Evaluation of the repeatability and matching accuracy between two identical intraoral spectrophotometers: an *in vivo* and *in vitro* study

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PURPOSE. The purpose of this study was to evaluate the repeatability and matching accuracy between two identical intraoral spectrophotometers. **MATERIALS AND METHODS.** The maxillary right central incisor, canine, and mandibular left central incisor of each of 30 patients were measured using 2 identical intraoral spectrophotometers with different serial numbers (EasyShade V). The color of each shade tab from 3 shade guides (VITA 3D-Master) was also determined with both devices. All measurements were performed by a single operator. Statistical analyses were performed to verify the repeatability, accuracy, and the differences between the devices with paired t-tests, one-way ANOVA, and intra-class correlation coefficients (ICCs) (α=.05). **RESULTS.** A high level of measurement repeatability (ICC>0.90) among *L**, *a**, and *b** color components was observed within and between devices (*P*<.001). Intra-device matching agreement rates were 80.00% and 81.11%, respectively, while inter-device matching agreement rate was 51.85%. ANOVA revealed no significant different color values within each device, while paired t-test provided significant different color values between both devices. The CIEDE2000 color differences between both devices were 2.28±1.61 ΔE_{00} for *in-vivo* readings. Regarding the clinical matching accuracy of both devices, ΔE_{00} values between teeth and matching shade tabs were 3.05±1.19 and 2.86±1.02, respectively. **CONCLUSION.** Although two EasyShade V devices with different serial numbers show high repeatability of CIE L*, a*, and b* measurements, they could provide different color values and shade for the same tooth. ***[J Adv Prosthodont 2018;10:252-8]***

KEYWORDS: Spectrophotometry; Color; Equipment failure analysis; Dimensional measurement accuracy

INTRODUCTION

Color matching would be one of the essential factor to achieve good esthetic results of dental restorations. The perceived color can be determined by complex phenomena, such as specular transmission, specular reflection, diffuse light reflection, absorption, and scattering as a result of light interaction with the tooth.[1] Visual color determination of a natural tooth can vary individually depending on anatomic and environmental conditions, leading to unreliable color assessment.[2-4] Electronic instrumental color measurement can be more consistent because the shade taking devices are not influenced by subjective variables of color analyses.[5] ISO defined the device repeatability as consistency of measurements of color parameters or matching to shade systems in repeated measurements, while the inter-device reliability as the degree of agreement among devices in color measurements or matching scales.[6]

Numerous studies have analyzed the repeatability[7-14] and accuracy[7,9,13-15] of intraoral color-measuring devices. The evaluated intraoral color-measuring devices provided relatively good repeatability of color values and thus, they could be useful for determining and communicating tooth color. On the contrary, the measured inter-device agreement was poor to high depending on the types of devices and the

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measurement conditions. In addition, the operating systems of the devices could affect the reliability and accuracy of tooth color measurements. A spectrophotometer is an analytical instrument used to quantitatively measure the reflection or transmission properties of a material as a function of wavelength, while a colorimeter detects the amount of light passing through a series of color filters.[16] According to the previous study, spot-measurement intraoral spectrophotometer displayed higher reliability than intraoral spectrophotometer of entire tooth measurement or colorimeter.[17] In another study, higher color values were noted with the intraoral spectrophotometer compared to the colorimeter.[8]

Several factors could affect clinical performance of the intraoral spectrophotometer.

The devices measure the curved tooth surface instead of flat surface and small aperture could yield edge-loss effect which can cause a deviation of color interpretation.[18] The translucency of the specimens can affect the device repeatability and accuracy.[19] Furthermore, it is not always possible to position the aperture on the identical tooth surface.[13] VITA Easyshade V (VITA Zahnfabrik, Bad Säckingen, Germany), which is the subject of this study, is a portable spectrophotometer and a new fifth generation of Easyshade. A technology has been developed that allow shade information to be interpreted in the VITA 3D-Master system, VITA classical system, VITABLOCS shades, or tooth bleaching shades. Color communication can be possible with the use of smartphone app VITA mobileAssist via Bluetooth connection.

