE) [15] did not provide evidence for an influence of fluorescence induced by daylight, such studies were only artificial as sunlight was not used.

The aim of this paper is to determine experimentally the significance of tooth fluorescence in natural sunlight on perceived tooth color.

## 2. Materials and methods

### 2.1. Specimen selection

A total of 78 extracted teeth were obtained from a private periodontal surgery in Perth, Western Australia over a period of 12 months. Immediately after extraction, the teeth were stored in 10% buffered formalin. Teeth containing restorations, endodontic treatment, or having caries lesions were excluded from the study. Four intact mandibular anteriors were considered too small in size to yield accurate measurement results and were hence excluded. Thirty-five remaining teeth were included (Table 1). All suitable specimens were cleaned and stored in distilled water at 4 °C. The apical tips were cut off.

### 2.2. Standardization

To allow for standardized evaluations, a small disc (WS-1-SL, Ocean Optics, Dunedin, FL, USA) made of white, non-fluorescing, and diffusely reflecting packed polytetrafluoroethylene (PTFE) was used. For precise repositioning, all samples and the holder were fixed to acrylonitrile butadiene styrene (ABS) polymer blocks (Brick 2 × 2 and 2 × 4, LEGO, Enfield, CT, USA) using cyanoacrylate adhesive (Loctite Super Glue Gel, Henkel Australia, Thomastown, VIC, Australia) and cure-catalyst spray (Accelerator Spray, Zirkonzahn, Gais, Italy).

### 2.3. Color measurements in sunlight

In order to obtain color measurements using sunlight, a custom-made box (Fig. 1) was built with an open top that could be completely covered with either of two filters. The bottom of the box was lined with an ABS polymer grid (Item 626, LEGO, Enfield, CT, USA). A 5.0-mm-thick sheet of clear UV-resistant polycarbonate (Sunlite, Welshpool, WA, Australia) was used as a UV-blocking filter (VIS). The other filter (UV/VIS) was a 6.0-mm-thick UV-grade fused silica window (Knights Optical, Harrietsham, Kent, UK) (Fig. 1) that attenuates the solar spectrum in the same way, but allows passage of the ultraviolet portion of the solar spectrum (Fig. 2).

Reflected emissions including fluorescence were collected by a reflectance/backscattering probe (EOS-676969, Ocean Optics, Dunedin, FL, USA), with a fiber thickness of 600 μm and with an acceptance angle of 25.4°. The other end of the probe was attached to a spectrometer (USB-650 Red Tide, Ocean Optics, Dunedin, FL, USA). The distance from the buccal/labial surface of the teeth or the reflection standard, respectively, was 10 mm.

Measurements were conducted in Perth, Western Australia, under sunlight incidence of approximately 80° to the labial/buccal surface of the specimens between the hours of 12:00 and 13:00 when the UV levels were recorded highest during the day; UV index = 4 (100 mW/m$^2$).

Each tooth was measured with the box covered with the UV-blocking lid and immediately thereafter with the UV-transmitting lid. To detect malfunctions, the instrument was

**Table 1 – A total of 35 teeth were used for the experiment.**

| Maxillary centrals | Mandibular centrals & laterals | Maxillary molars | Mandibular molars | Maxillary premolars | Mandibular premolars | Maxillary canines |
|---|---|---|---|---|---|---|
| 7 | 5 | 5 | 6 | 7 | 4 | 1 |

