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Research Article

Influence of Different Illuminants on Spectrophotometric Tooth Color Determination

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Abstract

Statement of problem: The vast majority of studies address the comparison of visual and instrumental tooth color determination. Although, the lighting conditions of the environment may affect the clinical shade matching performance. This study evaluated if and how different light sources can influence the spectrophotometric determination of natural tooth color.

Purpose: The purpose of this study was to evaluate the precision of the spectrophotometer in tooth shade determination under the influence of different illuminants.

Material and method: Three examiners, determined the shade of an upper central incisor with Vitapan 3D-Master (VITA Zahnfabrik, Bad Säckingen, Germany) and with the spectrophotometer (Vita Easyshade V, Vita Zahnfabrik, Bad Säckingen, Germany). A special fabricated device with eight light sources, designed to offer reproductible lighting conditions, was used to determine the efficiency of instrumental color determination under different illuminants.

Results: Natural light (300 lux) and dental unit light at full intensity (32500 lux) produced the less ΔEab modification. Color coordinates determined in the presence of halogen light (1800 lux), neon ambient light (3000 lux), LED with cold light (21200 lux), halogen light with neon ambient light (23400 lux), both warm and cold LED simultaneously (36000 lux) and all eight light sources of the device (44000 lux), suffered a slight modification of ΔE ab, which does not exceed the acceptability and the perceptibility threshold. The illuminant that caused the biggest modifications in color coordinates was LED warm light (1940 lux) with a ΔEab 5.804 ± 0.271, that exceeds the acceptability and perceptability threshold.

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Conclusions: LED warm light influences the instrumental tooth color determination and when used, can lead to errors in communication of the color to the dental laboratory, which can cause esthetic failure of a prosthetic restoration. The best illuminant for color determination is natural light, or illuminants that simulate lighting in daily living conditions.

Clinical implications: Based on the spectrophotometric readings, it was demonstrated that tooth color shifts with the change in ambient lighting conditions. Therefore, color determination should be performed with natural daylight illumination.

Keywords: Spectrophotometer; Illuminants; Tooth color; Light influence.

Introduction

The esthetic success of an esthetic restoration depends on how its final shade is close to the natural dentition color. Natural tooth color is influenced by a combination of intrinsic colour and the presence of any extrinsic stains that may form on the tooth surface [1]. The intrinsic color of a tooth is determined by how the light is scattered and absorbed on the surface and within its internal structure. The enamel represents a translucent scattering medium and his thickness in human teeth does not fully obscure the color of the underlying dentine [2]. Visual color assessment by human eye depends on three factors, such as illuminants, the object and the observer [3]. There are also variables that can result in variation: perception angle, environment, position of the illuminant, fatigue of the observer and color perception deficiencies [3].

There are mainly two methods of assessing tooth shade in clinical practice: subjective visual determination, using dental color shade guides, and instrumental measurements, that use special devices for color determination such as spectrometers, spectrophotometers and colorimeters [4–6]. In dental practice, color matching of an aesthetic restorative material is routinely performed with the aid of a shade guide [7]. Different types of shade guides are available on the market, although Vitapan 3D-Master Shade Guide (Vita Zahnfabrik, Bad Saäckingen, Germany) is probably the most used and include a broad combination of shades. The use of guides can lead to errors in color matching because the range of shades in the shade guides is not consistent with natural teeth, therefore many tooth colors must be defined by approximation to the nearest shade of the guide [8,9]. Shade matching technologies have been developed in order to increase the success of color matching and reproduction in clinical dentistry [10] and were supposed to overcome or reduce the imperfections and inconsistencies of traditional shade matching.

Spectrophotometers are the most accurate and flexible instruments for overall color matching in dentistry [11], they are able to measure the amount of light energy reflected from an object at 1-25nm intervals along the visible spectrum and are able to convert the measured spectral reflectance to color coordinates and various tooth shade values [1]. They can be also used to determine the translucency of a tooth, which is the second

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leading factor, after color, for matching a restoration to adjacent teeth [12]. Compared with color determination by conventional techniques, spectrophotometers offered a 33% accuracy increase and an objective match in selections of 93.3% [10].

