Journal of Dental Sciences 18 (2023) 1323–1329

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

Total solution of a smart shade matching

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Received 30 March 2023; Final revision received 5 April 2023
Available online 18 April 2023

KEYWORDS
Advanced reflectionless technology (ART);
eLAB;
Shade matching;
VITA Easyshade V

Abstract *Background/purpose:* The simulated color of restorations plays an important role in improving patient satisfaction. The aim of this study was to test a new intelligent colorimetric solution using the Advanced Reflectionless Technology (ART) monitor and compare them using commercially available shade systems.
Materials and methods: Six participants' right maxillary central incisors were tested with three devices, including the AUO Display Plus (Group A), a Canon single-lens reflex camera with eLAB's polar eyes filter (Group E), and the VITA Easyshade V (Group V). Each porcelain tooth was divided into three areas, and was assigned a CIELAB L*a*b* value by using the VITA Easyshade V. The original data were compared with the CIELAB L*a*b* obtained using the VITA Easyshade V. A prosthodontist compared the color of the porcelain veneers by eyes and gave the scores from 1 to 3.
Results: For the ΔE, the three areas of Group A had the smallest differences between the color of the fabricated teeth and that of the original teeth. Colorimetric analysis indicated that Groups A and V did not differ much in the color of the three areas of the tooth. Groups E and A exhibited significant differences between the cervical third and middle third of the tooth, and Groups E and V exhibited significant differences between the middle third and incisal third of the tooth.
Conclusion: Compared with traditional monitors, ART is closer to real images in terms of color, contrast, and detail grayscale. Technicians are able to produce realistic and pleasing colors.

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https://doi.org/10.1016/j.jds.2023.04.003

Introduction

With the continual development of digital dental technologies and biomedical materials, the production speed of dental prostheses and the precision of dentures are constantly improving. Although the color of dentures does not affect their final function, the naturalness of a denture's color is a key factor affecting a patient's satisfaction with their dentures. According to research, approximately 44%—63% of people who receive dentures perceive a color difference between dentures and adjacent teeth.[1,2] Therefore, the production of prosthetics must account for chewing function restoration and tooth aesthetics.[3,4] In addition, training for dentists and dental technicians in dental color matching is crucial for ensuring dental aesthetics. However, not every dentist or dental technician is sensitive to visual perception, and they must use many current products on the market, such as shade guides, white balance cards, and shade systems[5–9] to accurately compare the color of prostheses and adjacent teeth in order to improve the satisfaction of patients.[10–12] Shade guides are the most commonly used color comparison tool. They are inexpensive and easy to use, and they reduce errors that occur when color matching is done by eye alone. However, according to research, the rate of consistency obtained when shade guides are used by different individuals to compare the same teeth is only 26.6%.[13] Compared with shade guides, shade systems are more expensive, and the operation steps are relatively complicated, but their accuracy is higher; such systems can achieve up to 67% performance accuracy. Moreover, the colorimetric performance of spectrophotometers in shade systems is as high as 93%.[13–15] However, an actual tooth is not a single color. Because shade systems only send color values to dental technicians, perceiving the actual overall color of a tooth is difficult for dental technicians. If photographs are transmitted to dental technicians, the camera model or the screen color on different computers can influence color perception. This study tested a new intelligent colorimetric solution whereby images were captured using a camera and transmitted to the Advanced Reflectionless Technology (ART) monitor to enable technicians to fabricate porcelain veneers of different colors and compare them using commercially available shade system. This enables technicians to identify related differences and produce a veneer with a natural tooth color.

Materials and methods

Specimen preparation

This study was approved by the Ethical Review Committee of the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E(II)-20220042). Six participants were recruited for the study and were tested with three color matching devices. As reported in Table 1 an AUO Display Plus camera (ShadeART 2, Hsinchu, Taiwan) was used for Group A, a Canon single-lens reflex camera (Canon Inc, Tokyo, Japan) with eLAB's polar eyes filter (Emulation S. Hein, Freiburg im Breisgau, Germany) was used for Group E, and the VITA Easyshade V digital spectrophotometer with VITA 3D-MASTER shade guide (VITA Zahnfabrik, Bad Säckingen, Germany) was used for Group V. These three instruments were used to photograph the six participants' maxillary central incisors (tooth 11) without caries, enabling (1) the collection of tooth photos, (2) color coding using a shade guide color, and (3) the assignment of a CIELAB L*a*b* value. A dental technician manufactured a porcelain veneer for the right maxillary central incisor of each participant.