Although clinical performances of several color measuring devices have been investigated, there is only a limited number of *in vivo* evaluations of the repeatability and accuracy between identical intraoral spectrophotometers. Therefore, the purpose of this study was to evaluate the repeatability and accuracy of 2 identical intraoral spectrophotometers with different serial numbers. The null hypotheses to be tested were that there were no differences in color values and shade within and between 2 identical intraoral spectrophotometers to measure tooth color and that the color difference between recorded tooth shade given by the device and the matching shade guide would be within the range of 50:50% perceptibility threshold ($\Delta E_{00} < 1.3$).

MATERIALS AND METHODS

This study was approved by the institutional review board of Ajou University Hospital (no. AJIRB-MED-SUR-17-330). Thirty subjects, patients of the Department of Dentistry of Ajou University Medical Center (16 women and 14 men, mean age 32 ± 8 years), were recruited. Every participants received written information and signed an informed consent for the study. The maxillary right central incisor, canine, and the mandibular left central incisor of each of 30 participants were measured using 2 identical intraoral spectrophotometers with different serial numbers (VITA Easyshade V, Table 1). Un-restored natural teeth without caries, heterogeneous staining,[17] and irregular surface texture[8] were selected. Before the measurement, any specks from the tooth surface were removed and the tooth was wiped off with gauze to prevent any sliding. Subjects sat in the treatment chair and rested their head on a headrest for stabilization with their mouths slightly open.

All measurements were performed by a single experienced operator. For every measurement, each device was conducted a white balance on its calibration block. The shade was measured at the central tooth area of labial surface[8,15,17] in "base shade determination" mode with the measuring tip lying flush on the tooth surface to achieve an accurate measurement (Fig. 1). The color measurements were carried out 3 times with an interval of 1 hour for each device.[8,17,20] Thus, a total of 270 readings per each device were obtained. The measurement results could be displayed in the VITA 3D-Master system, VITA classical shade system, VITABLOC shade, or bleach index. In this study, VITA 3D-Master system was used to analyze matching performance of the devices. Shade coordinates were also obtained by clicking 3D-Master shade. The degree of matching to shade guide system was indicated by a green (good), yellow (average), or red bar (adjust). In this study, only "good" matching results were used (Fig. 2).

Fig. 1. The Easyshade V determined tooth color with the probe tip placing perpendicular to the tooth surface.

Table 1. Characteristics of VITA Easyshade V

Operating mode	Light source	Measurement range	Launch date	Serial number	Software version
Spectrophotometer	White LED D65	400 - 700 nm	2015	H54626 H53671	V507h V505p

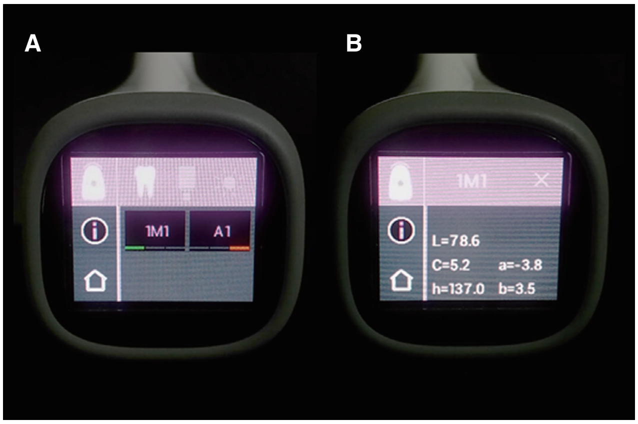

Fig. 2. The measurement result was displayed in the VITA 3D-Master and VITA classical systems (A) and the color coordinates could be obtained by clicking the shade value (B).

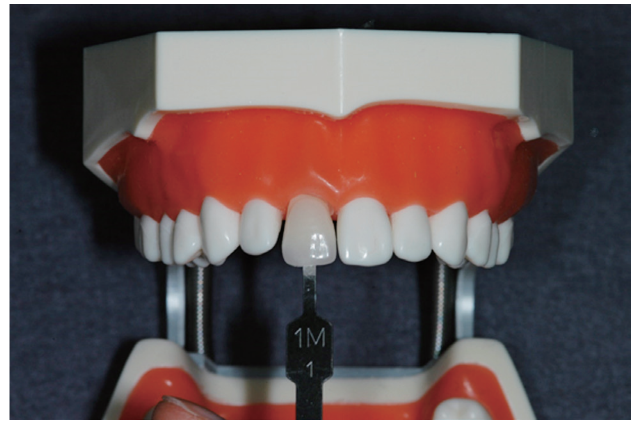

Fig. 3. Each shade tab to be measured was positioned in the dentiform model inside a black box.