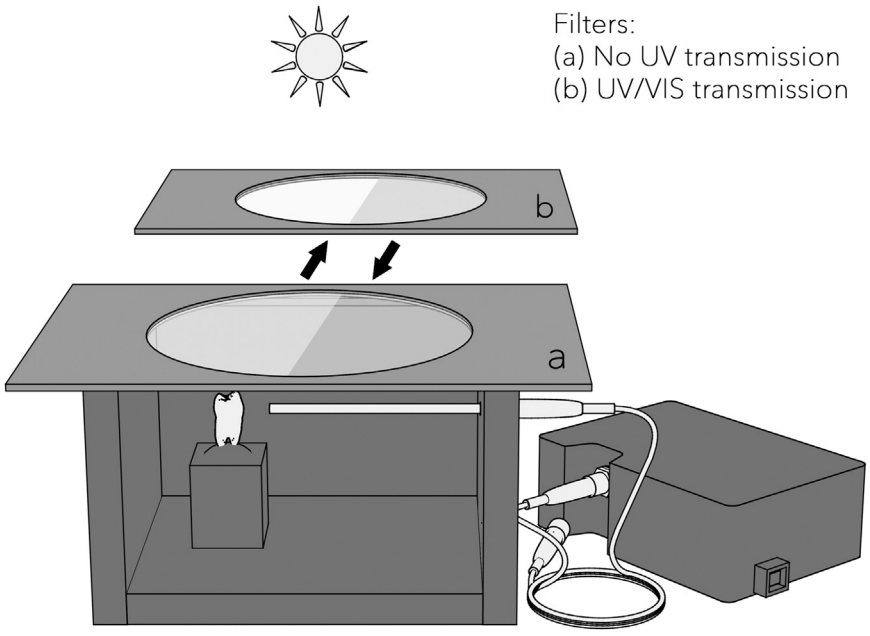


**Fig. 1 – Setting of the experiment where sunlight was used to measure tooth color using a spectophotometer and two interchangeable filters.**

calibrated with the white calibration standard before each of the 2 measurements of each tooth. If measured L*a*b* values of the white standard differed between measurements, due to sudden changes in solar intensity, the measurement cycle was aborted and repeated after a short waiting period. This was necessary in three cases. Each value obtained by the spectrometer was an automatic average of three measurements taken. The teeth were kept hydrated until they were placed in front of the reflectance probe. Measurements of each tooth were carried out rapidly (<1 min) to prevent dehydration.

### 2.4. *Evaluation of the data*

For each tooth, $\Delta E^*$ was calculated from $L^*_{UV/VIS} - L^*_{VIS}$, $a^*_{UV/VIS} - a^*_{VIS}$, and $b^*_{UV/VIS} - b^*_{VIS}$, as described in the CIE prescriptions [15]:

$$\Delta E* = \text{sqrt}[(L*_{UV/VIS} - L*_{VIS})^2 + (a*_{UV/VIS} - a*_{VIS})^2 + (b*_{UV/VIS} - b*_{VIS})^2].$$

The average, standard deviation, and standard error of the mean of all 35 teeth were analyzed.

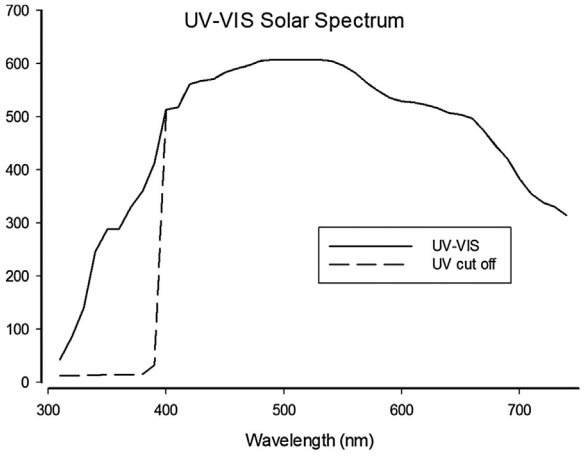


**Fig. 2 – Emission graph showing full spectrum transmission of the fused silica UV VIS filter (continuous line) and the polycarbonate UV cut off filter (dotted line).**

## 3. Results

The color differences $\Delta E^*$ between the UV/VIS and VIS illumination for each tooth were averaged over all 35 teeth, resulting in an average of $\Delta E^* = 0.527$. The standard deviation SD and standard error (SEM = SD/36) of these $\Delta E^*$ values are shown in the second column of Table 2. To provide further information, Table 2 also presents the average tooth color coordinates for each illumination together with the respective values of the SD and SEM. The differences in $L^*$, $a^*$, and $b^*$ values for each tooth between UV/VIS and VIS illumination are not shown in the table. Instead, the values of these differences (using $b^*/10$ rather than $b^*$) are categorized in classes of width 0.2 and the number of teeth is counted in each category. The result is shown in Fig. 3.