For accurate shade matching, the understanding of color principles is of great importance. The Commission Internationale de l'Eclairage CIE $L^*a^*b^*$ system represents a useful 3-dimensional color model. In this system, L^* represents the lightness of color (L^*-0 represents black and L^*=100 indicates diffuse white; specular white may be higher), a^* represents the color coordinate between red/magenta and green (negative a^* values indicate green, while positive a^* values indicate red/magenta) and b^* represents the color coordinate between yellow and blue (negative b^* values indicate blue, and positive b^* values indicate yellow) [3,13,14]. Spectrophotometers are fabricated based upon this system [13]. Color difference ΔEab is defined by the Euclidean distance between the coordinates of two stimuli in the CIE$L^*a^*b^*$ color space [1], and can be calculated with the formula bellow:

$$\Delta Eab = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Spectrophotometric color measurements depend on the measuring geometry and the illuminant [7]. The illuminant can be a source of natural or artificial light, and it can change the perceived color of an object [15]. Illuminants have different spectral power distributions and have been classified into standard illuminant categories from A to F, to provide a basis for comparing images under different lighting conditions [16]. An A illuminant represents domestic incandescent light of 2856 K color temperature, D50 to D75 the natural daylight of 5003 K to 7504 K, F1 to F11 the various types of fluorescent lighting of 2940 K to 6500 K, and lately LED the light-emitting diodes, which range from 2700 K to 6600 K [17].

The standard illuminants that were used to measure the color of dental materials are: illuminant D65–which represents midday light with a correlated color temperature of approximately 6500K; illuminant A–represents incandescent light with a correlated temperature of 2856K and illuminant F–represents fluorescent lamp light [1,18,19]. Currently, the CIE standard illuminant D65 is recommended for visual color in dentistry and the CIE standard illuminant A is recommended for indoor lighting [20]. Strict standards for the dental office lighting conditions are provided by the European Committee for Standardization in BSI Standard Publication Light and lighting (EN 12464-1:2011) [21]. A value between 500-1000 lux-illuminance is recommended for the examination room, while in the operating area is recommended up to 1000 lux-illumination [22].

Visual interpretation has been widely used in dentistry along with the perceptibility threshold (PT) and the acceptability threshold (AT) [23]. These two thresholds are used to define the visual match or incompatibility of the tooth color difference [24] and they also serve as a quality control tool for the interpretation of visual and instrumental findings in clinical dentistry and dental research [24–26]. Khashayar, et al. states that 54% of the literature reports a ΔE

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PT value of 1 as visually detectable 50% of the time, whereas the ΔE AT value ranges from 2.0 to 4.0, with the vast majority of the literature refers to its value as being 3.7 [27].

In this study it was evaluated the influence of different light sources on tooth shade determination with a spectrophotometer.

Material and method

Three examiners determined the shade of an upper central incisor with the shade guide Vitapan 3D-Master (VITA Zahnfabrik, Bad Säckingen, Germany) in the presence of natural light. A clinical use spectrophotometer was used for tooth color determination (Vita Easyshade V (VITA Zahnfabrik, Bad Säckingen, Germany).

The device consists of 3 main components: a light source, a measuring device that receives the reflecting light and a spectrometer. A digital lux meter (GM1010 Benetech) was used to measure and quantify the light intensity. The measurement was done by placing the diode of the lux meter in front of the tooth before spectrophotometric readings.

An original special conceived and fabricated device, called Luxvid 19 (Figure 1), with eight light sources connected in a parallel circuit was designed and manufactured to offer precise and reproductible lighting conditions. The light sources can function individually or together, depending on the need of the clinician. The entire circuit and the light sources were encapsulated in a long rigid plastic case with stands. The device has to be connected to a 220-240V socket via a standard AC power plug. In the exact order from the top to the bottom are: two separate fixed neon tubes (G13, Kingfisher, 1350Lm, 4000K, 18W), one big light-emitting diode (LED) light bulb (T100, Lohuis, 2950Lm, 6500K, 30W), big LED light bulb (T100, Hepol, 2850Lm, 3000K, 30W), a smaller but dimmable LED light bulb (BE27-12-DIM-CW, Hoff, 1050Lm, 6500K, 12W), another smaller and dimmable LED light bulb (BE27-12-DIM-WW, Hoff, 1050Lm, 3000K, 12W) and two final halogen lamps (TG-2205.0150, Total Green, 631Lm, 2800K, 50W). (Figure 1 A and B).

The readings were performed in the presence of: natural light, which represents the control group (300 lux), halogen light (1800 lux), led with warm light (1940 lux), neon ambient light (3000 lux), led with cold light (21200 lux), halogen light with neon ambient light (23400 lux), chair light at full intensity (32500 lux), both warm and cold led simultaneously on (36000 lux) and all eight light sources of the device on (44000 lux).