Colorimetric instruments

Smart dental shade matching

For Group A, an AUO Display Plus camera was used to photograph the tooth (Fig. 1). After the photo of the maxillary central incisor (tooth 11) was acquired, it was transmitted to an ART monitor (VT-170AMN1, AUO Display Plus, Hsinchu, Taiwan). The dental technician manufactured a porcelain veneer for the tooth according to the tooth color displayed on the ART monitor (Fig. 2).

Canon single-lens reflex camera and white balance card calibration

For Group E, which served as the control group, the Canon EOS RP and Canon EF100mm f/2.8 L Macro with eLAB's polar eyes filter were used to capture photographs, and the Emulation S. Hein white balance card (Emulation S. Hein, Freiburg im Breisgau, Germany) was applied (Fig. 3). The photographs were then sent to the dental technician's computer, on which eLAB prime software (Emulation S. Hein, Freiburg im Breisgau, Germany) was used to determine the tooth color and assign the CIELAB L*a*b* value. A porcelain veneer was then fabricated according to the determined tooth color.

VITA Easyshade V digital spectrophotometer with VITA 3D-MASTER shade guide

For Group V, the VITA Easyshade V digital spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany) used employed along with the VITA Linearguide 3D-MASTER shade guide (VITA Zahnfabrik, Bad Säckingen, Germany) to measure three areas of the maxillary central incisors, namely the cervical third, middle third, and incisal third, and to assign a CIELAB L*a*b* value and color code to the aforementioned teeth (Fig. 4). Subsequently, the dental technician manufactured color-matched porcelain veneers.

Table 1 Description of the three groups in this study.

Group	Equipment	Type	Output information
A	AUO Solution	Image capture device (Camera)	Tooth color picture
E	Canon single-lens reflex camera with eLAB's polar eyes filter	White Balance Card calibration	Tooth color picture &tooth color information
V	VITA Easyshade V with Vita 3D shade guide	Spectrophotometer	Tooth color information

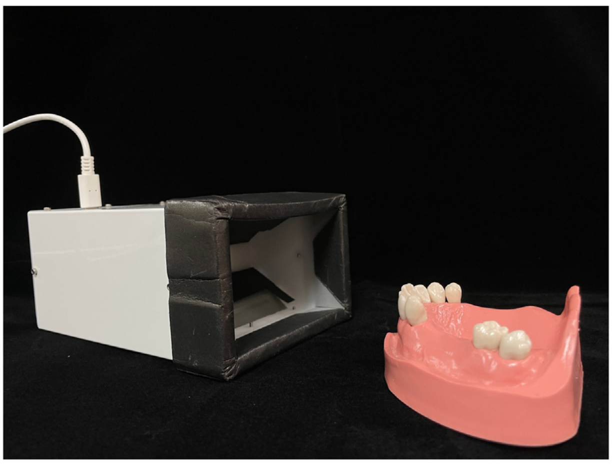

Figure 1 AUO Display Plus camera was used in this study.

Spectrometric measurement

Each fabricated porcelain tooth was divided into three areas, namely the cervical third, middle third, and incisal third, and each area was assigned a CIELAB L*a*b* value by using the VITA Easyshade V digital spectrophotometer. The CIELAB L*a*b* values represent opposing colors. $L^* = 0$ represents black, and $L^* = 100$ represents white; these values reflect the brightness of a tooth. When a* is a negative or positive value, the corresponding colors are green and red, respectively. When b* is a negative or positive value, the corresponding colors are blue and yellow, respectively.

ΔE is used to quantify color variation. The counting formula is $\Delta E = [(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2]^{1/2}$; L^*_1, a^*_1, and b^*_1 represent the formula mean standard values. Each fabricated porcelain tooth CIELAB L*a*b* value in this research was compared with the CIELAB L*a*b* values for tooth 11 obtained using the VITA Easyshade V digital spectrophotometer. Differences for each L, a, b value were also compared. The counting formula is $\Delta L = L^*_2 - L^*_1$; $\Delta a = a^*_2 - a^*_1$; $\Delta b = b^*_2 - b^*_1$. Porcelain veneers were manufactured using three colorimetric instruments. A prosthodontist from Kaohsiung Medical University Chung-Ho Memorial Hospital compared the color of the participants' teeth to that of the porcelain veneers by eye according to the cervical third, middle third, and incisal third areas of the tooth. If they determined the color matching to be close, they scored the matching 3 to 2 points; a score of 1 point indicated the largest degree of color variation.

Statistical analysis

The Kruskal—Wallis test ($\alpha = 0.05$) and Dunn's post hoc test were applied to analyze tooth color discrepancies, and JMP 10.0 software (SAS Institute, Cary, NC, USA) was used for the other statistical analyses.