## 4. Discussion

Tooth fluorescence is a relevant optical feature of natural teeth. As such, restorative materials should emulate it as faithfully as possible by providing fluorescence in adequate intensity. The distance metric between two colors has been defined as $\Delta E^*$ by the CIE [15]. Based on experimentation, a value of $\Delta E^* = 1.0$ has often been mentioned as the limit for the

**Table 2 – Average, standard deviation and standard error of the mean, as well as the same three quantities of the calculated ΔE*-values between the two situations of illumination.**

| | ΔE* | $L^*_{vis}$ | $a^*_{vis}$ | $b^*_{vis}$ | $L^*_{UV/vis}$ | $a^*_{UV/vis}$ | $b^*_{UV/vis}$ |
|---|---|---|---|---|---|---|---|
| Average | 0.527 | 72.21 | −2.42 | 22.35 | 72.00 | −2.47 | 22.44 |
| SD | 0.200 | 5.88 | 2.55 | 9.20 | 5.82 | 2.57 | 9.24 |
| SEM | 0.035 | 1.01 | 0.44 | 1.58 | 1.00 | 0.44 | 1.58 |

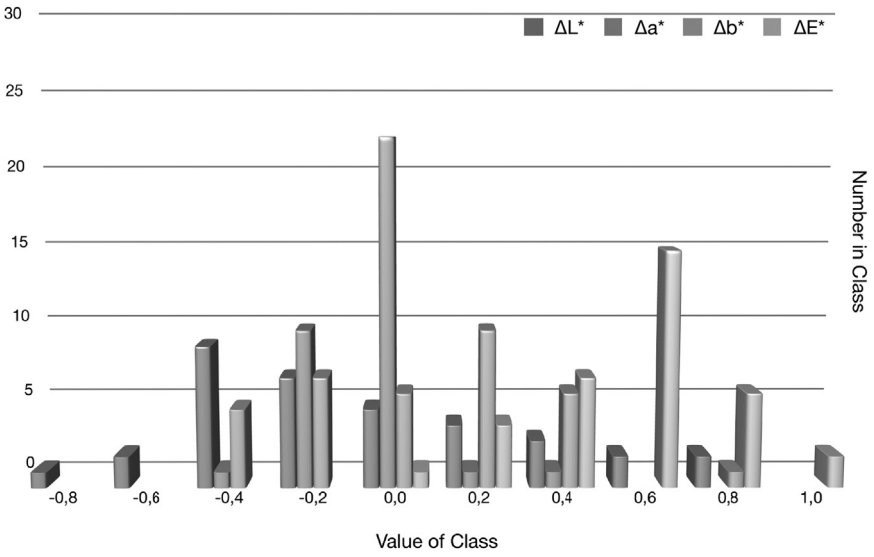


**Fig. 3 – Distribution of values in classes with width of 0,2.**

visually perceivable color metric [16]. In this study, the average tooth color metric as a function of the inclusion and exclusion of the UV spectrum of sunlight was found to be ΔE* = 0.53, which is below the value of 1.0. Only two of the 35 teeth had a ΔE* value of 1.0. In general, the distributions in Fig. 3 show no evidence of any systematic effects in color between the two situations of illumination.

Our study may be compared to two other studies in which no true sunlight was used, but the UV-containing Illuminant D65 or a good simulation thereof. Ten Bosch and Coops compared the colors of 102 teeth under two light sources consecutively, one being a simulated Illuminant D65, the other being an Illuminant A, and concluded that fluorescence plays no role in tooth color [14]. Lee [1] described a study in which Illuminant D65 was used with and without a UV-filter and presented different spectra and ΔE* values for dentine and several restorative materials. The comparison revealed that ΔE* is of the order of 0.3 for dentine.

Quantum yield (Φf) is the direct measure of the efficiency of the conversion of absorbed light into emitted light, which in the case of tooth fluorescence is likely to be too weak to play a visually noticeable role in the color-determining process.

