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Original Article

The comparison of current color measurement techniques in dental applications

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ABSTRACT:
Background: The color options of natural teeth and restorative materials have critical applications in clinical dental practice and research. This review provides information about the comparison of current color measurement techniques in dentistry. **Material-method:** Forty-four volunteers between the ages of 18 and 22 were included in this study. Shade selection was performed from the upper right central incisor using the VITA Classical (VITA Zahnfabrik, Germany) shade guide and the VITA Easyshade V spectrophotometer (VITA Zahnfabrik, Germany) in clinical setting. Photographs were taken using a smartphone (Apple iPhone XS), Smile Lite MDP (Smile Line, Switzerland) and gray card (Flexipalette Color Match, Smile Line, Switzerland), then color measurement was evaluated with software. The measurements were evaluated using CIELab color coordinates and ΔE value. **Results:** The ΔE value was statistically significant in this study compared to the groups. (p=0.001; p<0.01). In addition, it was found that the ΔE value of both dental photography groups was high compared to both shade guide groups (p=0,001; p<0,01). According to the groups, the L*, a* and b* values showed statistically significant differences (p=0.001; p<0.01). **Conclusions:** While there was a subtle difference between analysis techniques, the spectrophotometer is more accurate than other methods in color selection.

Keywords: Color matching, Spectrophotometer, CIELab, Smile Lite MDP, Smartphone

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INTRODUCTION

In dentistry, color matching is considered a process that depends on three main factors: light source, tooth and observer (dentists, patients or society). Color matching technologies have been developed to increase success in color matching, provide better communication between the technician and the clinician, and better reproduction dental characteristics.[1] In general, there are two methods for color matching, the visual and the instrumental method.[2]

In dentistry, color selection by the visual method is performed with various shade guides. Visual selection using shade guides is the most common and the most subjective technique.[1, 2] One of the most popular shade guides, VITA Classic (VITA Zahnfabrik, Germany), is based on the color frequency of natural dentition.[3] Four groups are formed according to the hue: A is reddish-brown (A1, A2, A3, A3.5, A4), B is reddish-yellow (B1, B2, B3, B4), C is gray (C1, C2, C3, C4), and D is reddish-gray (D2, D3, D4). The sort order within groups is based on the decreasing value and the increasing chroma.[4]

Color measurement by instrumental methods makes the color selection process faster and more objective.[5] Color selection with the instrumental method is performed with spectrophotometer, colorimeter, digital photography and intraoral scanners.[6-9]

Spectrophotometers are devices that use methods of measuring transmittance through materials or reflection from materials as a function of wavelength.[10] Studies have shown that instrumental measurements using a dental spectrophotometer can provide the most precise and accurate color matching results.[11] Dental spectrophotometers illuminate the tooth with 6500 K for color matching and determine the results based on the shade guide.[6, 7] Two types of spectrophotometers are available, spot-measurement spectrophotometers (VITA Easyshade V; VITA Zahnfabrik, Shade-X; X-Rite) and complete-tooth-measurement spectrophotometers (SpectroShade; MHT Optic Research AG, Crystaleye; Olympus).[3]

VITA Easyshade V (VITA Zahnfabrik, Germany) is a contact-type intraoral spectrophotometer with standard lighting and unaffected by surrounding lighting conditions. It measures the amount of energy of light reflected from an object at 25 nm intervals across the visible spectrum.[7]

Cross-polarizing filters prevent the tendency of flash photography to increase light reflection, reducing unwanted reflections and light from the camera flash.[12] Smile Lite MDP (Smile Line, Switzerland) can be considered a portable mini studio that allows the use of a large number of light settings. Smile Lite MDP aims to facilitate the procedure of taking intra-oral photographs in the dental clinic by using them together with smartphones. Eight led light sources in the center give the ring flash effect, and six led light sources on both sides to give the twin flash effect.[13] In addition, Smile Lite MDP along with a cross-polarized filter and light sources, reduces light reflection in photographs and allows better viewing of translucent areas of the tooth.[14]

CIELab determines a specific color in space using 3 coordinates; L* Value is the corresponding coordinate, a* is the coordinate from red to green and b* is the coordinate from yellow to blue. ΔE is used to evaluate the acceptability of the measured difference between 2 colors according to the formula below.[1, 15]

$$\Delta E=((L^*_1-L^*_2)^2+(a^*_1-a^*_2)^2+(b^*_1-b^*_2))^{1/2}$$

Under experimental conditions, $\Delta E>1$ is visible to the human eye; however, $\Delta E>3.7$ must be clinically visible for the color difference.[3]

