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ORIGINAL ARTICLE

Evaluation of the accuracy and limitations of three tooth-color measuring machines

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Abstract *Background/purpose:* To use dental shade guides as the standard to evaluate the accuracy of tooth-color matching devices and how they are affected by the limitation of uneven distribution and insufficient color space coverage of the dental shade guide. The aim of this study was to develop a systemic method to enhance the accuracy of using tooth-color matching devices.
Materials and methods: The tabs of the Munsell Book of Color were tested with three tooth-color measuring instruments (ShadeEye NCC, VITA Easyshade, and DeguDent Shadepilot). The results of each instrument were analyzed by an Analysis of Variance (ANOVA) test and a Tukey's *post-hoc* test to find out the limit of each instrument. Hue, chroma, and value were identified as factors that affect the results of the measurements.
Results: The accuracy of the DeguDent Shadepilot did not vary significantly with changes in the parameters hue, chroma, and value. The ShadeEye NCC had a ΔE value above the acceptable limit ($\Delta E = 4.2$) when value was lower than 4 and chroma was higher than 6. The VITA Easyshade had a large ΔE when hue ranged from 7.5YR and to 10YR, value was higher than 7, and chroma was higher than 6.
Conclusion: By knowing the limits of each machine after being analyzed with the Munsell Book of Color, we can use the color measuring instrument in the specific color space range that the

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devices measuring accuracy performs the best in to achieve objective and accurate tooth-color measuring results in routine dental practice.

Introduction

Many tooth-color matching devices have been introduced to make shade selection more accurate, allowing us to provide better esthetic results when fabricating artificial teeth and to more precisely gauge the results of tooth whitening procedures. However, the most suitable instrument for specific tooth shade evaluations cannot be selected as there is still no standard method to evaluate the accuracy and limitations for each specific device.

Using the CIELAB color system, which was widely used in tooth-color research,[1–4] we can quantify the difference between a standard color and the measured color. This system was developed by the Commission Internationale de l'éclairage (CIE, International Commission on Illumination) in 1976. A specific shade is defined by its location within the CIELAB system, which is based on three coordinates: L*, a*, and b*. L* runs vertically with a maximum of 100, which represents white. The a* and b* axes have no specific numerical limits. Positive a* indicates an increasing level of red, and negative a* represents green. Positive b* corresponds to yellow, and negative b* represents blue. The delta values ΔL*, Δa*, and Δb* indicate the degree to which the standard color and the sample color differ from one another in L*, a*, and b* in the color space. The total color difference ΔE is calculated using the following equation:

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

The value ΔE is used to evaluate the accuracy and acceptability of the true and measured color differences. This single value represents the differences between the L*, a*, and b* values of the two colors and is important in quantifying the color difference between two specimens. Under controlled conditions, when two objects are placed side by side, the smallest difference in color that can be detected by human observers is approximately 1 ΔE unit.[5] However, under clinical conditions, 3.3 ΔE units has been shown to be necessary for the human eye to detect color differences.[6] In the complex oral environment, an ΔE value greater than 3.7 units indicates a poor match based on clinical observations, and this level of color difference can be easily observed.[7] According to a recent study, when shade-matching artificial dentures teeth to natural teeth, 1.9 ΔE* units was the 50:50 perceptibility threshold, and 4.2 ΔE* units was the acceptability threshold used to compare different colors.[8]

Most of the past studies have attempted to evaluate the accuracy of the devices by using available dental shade guides as the standard. Owing to the uneven distribution and insufficient color space coverage of the dental shade guides, many studies have focused on the repeatability and interdevice differences of commercially available instruments.[9–14] It is important to note that the advantages and limitations of each instrument have rarely been reported. In our previous study,[15] systematically arranged Munsell Book of Color tabs were shown to be a suitable standard, which helped us easily determine the limits of the color measuring instruments. This system was created by Professor Albert H. Munsell in the first decade of the 20th century. The Munsell color system is based on steps of visual perception in which color is defined as a point within the three-dimensional Munsell color space. Munsell's system, particularly the later renovations, is based on rigorous measurements of individuals' visual responses to color, putting it on a firm experimental scientific basis. Owing to this basis in human visual perception, Munsell's system has outlasted its contemporary color models, and though it has been superseded for some uses by models such as CIELAB (*L*a*b**), it is still in wide use today.[16] The attributes of this system are Munsell hue (H), Munsell chroma (C), and Munsell value (V), and the color values are written in the form H V/C, which is called Munsell notation. Hue refers to any color found in its pure state in the spectrum, which is divided into five principal groups: red, yellow, green, blue, and purple. There are also five intermediate hues halfway between the adjacent principal hues. Chroma is the degree of a color's vividness, with a lower chroma indicating a lower purity of the color. Value represents the lightness or darkness of a color and varies 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 system to systematically illustrate the color in a three-dimensional space. This system has been widely used in many fields of color science as a standard system of color specification. In this study, we evaluated the accuracy and limitations of three popular tooth-color measuring instruments in a tooth-color matching procedure. We determined the accuracy of each instrument in this study to develop the best procedure for tooth color selection in routine dental practice.

Materials and methods

Three color measuring instruments that have been shown in previous studies to have high repeatability were evaluated in this study. The devices included were the ShadeEye NCC (Shofu Inc, Kyoto, Japan), the VITA Easyshade (VITA Zahnfabrik, Bad Säckingen, Germany), and the DeguDent Shadepilot (DeguDent GmbH, Hanau, Germany). The ShadeEye NCC is a type of colorimeter that reads the visible spectrum by using filtered photodetectors. The VITA Easyshade and DeguDent Shadepilot are types of spectrophotometers that