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ORIGINAL ARTICLE

Evaluating the accuracy of tooth color measurement by combining the Munsell color system and dental colorimeter

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Abstract As we pay increasing attention to dental aesthetics, tooth color matching has become an important part of daily dental practice. This aim of this study was to develop a method to enhance the accuracy of a tooth color matching machine. The Munsell color tabs in the range of natural human teeth were measured using a tooth color measuring machine (ShadeEye NCC). The machine's accuracy was analyzed using an analysis of variance test and a Tukey *post-hoc* test. When matching the Munsell color tabs with the ShadeEye NCC colorimeter, settings of Chroma greater than 6 and Value less than 4 showed unacceptable clinical results. When the CIELAB mode was used, the a^* value (which represents the red–green axis in the Commission Internationale de l'Eclairage color space) made no significant difference ($p = 0.84$), the L^* value (which represents the lightness) resulted in a negative correlation, and the b^* value (which represents the yellow–blue axis) resulted in a positive correlation with ΔE. When the Munsell color tabs and the Vitapan were measured in the same mode and compared, the inaccuracies showed that the Vitapan was not a proper tool for evaluating the stability and accuracy of ShadeEye NCC. By knowing the limitations of the machine, we evaluated the data using the Munsell color tabs; shade beyond the acceptable range should be reevaluated using a visual shade matching method, or if measured by another machine, this shade range should be covered to obtain more accurate results.

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Introduction

Color assessment and reproduction remain two of the most challenging aspects of aesthetic dentistry. Visual color matching with a commercially available dental shade guide is the most widely used method. However, the matching of a restoration to the existing tooth structure is not a predictable process [1,2]. For pursuing more objective and accurate shade selection, tooth color matching machines are thought to be reliable and useful in determining color for clinical shade matching in current dental practice [3–5]. Unfortunately, each dental color matching machine has its own limitations [6]. Many studies have focused on the comparison of the commercially available dental color measuring machines for repeatability and accuracy by using a dental shade guide as the standard measured subject [7,8]. Most devices had a similarly high reliability (more than 96%), indicating predictable shade values from repeated measurements. However, there was more variability in the accuracy among devices (67% to 93%), and differences in accuracy were seen with most device comparisons [9]. In addition, there are problems with the measured shade guides. For example, there can be uneven distribution in the color space, manufacturing errors, and gradual changes in the color of one tab, and the range of shades available may not cover the complete range of natural tooth colors [1,10–15]. All these problems can lead to errors in the evaluation results of dental color matching machines.

The Munsell color system is based on the steps of visual perception, with any color being defined as a point within the three-dimensional Munsell color space, which was created by Professor Albert H. Munsell in the first decade of the 20th century. The attributes of this system are Munsell Hue (H), Munsell Chroma (C), and Munsell Value (V), and they are written in the form H V/C, which is called the Munsell notation. Hue is the name of any color as found in its pure state in the spectrum, which was divided into five principal groups: Red, Yellow, Green, Blue, and Purple, along with five intermediate hues halfway between adjacent principal hues. Chroma is the degree of a color's vividness, with the lower chroma showed the less purity of the color. Value is the lightness or darkness of a color varied vertically along the color solid, from black (value 0) at the bottom, to white (value 10) at the top. Neutral grays lie along the vertical axis between black and white. The Munsell color system was the first system to separate hue, value, and chroma into perceptually uniform and independent dimensions, and was the first to systematically illustrate the colors in three-dimensional space. It has been widely used in many fields of color science as a standard system of color specification.

The value Δ*E*, calculated from the measured CIELAB value, was used to evaluate the accuracy and acceptability of the true and measured color differences. The CIELAB color order system was developed by the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination) in 1931. It is generally used in color research and is based on the color standardization of light sources and of observers. A specific shade is defined by its location within the CIELAB system using three coordinates: L^*, a^*, and b^* (Fig. 1). The CIELAB color scale is an approximately uniform color scale. L^* runs from top to bottom. The maximum for L^* is 100, which represents black. The a^* and b^* axes have no specific numerical limits. Positive a^* is red. Negative a^* is green. Positive b^* is yellow. Negative b^* is blue. The delta values—ΔL^*, Δa^*, and Δb^*—indicate how much a standard and sample differ from one another in L^*, a^*, and b^*. The total color difference ΔE, which was calculated using the following equation,

$$\Delta E = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2},$$

is a single value which takes into account the differences between the L^*, a^*, and b^* of the sample and standard.

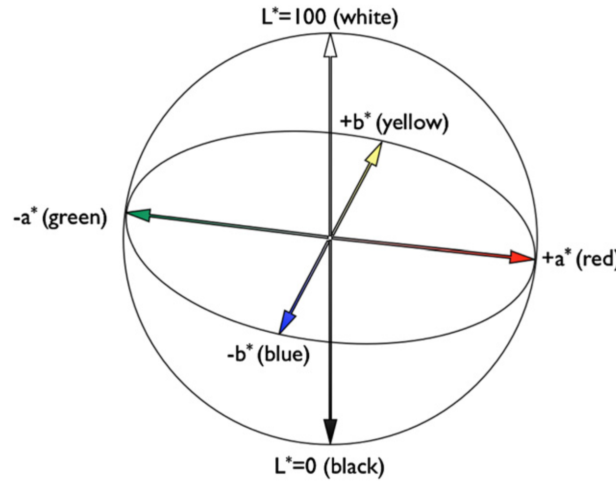

Figure 1. Schematic drawing representing the CIELAB color space.

It is important in quantifying the color difference between two specimens. Under controlled conditions, a ΔE value of 1 or greater can be perceived by the human eye. If two objects are placed side by side in a controlled environment, the smallest difference in color detected by human observers is a ΔE value of 1 [16]. However, under clinical conditions, a ΔE of 3.3 has been shown to be the upper limit for human eyes to detect color differences [17]. The ΔE value greater than 3.7 indicates a poor match based on clinical observations, and the color difference between the observed subjects can be easily seen [18]. *In vivo* studies have shown that the average color difference between teeth and shade tabs matched intraorally was caused by background distractions in the oral cavity, such as the mucosa, the gingiva, and shadowing caused by the lips [19–21]. These interferences make it more difficult to detect small color differences in daily intraoral tooth color matching.

Many devices and instruments have been developed to make the results of color matching more accurate and easier to achieve. However, there are still problems in evaluating the accuracy of tooth color matching machines. To prevent the above-mentioned disadvantages of dental shade guides, the Munsell color tabs distributed evenly in three-dimensional space were used in this study to evaluate the accuracy and limitations of a dental color measuring machine.

Methods and materials

According to the study by Hayashi and Clark that defined the range of the color of natural human teeth using Munsell