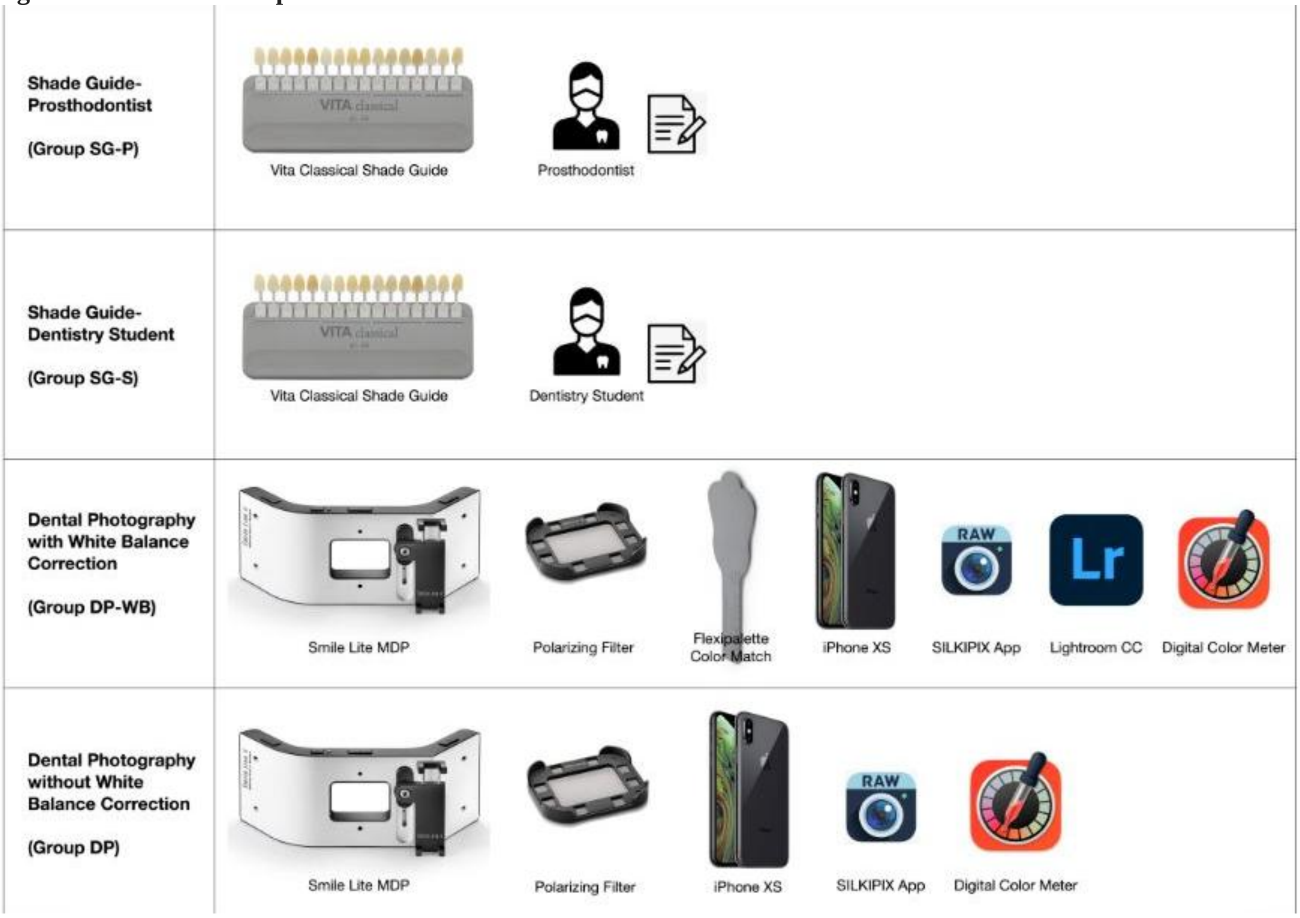
The aim of this study is to compare current color measurement techniques that can be applied in clinical practice. The null hypothesis was that no difference between current color measurement techniques in the clinical practice.