Color readings were performed with the aid of a spectrophotometer, which was calibrated before being used.

The middle third of one central incisor was examined visually and by instrumental means, as it can be seen in Fig.2, ensuring that shade matching was concentrated around the main body colored area to avoid the effect of the translucent incisal edge and to eliminate that of the gingival color on the cervical measurement.

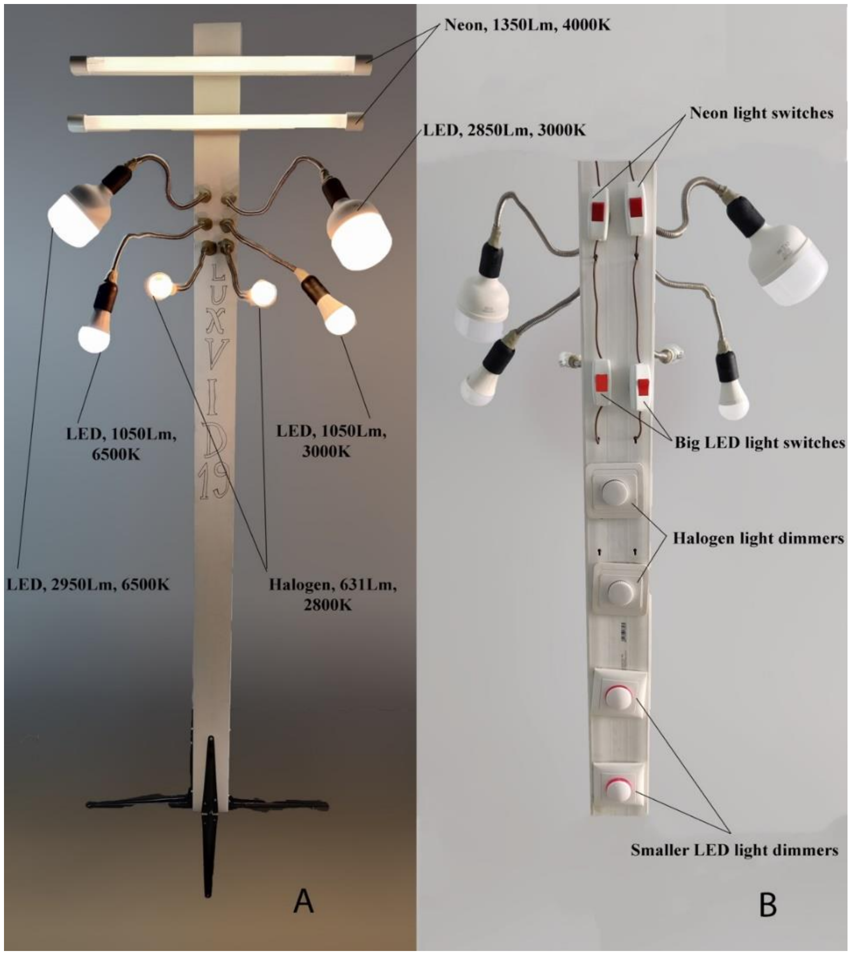

Figure 1: Lighting device named "Luxvid 19" designed specifically to aid in this study: (A) front view; (B) back panel containing the switches and dimmers.

Figure 2: Determination of tooth shade and color determinants with the spectrophotometer.

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Results

By conducting the Kolmorogov-Smirnov test, resulted that all of the values were normally distributed. One-way ANOVA test showed values $p<0.000$, all the results being statistically significant.

Determination of color coordinates in the presence of natural light showed the slightest Lab change, as it can be seen in Table 1. Also, tooth color determination in the presence of dental unit light at full intensity showed a slight change in Lab coordinates, with a mean ab of 1.2, value that falls into AT and PT with $F=120.4$ and $p<0.000$, the result being statistically significant.

	Natural light	Halogen light	Led with warm light	Neon ambient light	Led with cold light	Halogen light with neon ambient light	Chair light at full intensity	Warm and cold light	All light sources on
Avg.	0.467	3.155	5.804	2.527	3.023	2.958	1.208	3.103	2.782
St. dev.	0.119	0.212	0.271	0.160	0.075	0.070	0.163	0.214	0.093

Table 1: ΔEab average and standard deviation of different illuminants.