To verify the measurement repeatability within devices, the intraclass correlation coefficient (ICC) and 1-way ANOVA followed by Bonferroni multiple comparison for L^*, a^*, and b^* values were analyzed. The ICC was obtained as an average measurement with absolute agreement and a 2-way mixed effect model. For matching reliability within devices, whether or not the obtained shade matched the correct 3D-Master shade tab, intra-device matching agreement rate was calculated.

To assess the inter-device measurement reliability, ICC and paired t-test were conducted for L^*, a^*, and b^* values by using average values of three measurements for each tooth. The CIEDE2000 color differences (ΔE_{00}) between color values from both devices were also calculated;

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2},$$

where $\Delta C'$ and $\Delta H'$ are the differences in chroma and hue for a pair of color values from the devices, S_L, S_C, and S_H are the weighting functions, and the parametric factors, K_L, K_C, and K_H are the correction terms for variations in experimental conditions. R_T is a rotation function for the interaction between chroma and hue differences in the blue region.[21,22] For matching reliability between devices, the shade indicated by each device were compared and a percentage of identical matches to the shade tab for a total of 270 pairs was calculated as an inter-device matching agreement rate.

To estimate the clinical matching accuracy of both devices, each shade tab from 3 VITA 3D-Master shade guide (26 shades per each shade guide system) was positioned in the dentiform model inside a black box (30.0 × 15.0 × 14.0 cm) to mimic the oral cavity (Fig. 3), and then the central area of each shade tab was measured 3 times with an interval of 1 hour[20] for each device (234 measurements per each device). The 9 readings per each 3D-Master shade were obtained and average L^*, a^*, and b^* values were calculated. The ΔE_{00} color difference value between natural tooth and corresponding 3-D Master shade tab was calculated for each device. The calculated values were then evaluated based on the 50:50% perceptibility threshold (0.80 - 1.30 ΔE_{00} units) and 50:50% acceptability threshold (1.80 - 2.25 ΔE_{00} units) from the previous studies.[23-26]

In vitro matching agreement rates within devices and between devices were evaluated by counting the identical shade measurements per each shade tab irrespective of whether the indicated shade by the device selected the actual shade tab. *In vitro* matching accuracy was determined by calculating the percentage of correct shade matches to 3D-Master shade tab. All statistical analyses were performed by using a software (IBM SPSS Statistics for Windows, v23.0, IBM Corp., Chicago, IL, USA) ($\alpha = .05$).

RESULTS

A total of 540 measurements for the *in vivo* evaluation (270 measurements per each device) and 468 measurements for the *in vitro* evaluation (234 measurements per each device) were made in this study. The mean L^*, a^*, and b^* values (SD) for both devices in the *in vivo* models shown in Table 2. Intra-device ICCs for both devices and inter-device ICCs based on L^*, a^*, and b^* measurements of natural teeth are shown in Table 2. Intra-device ICCs for both devices (0.913 - 0.993) and inter-device ICCs (0.897-0.994) were very high and b^* values exhibited the highest repeatability for intra- and inter-device assessment. Although a high level of measurement repeatability among L^*, a^*, and b^* color components was observed between and within devices ($P < .001$), the CIEDE2000 color difference between the devices was 2.28 (1.61) ΔE_{00} units for *in-vivo* readings, which might be an unacceptable color match based on the previous studies.[23-26] ANOVA revealed that there were no significant differences

Table 2. CIE L^*, a^*, and b^* values and intraclass correlation coefficients (ICCs) indicating device repeatability and inter-device reliability in measuring tooth color (n = 270)

