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ACCURACY AND REPEATABILITY OF DIGITAL INTRA ORAL SCANNER WITH INTEGRATED BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION IN TOOTH COLOR DETERMINATION

Dalia N. Abd Alaziz1 BDS, Sanaa H. Abd Elkader2 PhD,
Islam M. Abdel Raheem3 PhD

ABSTRACT

INTRODUCTION: Recently, digital intraoral scanners (IOS) can determine natural tooth color. However, there is paucity of information concerning shade determination of a new intraoral scanner that uses triangulation combined with bidirectional reflectance distribution function (BRDF).
OBJECTIVES: Assessment of accuracy and repeatability of CS3700 IOS integrated with BRDF compared to reference EasyShade spectrophotometer (VS).
MATERIAL AND METHODS: Twenty participants with vital intact 4 maxillary incisors were recruited in this study. A total of 80 tooth surfaces were scanned by CS3700 IOS. Shade values obtained in Vita classical and Vita 3D master. Vita EasyShade spectrophotometer was used to determine the shade of tooth surfaces to act as a reference device to measure the accuracy of the IOS. The agreement percent of shade values and Lab values was calculated. For the repeatability assessment, all scanning procedures were performed twice by IOS and VS with one month interval.
RESULTS: The agreement of CS3700 was 50.6% as Vita Classical values when compared to VS. The agreement as 3D Master values was 28.6% automatically and 34.5% manually. The mean ΔE between CS3700 and VS was found to be between 6 and 6.9. Repeatability of CS3700 was 71.4% automatically and 75% manually in Vita Classical values. Repeatability of CS3700 as 3D Master was 54.8% automatically and manually. Repeatability of VS was 73.8% as Vita Classical and 69% as 3D Master values.
CONCLUSIONS: The accuracy of CS3700 IOS in tooth shade determination was considered poor to fair when compared to spectrophotometer. Both instruments revealed moderate to good repeatability.
KEYWORDS: Intraoral digital spectrophotometer, Shade matching, Intraoral digital scanner, Color determination.
RUNNING TITLE: Accuracy of intra oral scanner in shade determination.

1 Graduate student, Division of Fixed Prosthodontics, Conservative Dentistry Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
2 Professor, Division of Fixed Prosthodontics, Conservative Dentistry Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
3 Lecturer, Division of Fixed Prosthodontics, Conservative Dentistry Department, Faculty of Dentistry, Faculty of Dentistry, Alexandria University, Alexandria, Egypt

** Corresponding Author:*
E-mail: dalianazeehabdalaziz@gmail.com

INTRODUCTION

Dental restoration is considered successful; when it restores both function and aesthetics of natural teeth (1). Aesthetics plays an important role nowadays; due to increased patient's awareness and demands for aesthetically satisfying restorations (1). Color reproduction of anterior natural teeth to dental restorations is challenging (2). To detect color of a natural tooth, several methods are used for this purpose which include visual or instrumental methods (3).

Visual methods of shade detection comprise the selection of the closest shade tab of a shade guide. One of the most commonly used shade guides is the Vita Classical (Vita Zahnfabrik) which is based on the hue of natural dentition (4). Other shade guides include: Chromascop; Ivoclar Vivadent AG, Bioform; Dentsply Sirona) and Vita 3D-Master [VM]; Vita Zahnfabrik). Vita 3D Master shade guide is more reliable in shade selection procedure. (5). However, visual methods are considered subjective and susceptible to multiple errors due to various factors such as; metamerism, eye fatigue and binocular difference in color perception (3, 6).

Instrumental methods have been developed to overcome the subjectivity and the aforementioned factors that may lead to errors related to the conventional methods (7). Spectrophotometers, colorimeters and digital cameras are color measuring devices that record shade of natural teeth digitally. These devices have been introduced to optimize color determination of natural dentition, hence better communication between clinicians and dental technicians (8-10).

Spectrophotometer working principle is based on the reflection of light energy from tooth surface at 1-25 nm intervals of the visible spectrum (11).

Spectrophotometers are considered reliable instrument and the gold standard in tooth color determination (12). Vita easyshade (Vita Zahnfabrik, Germany) in particular, is used as a reference instrument in shade detection in many studies (7, 13-16).

However, both spectrophotometers and colorimeters may result in incorrect color readings because of the edge loss effect due to the curvatures of the natural tooth surface; these curved surfaces may cause fraction of light and therefore color cannot be detected by the sensor in the device (17, 18).

Recently, digital intraoral scanners have the ability to generate meshes with natural tooth color that would allow color determination of natural teeth (19).