MATERIAL & METHODS

Forty-four volunteers between the ages of 18 to 22 were included in this study. It was noted that the individuals participating did not have whitening treatment in the last six months, anterior restorations, and enamel defects. The clinicians who would conduct the study were screened for color blindness using Ishihara plates. Color selection was performed by two experienced prosthodontists and one dentistry student. All measurements were taken separately at the same time of day, in the same clinic, in an environment with neutral-colored walls and a naturally lit window. Color measurement of the upper right central tooth was performed separately by an experienced dentist and a dentistry student using the VITA Classical shade guide (VITA Zahnfabrik, Germany).

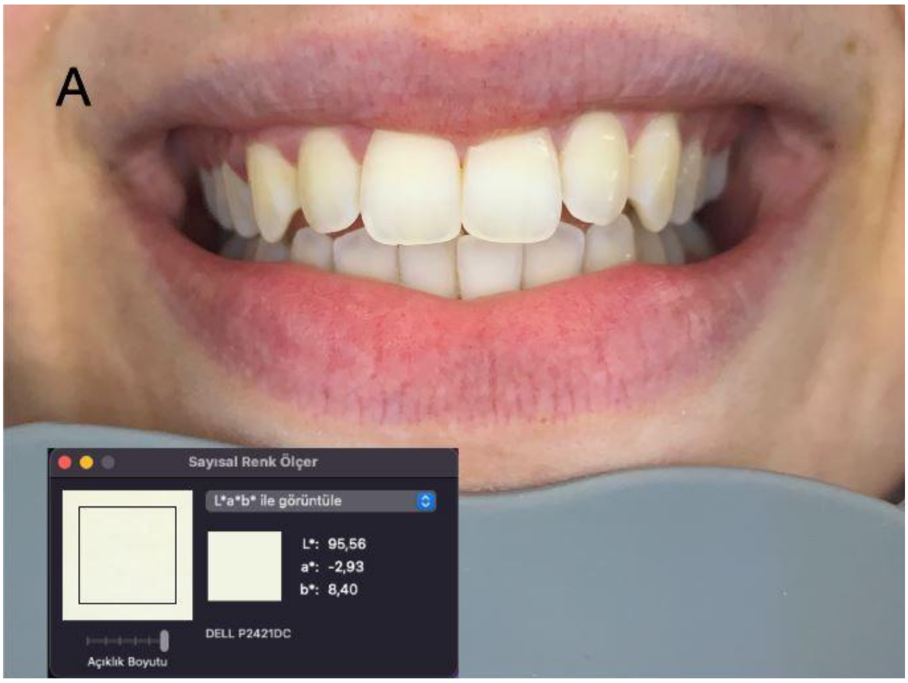
A photograph of the anterior teeth was taken from the participants using iPhone XS (Apple Inc., California), Smile Lite MDP (Smile Line, Switzerland), cross-polarized filter (MDP Polarizing Filter, Smile Line, Switzerland) and 18% gray card (Flexipalette Color Match, Smile Line, Switzerland). Photographs were taken with the white balance set to 5500K via the SILKYPIX Shot Camera v1.1 (Ichikawa Soft Laboratory, Japan) application (Fig. 1).

Figure1. Shade selection protocols used



An extra copy of the captured photographs was created, and the white balance was adjusted with the Adobe Photoshop Lightroom v4.3 (Adobe Inc., California, USA) software using the 18% gray card as a reference. CIELab coordinates were obtained from the photographs using Digital Color Meter v5.22 (Apple Inc., California, USA) software (Fig. 2).

Figure2. CIELab color measurements made from the center of the right central tooth using Digital Color Meter application. A, measurement without white balance correction. B, measurement with white balance correction



L* a* b* values obtained from photographs with and without white balance correction are recorded in the data table.
Color measurement was performed using VITA Easyshade V (VITA Zahnfabrik, Germany) in the "shade determination of tooth area" mode from the mesiodistal and inciso-cervical middle third of the crown. Calibration of the device was achieved before each measurement. CIELab coordinates obtained on the spectrophotometer screen were recorded in the data table. The mouth was kept closed between measurements to avoid dehydration of the teeth.
In order to determine the accuracy of the color measurements made using the dental photography and shade guide, measurements made with the spectrophotometer were determined as a control group and accepted as accurate color measurement. ΔE was calculated between all color measurements and spectrophotometer values.
NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) software was used for statistical analysis. Descriptive statistical methods were used when evaluating the study data, and the distribution of the data was evaluated using the Shapiro-Wilk Test. In addition, Kruskal-Wallis test was used in three and above groups, and Mann-Whitney U test was used in binary groups to compare quantitative data. Significance was evaluated at $P<0.05$.