Results

In the cervical third area of the tooth, each group's colorimetric ΔL color was darker than the original (a negative value). The smallest difference was noted in Group V, followed by Group A; the largest difference was observed in Group E (Table 2). The sequence from the smallest difference to largest difference was thus A → V → E. The score of Group A was significantly higher than that of Group E. For the middle third area, each group's colorimetric ΔL color was darker (a negative value) than the original color. The value for Group A and Group V were 1.52 and −1.68, with Group E obtaining the largest discrepancy (−3.28). Each group's colorimetric Δa color was redder than the original color, with all group's discrepancy values ranging between 3 and 4. The sequence from the smallest difference to largest difference was A → V → E. Each group's colorimetric Δb color was blue. Moreover, the error for the middle third area was larger than those for the cervical and incisal third areas; the sequence from the smallest difference to the largest was also A → V → E. For differences in ΔE, the group with the smallest difference in terms of the comprehensive values was Group A, followed by Group V and Group E; these differences were not statistically significant. According to the observations of doctors, for the middle third area, the color of the manufactured and original teeth was closest in Group A and Group V; these groups had the same discrepancy score. The discrepancy value for Group E was the largest, indicating a significant difference.

The incisal third ΔL color was brighter than that of the original teeth (a positive value). The smallest difference in brightness was observed in Group A, which had a discrepancy value of 3.53; the discrepancy values for Group E and Group V were 4.12 and 4.70, respectively. For the color in this area, the manufactured teeth were all redder than the original teeth, and the discrepancy values for Group A, Group E, and Group V were 3.03, 3.33, and 3.48, respectively. Each group's colorimetric Δb color was bluer than the original tooth color. Group A had the

Figure 2 The dental technician fabricated porcelain veneers based on the ART monitor.

smallest difference in color between the manufactured and original tooth with a value of 2.25; the largest discrepancy value was 5.18 for Group V. The group with the smallest ΔE difference in terms of comprehensive values was Group A, followed by Group E and Group V; these differences were not statistically significant. According to the observations of doctors, the color of the incisal third area was most similar to the original tooth color in Group V, followed by that in Group A and Group E; the inspections revealed a significant difference in the scores of Group V and Group E.

In terms of differences in ΔE, the cervical third, middle third, and incisal third areas of Group A had the smallest different between the color of the fabricated teeth and that of the original teeth. However, the between-group differences were nonsignificant.

The doctors' colorimetric analysis indicated that Group A and Group V did not differ much in the color of the three areas of the teeth (Table 3). Group E and Group A exhibited significant differences between the cervical third and middle third of the teeth, and Group E and Group V exhibited significant differences between the middle third and incisal third of the teeth.

Discussion

In this study, we used the VITA Easyshade V spectrophotometric device,[16] the AUO and eLAB imaging systems.

Figure 3 Canon EOS camera and a white balance card were applied to take pictures.

Spectrophotometric device can be affected by environmental light sources.[14] Before using VITA Easyshade V in this study, we completed a light-correction process to ensure similarity between the light conditions for analysis and those under which the shade matching was completed. The results of VITA Easyshade V—based shade matching were average and similar to the performance achieved in 67% of typical studies.[13—15] The doctors recommended the use of a spectrophotometric device as an instrument for shade matching. Although the scores did not differ significantly between Group A and Group V, the scores were higher in the middle and incision areas. This might be because the light source of the spectrophotometric device and that used by the group of doctors were the same. The limitations of spectrophotometric devices are that the color of the tooth to be analyzed cannot be complex, and only three areas of tooth color can be simultaneously analyzed. Nevertheless, because spectrophotometric devices can adjust to environmental light conditions when matching colors, they are useful and efficient tools for color matching.[17]

To overcome the limitations of spectrophotometric devices, the eLAB imaging system was developed for color matching. Although the shade of the front teeth can be easily matched under the same environmental conditions by using spectrophotometric devices, doing so for the rear teeth is difficult. Environmental light sources often do not reach the rear teeth, which can affect the spectrophotometric device results. In the eLAB system, the light from a camera flash is used as the light source and a white card is used for calibration. The camera flash helps overcome the problem related to the insufficiency of environmental light, and the system software performs color matching by using the white card.[18] The advantage of the eLAB system lies in the fact that it can color match any area of a tooth rather than only the area between the cervical and incisal regions. The largest difference in ΔE might be attributed to the computer screen used by the technician. The porcelain veneers were processed in front of a computer screen.

Figure 4 VITA Easyshade V was used to detect the tooth shade in the cervical third, middle third, and incisal third of a tooth. L: Percentage of lightness value, C: Chroma value, h: Hue value, a: A-axis of the CIELAB, b: B-axis of the CIELAB.

