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Development of a customized whiteness index for dentistry based on CIELAB color space

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ABSTRACT

Objectives. To develop a customized CIELAB-based whiteness index for dentistry that accurately correlates to perception of tooth whiteness.
Methods. Four psychophysical experiments (PE1-4) were conducted by three panels of observers (OP1-3) under diffuse/0° observation/measuring conditions and under typical clinical viewing conditions. Nine whiteness indices (WI, Z%, WIC, WIO, W31, W64, W, WLAB, W*), two yellowness indices (YID1925, YIE313) and tint of white in the CIELAB color system (T) were compared with regard to their ability to measure the perceived whiteness of human teeth. Determination coefficient (R^2) and '% wrong decision' (%WD) method were used as direct measures of the quality of the indices for whiteness perception in dentistry.
Results. CIELAB-based whiteness index ($WI_D = 0.511L^* - 2.324a^* - 1.100b^*$) was developed through optimization from the data obtained in PE1. The proposed WI_D performed better than all the CIELAB and CIE1931 XYZ-based indices under laboratory and clinical conditions (only WIO was comparable to WI_D in PE2 and PE4).
Conclusion. The validation experiments under laboratory and typical clinical conditions revealed that the proposed index WI_D outperformed previous indices, being the only CIELAB-based index developed for evaluation of whiteness in dentistry.

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1. Introduction

Currently, the CIE $L^*a^*b^*$ (CIELAB, CIE76) color notation system of the CIE-Commission Internationale de l'Eclairage (International Commission on Illumination) is the most frequently used in both in vivo and in vitro research and color characterization in dentistry, with the rare usage of CIEDE2000 (ΔE_{00}) color difference formula [1–3]. In addition, it is important to point out that color measuring devices currently used in dentistry almost exclusively use the CIELAB color space for color measurements. Moreover, chromatic changes in clinical practice situations and research are usually assessed by means of the color differences associated with this color space [2,3].

In addition to color measurement, proper measurement of whiteness is important for research and manufacturing of dental materials, and for the clinical practice, including tooth whitening monitoring (effectiveness of different bleaching agents). In spectral terms, a white material is the material whose reflectance across the entire visible wavelength range is constant and high (near to 100%). In terms of CIELAB color space, this type of spectral behavior is translated into a very high lightness and very low (ideally zero) saturation.

Some whiteness indices based on the CIE 1931 XYZ color notation system, such as the CIE whiteness index WIC [4–6] and the WI whiteness index according to ASTM E-313-73 [7], have been used in dental research [8–10]. Within this context, it is worth mentioning the optimized whiteness index, WIO [11], developed specifically for evaluation of tooth whiteness. WIO maintains the functional form of the CIE WIC index and has been proven adequate for tooth whitening research and monitoring [11].

Given the need to establish a CIELAB-based whiteness index that exhibits good correlation with visual evaluation, Ganz and Pauli [12] performed a lineal approximation of the previous CIE whiteness and tint formulas [6] in the CIELAB color space, thus developing the *W* and *T* indices [12]. Although these formulas characterized the whiteness appearance well, they poorly correlated with visual evaluation and often failed in the evaluation of white specimens. These results, together with the great industrial applicability of the CIELAB color notation system, led to the development of a new whiteness index (WLAB) [13] which had better correlation with visual evaluations of observers and also had better results in terms of uniformity and applicability than the WIC index. However, none of these indices was used so far in dentistry and their applicability in dental practice has not been evaluated.

Although the CIELAB system is currently used routinely in color research in dentistry, with whiteness indices based on this color notation system occurs the opposite. The following parameters have been predominantly used in evaluating whiteness efficacy: the overall color difference (ΔE^*_{ab}, ΔE_{00}), changes in color coordinates (ΔL^*, lightness; Δa^*, green–red coordinate; and Δb^*, blue–yellow coordinate) [14–16], Δb^* [11] coordinate and the W* index, described by Gelarch et al. [17] and based on the distance of a color value from a nominal white point, represented in CIELAB color space as $L^* = 100$, $a^* = 0$ and $b^* = 0$.

In this study, a psychophysical experiment was performed, aiming to develop and assess a new whiteness index (WI_D), designed specifically for dentistry and based on the CIELAB color notation system. It was expected that WI_D would correlate with visual findings, and that it would perform well compared with other whiteness indices based on both CIELAB and the CIE 1931 XYZ color notation systems. Consequently, the null hypothesis was that the newly proposed WI_D whiteness index did not differ in performance compared to previous indices.

2. Materials and methods

2.1. Specimens

Three different sets of specimens were used, as follows:

- *Specimen Set A (SSA)*: 29 tabs of a VITA Linearguide 3D-MASTER (Vita Zahnfabrik, Bad Säckingen, Germany) shade guide;
- *Specimen Set B (SSB)*: 16 tabs of a Vitapan Classical (Vita Zahnfabrik, Bad Säckingen, Germany) shade guide;
- *Specimen Set C (SSC)*: 25 experimental (laboratory manufactured) resin composite specimens within the color range of natural teeth in the CIELAB color space (10 mm in diameter, 1-mm thick).

The experimental resin composites were custom fabricated as a mixture of organic matrix, inorganic filler, photo activator and other components in minor quantities and four types of pigments in various mixtures in order to generate composites with different colors [18]. Specimens in SSC were made on a glass plate (Knittel GLASER, Bielefeld, Germany) and clear plastic sheet (Acrylite Plus Clear, Tap Plastics, Dublin, CA, USA) on the top and bottom of the jig. After placement of composites, another glass plate was pressed onto the top of the specimen to standardize the thickness. All specimens were light-cured during 40 s using a using a LED light-curing-unit (Bluephase Ivoclar Vivadent, Shaan, Liechtenstein) operating on standard mode and emitting 1100 mW/cm^2.

2.2. Color measurements

A non-contact spectroradiometer (SpectraScan PR-704, Photo Research, Chatsworth, USA) was used to measure the spectral reflectance of shade guide tabs and resin composite specimens. The specimens were placed in the center of a viewing cabinet (VeriVide CAC60, VeriVide Limited, Leicester, United Kingdom) on a 45° tilted base and a light source simulating the spectral relative irradiance of CIE D65 standard illuminant was used to provide consistent illuminating/viewing conditions. The shade guide tabs and the experimental resin composites were positioned 40 cm away from the spectrorradiometer and measured at 0° (corresponding to diffuse/0° illuminanting/measuring geometry) and the CIE 1931 2° Standard Colorimetric Observer was used to calculate the CIE tristimulus values from the reflectance factors. As the oral cavity is dark, a black ($L^* = 3.1$, $a^* = 0.7$