The story of tooth fluorescence in the field of esthetic/cosmetic dentistry is interesting. Despite a lack of evidence, there appears to be a persistent belief that the visually perceivable effects of tooth fluorescence are not merely limited to UV-rich environments, but extend to all light conditions, including daylight. Some authors have reported that the many practical applications of fluorescence in restorative dentistry apparently include blocking out dark stump shades, increasing the value of restorations through luminescence, and minimizing metameric effects between natural tooth structure and restorative materials under various light conditions [17,18].

In the literature prior to 1990, the topic of fluorescence and its relevance for dental esthetics received relatively little attention. Authors of this period were also considerably more careful to distinguish between the effects of tooth fluorescence in UV-rich environments and normal light conditions [19,20]. This seems to have changed in 1993 when Monsénégo et al. suggested that tooth fluorescence makes teeth whiter and brighter in daylight [13] without offering evidence in support of this claim. Subsequently, a type of "fluorescence myth" was established and perpetuated by subsequent authors. Fluorescence began to be perceived as an important requirement for successful esthetic integration of direct and indirect restorations under all light conditions [21,22]. The resulting fashion trend did not go unnoticed by manufacturers who gradually adopted the new paradigm. A recent study by Meller et al. [23] showed that the fluorescence of the majority of tested direct composites noticeably exceeded the fluorescence emission of natural dentine. For one particular product, the measured emission was 4 times stronger than the natural fluorescence threshold for human dentine.

The result of our study may contradict everyday empirical observation, because many restorative materials, including glass ceramics that are labeled as fluorescent by the manufacturers, usually exhibit a vivid bright appearance under normal light conditions. When two variables are found to be correlated, it is tempting to assume that one variable causes the other. This fallacy is known as "*post hoc ergo propter hoc*", or simply "correlation proves causation." It is likely that such

materials owe their bright appearance under normal light conditions not necessarily to the effects of fluorescence, but instead to increased scattering behavior as a consequence of the presence of a combination of cerium and terbium oxide particles together with other rare earth particles that serve as fluorescence activators that are suspended in the glassy matrix and that possess a higher index of refraction (IOR) relative to that of the host matrix, hence acting as opacifiers. The opacity is thus controlled by a difference in the refractive index between the two phases in the glass ceramic, which can be as small as 0.05 from the glass, as well as by other factors, including the particle size of the mineral phases dispersed in the glass and the degree of particle size distribution. The opacity is found to increase as the number of reflecting particles per unit volume increases [24].

A considerable amount of research has been conducted with the aim to better understand the optical properties of natural dentition [25], pointing toward specific absorption and reflection behavior as well as complex dentine scattering acting as the possible main cause of metameric failure between teeth and dental restorations. Other aspects such as refractive index gradients within human enamel [26] as well as increased enamel carbonation as a function of aging affecting enamel translucency [27,28] may play a more relevant role in the appearance of natural teeth under normal light conditions. Dental manufacturers need to continue to improve the optical behavior of dental materials with an increased focus on the emulation of these aspects instead of placing exaggerated emphasis on the relevance of fluorescence under normal light conditions.

## 5. Conclusion

In our study, the UV-induced fluorescence of natural teeth did not influence tooth color under normal daylight conditions.

## REFERENCES


[1] Lee YK. Fluorescence properties of human teeth and dental calculus for clinical applications. J Biomed Opt 2015;20, 040901.

[2] ten Bosch JJ, Zijp JR. Optical properties of dentin. In: Thylstrup A, Leach SA, Qvist V, editors. Dentine and dentine reactions in the oral cavity. Oxford, England: IRL Press Ltd; 1987.

[3] Spitzer D, ten Bosch JJ. The total luminescence of bovine and human dental enamel. Calcif Tissue Res 1976;20:201–8.

[4] Angmar-Månsson B, ten Bosch JJ. Optical methods for the detection and quantification of caries. Adv Dent Res 1987;1:14–20.

[5] Moore JE, MacCulloch WT. The inclusion of radioactive compounds in dental porcelains. Br Dent J 1974;136:101–6.