Table 2 The Kruskal–Wallis test was used to compare the differences between CIEL*a*b* values and color discrepancies of different groups.

	Group	ΔL			Δa			Δb			ΔE		
		Mean	SD	*P* value	Mean	SD	*P* value	Mean	SD	*P* value	Mean	SD	*P* value
Cervical third	A	−8.10	3.55	0.9612	2.50	0.72	0.90	4.07	2.94	0.8948	9.69	3.89	0.8490
	E	−8.30	3.98		2.58	0.86		4.73	5.20		10.90	4.32	
	V	−7.82	3.18		2.72	0.93		5.07	3.94		10.04	4.31	
Middle third	A	−1.52	0.87	0.4843	3.03	0.59	0.35	5.60	3.00	0.5671	6.79	2.50	0.2778
	E	−3.28	2.22		3.42	0.43		7.18	4.33		9.15	3.51	
	V	−1.68	4.29		3.35	0.97		6.50	2.50		8.51	2.49	
Incisal third	A	3.53	3.14	0.8102	3.03	1.29	0.70	2.25	3.48	0.2026	6.62	1.78	0.1956
	E	4.12	3.19		3.33	0.90		3.87	3.62		7.69	2.18	
	V	4.70	3.52		3.48	1.21		5.18	3.72		8.92	2.35	

A, AUO Display Plus; E, Canon single-lens reflex camera with eLAB's polar eyes filter; V, VITA Easyshade V; SD, standard deviation.

Although the color matching software could identify the color, the screen might have caused misleading color representation and subsequently affected the results of shade matching. Thus, the eLAB system received the lowest score from the doctors.

The AUO system helped overcome the limitations of the eLAB imaging system and spectrophotometric device. Because the camera used in the AUO system has its own light source, environmental light does not affect shade selection. In addition, because the AUO system uses a camera, a white card is not required for calibration; the camera's settings and white balance remain unchanged throughout the shade selection process. This reduces the likelihood of errors resulting from the use of different cameras for different shades during the matching process.[19] Upon capturing a photo, the AUO software automatically adjusts the white balance and identifies the color. Because the same camera is used for all shades, the accuracy of white balance adjustment is high. In addition, the AUO system includes a screen that displays the true color of a tooth to the technician, thus enhancing the accuracy of shade matching. The ΔE value was lower for the AUO system than for the other two instruments. The doctors' feedback for the AUO system was positive; they assigned it a high score, which was not significantly different from that assigned to VITA Easyshade V.

Table 3 The Kruskal–Wallis test was used to compare the differences between CIEL*a*b* values and color discrepancies of different groups under the observation of the prosthodontist. The post hoc test was the Dunn's test.

	Group	Rank-Score			
		Mean	SD	*P* value	Dunn's test
Cervical third	A	2.50	0.51	0.0013*	A = V, A > E, V = E
	E	1.78	0.90		
	V	2.08	0.81		
Middle third	A	2.36	0.54	<0.0001*	A = V > E
	E	1.28	0.61		
	V	2.36	0.76		
Incisal third	A	1.94	0.75	0.0312*	A = V, A = E, V > E
	E	1.78	0.83		
	V	2.28	0.81		

A, AUO Display Plus; E, Canon single-lens reflex camera with eLAB's polar eyes filter; V, VITA Easyshade V; SD, standard deviation; *, statistical significance ($P < 0.05$).

Advanced Reflectionless Technology (ART) will make a surface structure to change the direction of reflected light and through low reflectivity, coating to reduce the scattered light and outside environmental disturb effectively. Compared to a traditional monitor, ART is closer to the real image no matter the present of its color, contrast, and detailed grayscale. It can also assist the medical staff and technicians to effectively improve the accuracy of interpretation and reduce eye fatigue.[20]

Senior technicians have been accustomed to firing porcelain by using the colorimetric values of dentists' clinically taken images. However, the intelligent dental colorimetric is established in the special design's clinical orientation equipment.[5–9] Use gray card RGB value to capture the image and cloud software to calibrate the color of the teeth and present them through the ART monitor. The AUO system and the ART monitor are easy to operate and can control most factors from chairside color matching to laboratory display of the realistic colors. Although additional equipment is required, the effectiveness and accuracy of color matching makes the system worth the investment. Therefore, in the future, the technician will be able to use the original color data in firing porcelain with the help of this innovative technology to produce realistic and satisfying colors next time.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

The authors are grateful to Southern Taiwan Science Park Precision Health Cluster of National Science and Technology Council [BX-03-11-15-111] for supporting this research. Furthermore, this study was supported by AUO Display Plus Corporation.

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