RESULTS
The ΔE value is statistically significant in this study compared to the groups as seen in Table 1.

Table 1: Comparison of ΔE values between different color selection methods and spectrophotometer

Shade Selection Method	ΔE (Mean)	ΔE Min-Max (Median)	p
Dental Photography without White Balance correction (Group DP)	13,84±3,78	6,35-24,88 (13,31)	0,001**
Dental Photography with White Balance correction (Group DP-WB)	14,5±4,32	6,88-28,39 (14,09)	
Shade Guide-Prosthodontist (Group SG-P)	8,63±4	2,8-22,27 (7,68)	
Shade Guide-Dentistry Student (Group SG-S)	7,46±4,39	1,01-18,69 (6,42)	

Kruskal-Wallis Test (*p<0,05 **p<0,01)

($p=0.001$; $p<0.01$). In addition, it was found that the ΔE value of both dental photography groups was high compared to both shade guide groups ($p=0,001$; $p<0,01$).
According to the groups, the L*, a* and b* values showed statistically significant differences as seen in Table 2 ($p=0.001$; $p<0.01$)

Table 2: Comparison of CIELab coordinates values by groups

CIELab Coordinates	Shade Selection Method	Mean	Min-Max (Median)	p
L*	Spectrophotometer	83,16±5,55	68,4-100 (83,4)	0,001**
	Group DP	95,18±1,71	90,32-98,23 (95,44)	
	Group DP-WB	96,41±1,64	91,66-98,86 (96,8)	
	Group SG-P	76,34±2,49	71,2-81,8 (77,6)	
	Group SG-s	78,35±3,22	68,1-81,8 (79,5)	
a*	Spectrophotometer	-0,11±2,01	-2,8-8,9 (0,35)	0,001**
	Group DP	-2,17±1,36	-5,27-0,31 (-2,14)	
	Group DP-WB	0,26±1,27	-1,82-4,25 (0,04)	
	Group SG-P	1,24±0,73	-0,5-2,1 (1,3)	
	Group SG-S	0,45±0,96	-1,2-2,1 (0)	
b*	Spectrophotometer	18,13±3,74	10,6-29,7 (18,15)	0,001**
	Group DP	14,29±4,59	6,04-25,21 (14,52)	
	Group DP-WB	15,36±6,02	0,25-31,47 (14,95)	
	Group SG-P	18,7±2,95	11,7-25,9 (17,7)	
	Group SG-S	17,23±2,83	13-25,9 (17,7)	

Kruskal-Wallis Test (*p<0,05 **p<0,01)

Furthermore, it was statistically significant that the L value of the group without white balance was lower than the group with white balance correction (p=0.001; p<0.01). The L values of both dental photography groups were found to be higher than the spectrophotometer and both shade guide groups (p=0.001; p<0.01). In addition, the L value of the SG-P group was found to be lower than the SG-S group (p=0.001; p<0.01).

According to the groups, the a* values showed statistically significant differences (p=0.001; p<0.01). In addition, it was found that the a* value of the DP group was lower than other groups (p=0.001; p<0.01). It was found that the a* value of the SG-P group was higher than other groups (p=0.001; p<0.01).

According to the groups, the b* values showed statistically significant differences (p=0.001; p<0.01). In addition, the b* values of both dental photography groups were lower than the spectrophotometer and both shade guide groups (p=0.001; p<0.01).

DISCUSSION

As a result of this study, the H_0 hypothesis was decried, and differences were found between color selection methods. In this study, ΔE>3,7 was found in both the dental photography and the color scale methods.