Trios intraoral scanner 3Shape A/S (Copenhagen, Denmark) is one of the intraoral scanners with shade matching function and is based on parallel confocal imaging technology with rapid point and stitch reconstruction (19). Trios intraoral scanner has been proven to be accurate among a total of six tested intraoral scanners in shade detection (20).

However, confocal based intraoral scanners may result in inaccurate color readings and less detailed reproduction of three dimensional color; because confocal systems record shade values and project light from a single angle (21). Triangulation based intraoral scanners integrated with BRDF (Bidirectional Reflectance Distribution Function) have been introduced to overcome the previous limitations, and to reduce the possible source of errors during color registration. This principle can detect tooth shade with varying illumination and detection angles along different paths (22,23).

Carestream CS 3700 intraoral digital scanner (Carestream Dental LLC Atlanta, Georgia, USA) depends on triangulation scanning technology combined with BRDF which allow for smart shade matching and provide a shade report of the teeth (22,23).

The aim of this clinical study is to evaluate the accuracy and the repeatability of the manual and automatic methods of CS 3700 intraoral scanner in shade detection with the Vita EasyShade served as control. The null hypothesis of this research is that there is no significant difference in shade values between the two methods in shade selection of natural teeth; there is a near perfect agreement of the two methods. The secondary null hypothesis is that there is no significant difference in shade values produced by one instrument upon multiple tests (near perfect reliability).

MATERIAL AND METHODS

This study was approved by the ethics committee of Faculty of Dentistry, Alexandria University (serial no. 0253-06/2021) (IRB no: 00010556 – IORG 0008839). It was conducted at the Faculty of Dentistry, Alexandria university, Egypt.

This clinical study aimed to evaluate the accuracy of the manual and automatic methods of CS3700 IOS in comparison to a reference Vita EasyShade spectrophotometer, and the repeatability of both instruments as well. The clinical study was based on the guidelines of the Standards for Reporting of Diagnostic Accuracy Studies (STARD) (24). Sample size was estimated assuming 5% alpha, 20% Beta error and 80% study power. The sample size based on comparison of proportions in a study (7) of accuracy of different intraoral scanners and Vita EasyShade spectrophotometer. Sample size was calculated to be 77 tooth surface. Total numbers of the tooth surfaces that have been measured were 80 to compensate for the drop out. A total of 22 participants aged (20-40 years old) with vital intact, well aligned maxillary incisors (maxillary central and lateral incisors) satisfying the inclusion criteria were recruited in this study. Participants with previous root canal treatment, orthodontic treatment and a history of previous bleaching were excluded from this clinical study. The clinical study was conducted in the post graduate clinic of the Conservative Dentistry Department, Alexandria University. All participants were informed of all procedures to be performed and signed a written consent. Before shade selection procedure, each participant received dental prophylaxis procedure that involved polishing of the teeth to remove any stains to eliminate any possible errors.

Tooth color determination using Carestream CS3700 intraoral scanner

The participants were seated in the same dental chair facing a wall with no windows in the room. There is no direct sunlight in the room, and the light of the dental chair was turned off. Only the room light was turned on (25, 26). A single operator made all the measurements to avoid inter-examiner variation.

Before scanning, the IOS was calibrated then a full arch maxillary digital impression was made for each participant. During scanning procedure, the soft tissue and the teeth were highlighted in blue. The scanning procedure was continued until the blue highlight disappear to capture shade information. After refining the meshes, the “shade matching tool” was used in two modes: “central area check” to make manual selection and “smart shade report” to generate the automatic shade report. For manual shade selection, “central area check” tool was selected, and the shade appeared at different areas by moving the arrow over the tooth, where shade was determined at the middle third of the labial surface at three different positions and the median was taken as the shade value. (Fig. 1) For automatic shade selection, "smart shade report" tool was selected, and the generated shade report presented the readings of the selected teeth in three regions (cervical, middle and incisal). The shade values were drawn from only the middle third. Shade of each tooth surface was recorded in Vita Classical and Vita 3D master values (Fig. 1-3). Color coordinates (L,a, and b) were also recorded based on the conversion table by Bayindir et al (27).

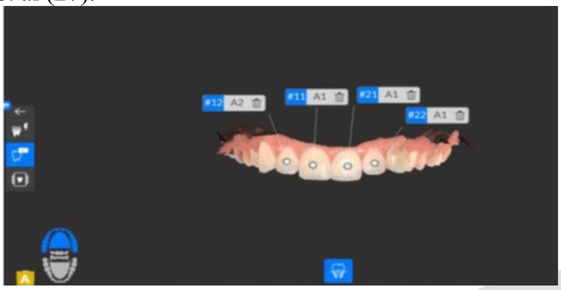

Figure 1: Manual shade selection as Vita Classical values.