The statistical evaluation revealed that warm light with led had the greatest ΔEab change, with a median ± SD of 5.804 ± 0.271 with a F value of 2907.87 and $p<0.000$ that shows that the result is statistically significant. A ΔEab of 5.8 exceeds both, the AT and PT.

Beside warm light with led, all illuminants revealed slight changes (ΔEab) in the CIELab withΔE ab values that do not exceed the AT and PT, the result being statistically significant, which can be seen in Figure 3.

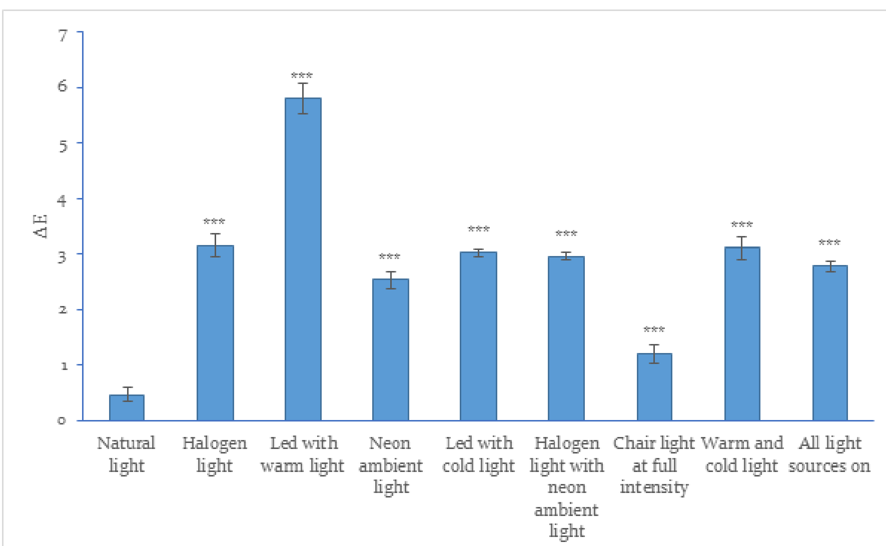

Figure 3: Mean and standard deviation of ΔEab values with statistically significance under different illuminants.

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Discussion

The vast majority of studies address the comparison of visual and instrumental tooth color determination. Spectrophotometers are indicated to be the most reliable standard for color matching studies in previous reports, but the precision and accuracy of spectrophotometric measurements can be affected by a variety of factors, such as the instrument and its accessories, the operator and the photo-electrical reaction [28].

The objective of this study was to demonstrate if Vita Easyshade spectrophotometer is influenced by the environmental light when used to determine tooth color. The recommended illuminant for shade determination is neutral daylight, which is rarely available in clinical practice because of the variability of weather conditions, time of the day and season of the year. As literature suggests, environmental parameters have a substantial influence on the visually subjective determination of color [29]. Human teeth do not exhibit color homogeneity. Natural coating of saliva affects the reflection of light and can influence subjectively color perception [25,29]. The successful use of a shade guide depends on the accuracy of the color assessment by the individual choosing the shade [30].

In clinical dentistry, tooth color evaluation under ideal conditions is difficult to achieve, so it is useful to use a color-measuring device that produces constant values under any given condition. It is important that constant color values can be determined repeatedly in a clinical situation [31]. Therefore, in this study, it was examined the stability of the determined color values under different type of illumination, and color differences were quantified by ΔEab values. In another study, Lee et al, concluded that instrumental color matching should be performed under lighting conditions common in daily living, because of the influence of color coordinates of different illuminants [32]. Park et all concludes that color parameters varied significantly by the illuminant [7].

Another recent study conducted by Melgosa et al, concluded that LED illuminants produced considerably high color changes in color determination and dentist should be aware of these lightning effects [20]. Lehmann et al. stated that dental measuring devices showed excellent repeatability, but Vita Easyshade showed substantial deviations of the calculated color coordinates [33]. The special device fabricated for this study was used to analyze the influence the lightning conditions for the accuracy of intraoral scanning. The present study shows that warm light (1940lux) may have a statistically significant effect on instrumental color determination. The best illuminants with respect to tooth shade determination turned out to be the dental unit light at full intensity (32500lux) and natural light (300 lux).

Conclusion

Within the limitation of this study, the color shift phenomenon, which is routinely observed in clinical practice, was confirmed by the spectrophotometer. The color coordinates were modified when LED warm light was used for color determination. Color matching should be performed under optimal lighting conditions which simulate lighting in daily living.

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