Color measuring instruments and systems are increasingly used in research, such as evaluating visual color thresholds, comparing visual and instrumental assessments, color compatibility and stability, teeth whitening methods, and color harmony of natural teeth and restorative materials.[9] The precision of a device is evaluated by testing the repeatability (same method, operator, or instrument) and reproducibility (different method, operator, and/or instrument) of the instrument.[5]

The visual technique is a subjective method affected by many factors related to the observer and the patient. Since the visual color determination method is the most commonly used method in dentistry, a shade guide was used in this study.[16, 17] In this study, a difference was found between the spectrophotometer and the visual technique. This result is consistent with previous studies.[6, 18, 19]The reason for this difference may be that the visual technique is subjective and affected by environmental conditions.[7] Another reason for the differences between the visual technique and the spectrophotometer can be explained by a mismatch between colors in shade guide and natural teeth.[15] The colors of the shade guide were matched to the CIELAB coordinate system using a spectrophotometer for this study, but since the manufacturer did not provide these values, the deviation in the measurements may have occurred. In addition, a prosthodontist and a dentistry student made color selections independently of each other under the same conditions. As a result, measurements made by both users deviated compared to the spectrophotometer. This result shows that the experience for color selection with the shade guide is ineffective.

In dental photography, it is recommended to use the cross-polarized filter, 18% gray reference card and standardized parameters for color selection.[2] Studies have evaluated the use of spectrophotometers, intraoral scanners and digital photography for color selection. .[1, 2, 7, 8] However, few studies evaluate smartphone use in color selection.[12, 20] Smile Lite MDP standardizes the light source, allowing the color and amount of light to be used. In addition, light reflections could be prevented with a cross-polarized filter mounted on the device.[21] However, comparisons between the spectrophotometer and dental photographs found ΔE>3.7. In this study, the iPhone XS smartphone camera was used for photos; this device's native camera app does not support RAW photo shooting and white balance adjustment. The manufacturer of Smile Lite MDP recommended the use of SILKYPIX Shot Camera because of the lack of this smartphone. Different smartphones and camera applications were not compared in this study. The white balance setting on SILKYPIX Shot Camera may not be accurate.

Smartphone cameras, unlike digital cameras, do not allow adjustment of shutter speed, aperture, and ISO speed. These settings are essential for adjusting the amount of light in the photo. In this study, it was found that the L* value was incredibly high when comparing dental photos with spectrophotometers. The lightness value, L*, defines black at 0 and white at 100. These results show that the automatic light setting of the smartphone camera or camera application is inadequate. Although the light source is stable, the automatic settings of the smartphone other than the white balance may have affected the standardization of this study. Dental photos showed a high amount of light according to the results of the spectrophotometer. Mahn et al., in their study, reported that the L* and b* coordinates were statistically similar in color measurements with a photo and spectrophotometer using a cross-polarized filter.[1] Otherwise, in this study, only the a* coordinate is statistically similar; there is a statistically significant difference in the L* and b* coordinates. The reason for this difference between studies may be the use of smartphones in this study. In addition, the coordinates a* and b* in the CIELab color space provide information about the hue of color. As a result of adjusting the white balance in photos made using Lightroom software, only changes in a* values were observed. Therefore, an expected result was a change in a* and b* values and no change in L* values on the CIELab color space. However, unlike expected, there was no statistically significant difference in the b* value change. In addition, there was no statistically significant difference in ΔE. The reason for this result may be the adjustment of 5500K light color on the camera app (SILKYPIX Shot Camera) during photo shooting with the smartphone. This value is the color of the Smile Lite MDP light source.

Measurements using a spectrophotometer perform more accurate results due to its easy and fully automatic operation.[22] More accurate results can be obtained by calibration before each measurement. However, difficulty in placing the flat-tipped probe at the correct angle and position on the convex tooth surfaces may be encountered during operation.[18] In this study, the spectrophotometer was used as a reference method and to compare the accuracy of other methods. Studies have confirmed that the choice of tooth color using a spectrophotometer is more accurate and effective than other methods.[6, 23, 24] In addition, spectrophotometers are the best-adapted devices for color measurement, as they record L* a* b* values of colors. However, they must convert these numeric values to a reference in the most related color shade. Dental technicians evaluate the information given to them and create the restoration with different ceramic powders. Some current techniques, such as eLab, try to avoid the limited selection of colors and define the exact proportion of ceramic powders based on the L* a* b* coordinates of the tooth color.[8]

In the limitations of this study include that existing smartphones and different camera applications have not been tested. In addition, smartphone models change periodically, and the results from the current clinical trial may vary depending on the smartphone used.

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