Color values	Mean (SD)		ICC		
	Device 1	Device 2	Device 1	Device 2	Inter-device
L^*	82.10 (4.94)	84.90 (5.18)	0.913 ($P < .001$)	0.939 ($P < .001$)	0.897 ($P < .001$)
a^*	-0.44 (1.50)	-0.78 (1.63)	0.967 ($P < .001$)	0.990 ($P < .001$)	0.986 ($P < .001$)
b^*	20.76 (5.87)	21.13 (5.86)	0.992 ($P < .001$)	0.993 ($P < .001$)	0.994 ($P < .001$)

Table 3. Results of ANOVA test within devices and paired t-test between devices indicating *in vivo* measurement differences in CIE L^*, a^*, and b^* color parameters

	ANOVA test		Paired t-test
	Device 1	Device 2	
L^*	$F(2,267) = 1.185$, $P = .307$	$F(2,267) = 1.007$, $P = .367$	$t(89) = -9.205$, $P < .001$
a^*	$F(2,267) = 0.017$, $P = .983$	$F(2,267) = 0.002$, $P = .998$	$t(89) = 9.081$, $P < .001$
b^*	$F(2,267) = 0.017$, $P = .983$	$F(2,267) = 0.105$, $P = .901$	$t(89) = -3.839$, $P < .001$

Table 4. *In vivo* and *in vitro* matching agreement rates of shade measurements within devices and between devices

	Device 1	Device 2	Inter-device
In vivo	80.00%	81.11%	51.85%
In vitro	97.01%	94.02%	11.54%

among L^*, a^*, and b^* color parameters within each device, while paired t-test performed on these values showed significant differences between devices for all color coordinates (Table 3). The matching agreement rates of devices in matching teeth to 3D-Master shade guide systems are given in Table 4. The matching agreement rates within devices were higher than the agreement rate between devices.

The mean L^*, a^*, and b^* values (SD) for each shade tab in the 3D-Master shade were shown in Table 5. The color difference ΔE_{00} values by shade tabs between devices were 2.26 (0.43), which would be an unacceptable color match to the human eye based on the previous studies.[23-26]

As an estimation of *in vivo* matching accuracy, the color difference ΔE_{00} values between recorded shade given by the device and matching shade tab were calculated; 3.05 (1.19) for device 1 and 2.86 (1.02) for device 2. Those values were beyond the 50%:50% acceptability threshold based on the previous studies.[23-26]

In vitro matching agreement rates of shade measurements within devices and between devices were presented in Table 4. The *in vitro* matching agreement rates within devices were higher than *in vivo* agreement rates, while poor agreement rate between devices were noted especially for the *in vitro* setting. With regard to *in vitro* matching accuracy, 20.94% for device 1 and 12.82% for device 2 were found.

DISCUSSION

Based on the results of this study, 2 identical intraoral spectrophotometers (VITA Easyshade V) with different serial numbers exhibited high intra-device repeatability (ICC > 0.9), while the noticeably different tooth color ($P < .001$) could be measured between the devices. The color differences between recorded tooth shade given by the device and the matching 3D-Master shade guide were beyond the range of 50%:50% perceptibility threshold ($\Delta E_{00} > 1.3$) for each device. Thus, the null hypothesis was rejected.

Teeth are usually not one color throughout, but a variety of optical characteristics should be understood before the color interpretation.[27] Thus, clinical shade identification with specific shade guide system would be difficult. In this study, *in vitro* matching agreement rates of shade measurements within devices were higher than *in vivo* matching agreement rates for both devices. A previous study reported that VITA 3D-Master shade guide system included more adequate color range of natural tooth than VITA classical system[28] and that the ceramic restoration fabricated using VITA 3D-Master system revealed smaller color difference with the natural tooth than that fabricated using VITA classical system.[29] Therefore, the measured shade in 3D-Master shade system was used in this study.