[6] Lu H, Lee YK, Villalta P, Powers JM, Garcia-Godoy F. Influence of the amount of UV component in daylight simulator on the color of dental composite resins. J Prosthet Dent 2006;96:322–7.

[7] Lim YK, Lee YK. Fluorescent emission of varied shades of resin composites. Dent Mater 2007;23:1262–8.

[8] Schmeling M, Sartori N, Peruchi LD, Baratieri LN. Fluorescence of natural teeth and direct composite resin restorations: seeking blue esthetics. Am J Esthet Dent 2013;3:100–11.

[9] Takahashi MK, Vieira S, Rached RN, Almeida JB, Aguiar M, Souza EM. Fluorescence intensity of resin composites and dental tissue before and after accelerated aging: a comparative study. Oper Dent 2008;33:189–95.

[10] Lee YK, Lu H, Powers JM. Changes in opalescence and fluorescence properties of resin composites after accelerated aging. Dent Mater 2006;22:653–60.

[11] da Silva TM, de Oliviera H, Severino D, Balducci I, Huhtala M, Gonçalves S. Direct spectrometry: a new alternative for measuring the fluorescence of composite resins and dental tissues. Oper Dent 2014;39:407–15.

[12] Lefever D, Mayoral JR, Mercade M, Basilio J, Roig M. Optical integration and fluorescence: a comparison among restorative materials with spectrophotometric analysis. Quintessence Int 2010;41:837–44.

[13] Monsénégo G, Burdairon G, Clerjaud B. Fluorescence of dental porcelain. J Prosthet Dent 1993;69:106–13.

[14] ten Bosch JJ, Coops JC. Tooth color and reflectance as related to light scattering and enamel hardness. J Dent Res 1995;74:374–80.

[15] Commission Internationale de líEclairage. CIE technical report: colorimetry. CIE Pub no. 15.3. Vienna, Austria: CIE Central Bureau; 2004.

[16] Volbrecht VJ, Kliegl R. The perception of blackness: an historical and contemporary review. In: Backhaus W, Kliegl R, Werner JS, editors. Color vision: perspectives from different disciplines. Berlin: De Gruyter; 1998.

[17] Figueira JA, McLaren E, Park S. The essence of fluorescence: understanding the role of ceramic layering on fluorescence when fabricating esthetic ceramic restorations. J Cosmet Dent 2015;30:82–92.

[18] Gamborena I, Blatz M. Fluorescence. Mimicking nature for ultimate esthetics in implant dentistry. Quintessence Dent Technol 2011;34:7–23.

[19] Panzeri H, Teixeira L, Minelli CJ. Spectral fluorescence of direct anterior restorative materials. Aust Dent J 1977;22:458–61.

[20] Wozniak WT, Moore BK. Luminescence spectra of dental porcelains. J Dent Res 1978;57:971–4.

[21] Chu SJ, Devigus A, Mieleszko A. Fundamentals of color, shade matching and communication in esthetic dentistry, vol. 3. Quintessence Publications; 2004. p. 54–75.

[22] Miller M. Composite resin fluorescence. J Esthet Restor Dent 2004;16:335.

[23] Meller CH, Klein CH. Fluorescence properties of commercial composite resin restorative materials in dentistry. Dent Mater J 2012;31:916—923.

[24] El-Meliegy E, van Noort R. Glass and glass ceramics for medical applications. New York: Springer; 2012. p. 152–4.

[25] Bazos P, Magne P. Bio-emulation: biomimetically emulating nature utilizing a histo-anatomic approach; structural analysis. Eur J Esthet Dent 2011;6:8–19.

[26] Wiemann Jr MR, Besic FC, Keller O. Application of dispersion staining to the study of refractive index of dental enamel. J Dent Res 1970;49:174.

[27] Eimar H, Marelli B, Nazhat SN, Abi Nader S, Amin WM, Torres J, et al. The role of enamel crystallography on tooth shade. J Dent 2011;39:3–10.

[28] Leventouri T, Antonakos A, Kyriacou A, Venturelli R, Liarokapis E, Perdikatsis V, et al. Crystal structure studies of human dental apatite as a function of age. Int J Biomater 2009;2009, 698547.