In this study, 2 identical devices showed high intra-device repeatability based on ICCs (0.91 - 0.99) and

Table 5. Means (SD) of CIE L^*, a^*, and b^* for each shade tab in the 3D-Master shade guide system (n = 9)

	Device 1			Device 2		
	L^*	a^*	b^*	L^*	a^*	b^*
1M1	83.89 (0.77)	-0.92 (0.16)	11.34 (0.46)	85.37 (1.47)	-1.52 (0.57)	11.02 (2.21)
1M2	83.96 (0.93)	0.30 (0.21)	16.88 (0.63)	87.26 (1.25)	-0.42 (0.17)	16.34 (0.54)
2L1.5	79.11 (1.46)	0.21 (0.15)	15.91 (0.67)	82.31 (1.19)	-0.34 (0.15)	15.71 (0.60)
2L2.5	78.33 (0.98)	0.64 (0.23)	22.32 (2.24)	81.13 (1.01)	0.62 (0.37)	22.01 (2.15)
2M1	79.63 (1.49)	-0.17 (0.05)	13.07 (0.71)	83.51 (1.75)	-0.67 (0.29)	13.00 (1.05)
2M2	79.50 (0.75)	1.41 (0.20)	18.46 (0.42)	82.44 (0.51)	0.84 (0.20)	17.98 (0.28)
2M3	80.17 (0.46)	0.62 (0.14)	24.59 (1.23)	81.92 (1.63)	0.50 (0.17)	22.62 (2.81)
2R1.5	79.74 (0.28)	0.81 (0.28)	14.76 (0.57)	82.27 (0.41)	0.01 (0.26)	13.98 (0.69)
2R2.5	80.80 (0.35)	1.12 (0.19)	23.59 (0.16)	83.38 (0.31)	0.87 (0.19)	23.19 (0.26)
3L1.5	72.98 (0.55)	2.11 (0.16)	18.58 (0.15)	75.89 (0.57)	1.64 (0.26)	18.23 (0.48)
3L2.5	75.04 (0.85)	1.17 (0.12)	25.57 (1.17)	78.03 (0.59)	1.06 (0.07)	26.41 (0.40)
3M1	74.27 (0.17)	1.06 (0.14)	14.00 (0.52)	77.08 (0.48)	0.58 (0.20)	13.94 (0.44)
3M2	74.05 (0.45)	2.44 (0.25)	19.33 (0.74)	77.01 (0.52)	2.33 (0.13)	19.75 (0.42)
3M3	75.14 (0.26)	1.34 (0.12)	27.86 (0.65)	78.20 (0.61)	1.30 (0.11)	28.48 (0.55)
3R1.5	74.63 (0.80)	2.21 (0.11)	16.11 (0.18)	77.58 (0.65)	1.86 (0.11)	16.08 (0.15)
3R2.5	75.37 (0.20)	1.98 (0.07)	26.32 (0.61)	78.13 (0.54)	1.93 (0.09)	26.90 (0.39)
4L1.5	69.10 (0.56)	3.50 (0.28)	20.23 (0.31)	72.37 (1.18)	2.88 (0.61)	21.33 (1.61)
4L2.5	70.09 (0.43)	2.11 (0.20)	28.79 (0.83)	73.03 (0.19)	2.12 (0.20)	30.04 (0.99)
4M1	69.24 (0.29)	2.58 (0.23)	15.88 (0.32)	72.51 (0.38)	2.38 (0.32)	16.23 (0.50)
4M2	70.73 (0.44)	2.41 (0.12)	24.28 (0.50)	74.00 (0.69)	2.43 (0.18)	25.79 (0.70)
4M3	70.81 (0.65)	2.56 (0.07)	31.12 (1.17)	73.69 (0.81)	2.60 (0.09)	32.00 (0.67)
4R1.5	69.73 (0.16)	4.32 (0.15)	19.18 (0.28)	73.73 (0.80)	3.37 (0.50)	21.70 (1.88)
4R2.5	71.14 (0.39)	3.00 (0.19)	28.51 (0.90)	74.36 (0.60)	3.02 (0.20)	28.89 (0.97)
5M1	64.24 (0.15)	4.14 (0.22)	17.60 (0.52)	67.62 (0.25)	3.83 (0.19)	17.33 (0.56)
5M2	66.49 (0.42)	3.56 (0.19)	28.10 (0.84)	69.48 (0.33)	3.50 (0.15)	28.04 (0.74)
5M3	66.50 (0.71)	3.78 (0.13)	34.53 (0.95)	69.16 (1.15)	3.98 (0.08)	35.64 (0.94)

ANOVA testing ($P > .307$), even higher ICCs than those of the previous studies (ICCs: 0.68 - 0.93 in Lagouvardos *et al.*'s study[8] and 0.80 - 0.99 in Lehmann *et al.*'s study[10]) in measuring tooth color. In terms of inter-device reliability, some previous *in vivo* studies reported that inter-device measurement reliability was lower than intra-device measurement repeatability,[8,10,11] while Lagouvardos *et al.*'s[8] *in vivo* study showed that inter-device matching reliability (ICCs: 0.64 - 0.87) was higher than inter-device measurement reliability (ICCs: 0.40 - 0.49). Although higher ICCs (0.90 - 0.99) were calculated in this study than those of the previous studies,[8,10,11] paired t-test revealed significantly different color values ($P < .001$) between devices were noted, suggesting that color data cannot be reproduced in a predictable way even with the identical device.

In the present study, the inter-device color difference values in measuring tooth color were 2.28 (1.61) ΔE_{00} units, which might be an unacceptable color match to the human eye, while those in Lehmann *et al.*'s study were 5.04 - 14.63 ΔE^*_{ab} units. The study used three devices of different specifications (operation mode, light source, measurement region, and spectral resolution), and thus large color differences were identified although color difference was quantified using CIELab formula in Lehmann *et al.*'s study. Recent *in vitro* study[12] investigated the inter-device reliability of 8 identical electronic color measuring devices. They used VITA Easyshade Advance, the fourth generation of VITA Easyshade, and colors were measured on the ceramic samples. Intra-device repeatability of all color parameters (ICCs > 0.99) were slightly higher than those of the present study and the color differences among devices by 3D-Master shade tabs among 8 devices were 0.62 - 1.67 ΔE^*_{ab} units.

One previous study[7] investigated *in vitro* matching accuracy to shade guide systems using an intraoral shade-matching device, ShadeScan, which is a combination of a colorimeter and digital imaging. The matching accuracy to 3D-Master shade system was 54.2%, which was a higher percentage value than that measured in this study with VITA Easyshade devices (12.82 - 20.94%). The operating system and any manufacturing variations of the device might influence the accuracy performance of the electronic shade selection devices. In this study, to identify the device accuracy in measuring tooth color, the CIEDE2000 color difference between recorded shade given by the device and matching shade tab were calculated. Since the obtained values (2.86 - 3.05 ΔE_{00} units) could be considered to be unacceptable,[23-26] unreliable color matching of the device tested in this study would be expected. Several studied investigated the accuracy of color-matching devices. One study measured color deviations of the intraoral devices from the spectrophotometric reference system.[9] Zenthöfer *et al.* used spectroradiometric data as reference values to calculate the color difference[15] and another study compared the devices with reference values of the shade tab from SpectroShade's database.[13]

Several factors, such as an operating mode of the device,[9,13] training and experience of the examiner,[30] tooth position,[30] matching shade guide,[31] and illumination[11] can affect the reliability and accuracy of the intraoral color measuring devices. Different training methods affected the color data and more consistent measurements were noted for canines compared to central incisors in Hassel *et al.*'s study.[30] The most consistent shade match between spectrophotometric shade selection and visual shade selection were noted with VITA classical shade guide system.[31] The illumination effect on the color measurement would be more pronounced with Spectroshade than with Easyshade in Sarafianou *et al.*'s study.[11] In addition, the measurement area of a spectrophotometer could influence the deviation of color readings.[13] In this study, minor variations in device positioning and the convexity of the external tooth surface and the shade tab could affect light interactions with materials causing discrepancies in measurement consistency even between identical devices. In addition, poor matching accuracy for *in vitro* examination with 3D-Master shade guide system may be attributed to possible variations in color parameters among different 3D-Master shade guides.

The limitation of this study was that only 2 devices of a single type were tested. In addition, the number of measurements in clinical setting (3 per tooth) might affect the device repeatability and accuracy.

CONCLUSION

Although two Easyshade V devices with different serial numbers show high repeatability of CIE L^*, a^*, and b^* measurements, they could provide different color values and shades for the same tooth due to spectrophotometric technical sensitivity. Thus, unreliable color determination might be expected between identical devices.

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