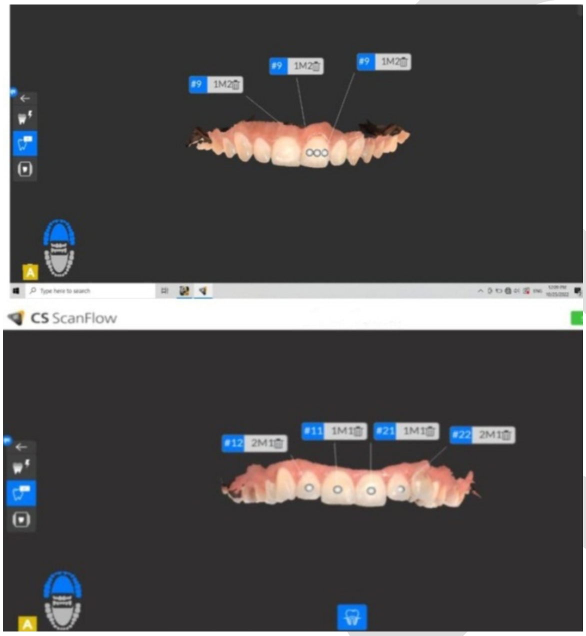

Figure 2: Manual shade selection as Vita 3D Master values.

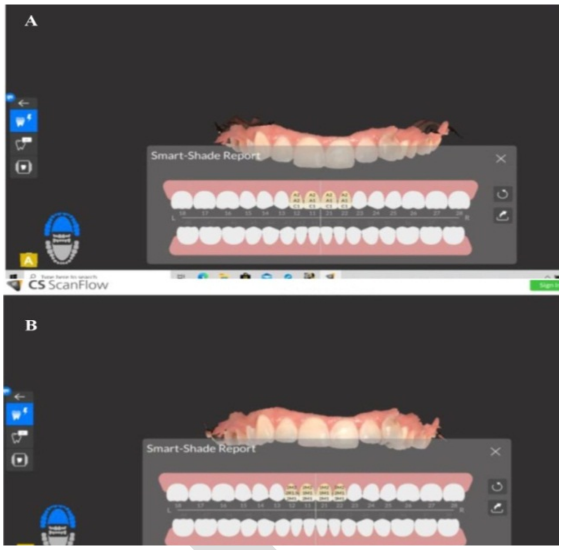

Figure 3: Automatic shade selection as (A) Vita Classical values. (B) Vita 3D Master values.

Tooth color determination using Vita Easyshade spectrophotometer

The same conditions were maintained during shade selection using VS. The Vita Easyshade was calibrated before each measurement according to manufacturer's instructions and was used as control in this clinical study. The probe tip of the spectrophotometer was placed at the middle region of each tooth being considered for comparison (central and lateral incisors). This procedure was performed 3 times for each tooth surface, and the median shade value of the 3 measurements was assumed the drawn value. L, a and b values were determined in each measurement and were averaged for each tooth surface. Shade values were recorded in Vita Classical and Vita 3D Master.

Calculation of mean color difference ΔE

The mean color difference **ΔE** between CS3700 IOS and Vita EasyShade spectrophotometer was calculated using the following formula:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

Calculation of repeatability

For the repeatability assessment, each of the 80 tooth surface was measured twice by IOS and spectrophotometer. One month interval was commenced between measurements at the first and second visits. Before shade selection procedure in the second visit, a dental prophylaxis procedure was also conducted. The measurements by CS3700 IOS and spectrophotometer were obtained in both Vita Classical and Vita 3D Master shade values.

A transparent acrylic resin was used as a guide to be positioned in the same exact location on the labial surface for the spectrophotometric repeatability assessment.

Randomization

In each session, IOS and VS were used to determine the shade value. The sequence of whether the shade is determined by IOS or VS first was randomized. The randomization was done by using online flip coin method (Google flip coin https://g.co/kgs/cR4i7v). The flip coin was made 20 times.

Statistical analysis

Data were analyzed using IBM SPSS for Windows (Version 23.0). Categorical (qualitative) data (shade categories) were represented as frequencies and percentages, while quantitative data (color coordinates) were represented as means and standard deviation (SD). Percent agreement and Kappa coefficient between the spectrophotometer and IOS shade category was calculated. Agreement between color coordinates measured using both techniques was assessed using Intraclass Correlation Coefficient (ICC). Repeatability of measurements was assessed for each technique using Kappa coefficient and ICC for shade and color coordinates, respectively. (Fig. 4)

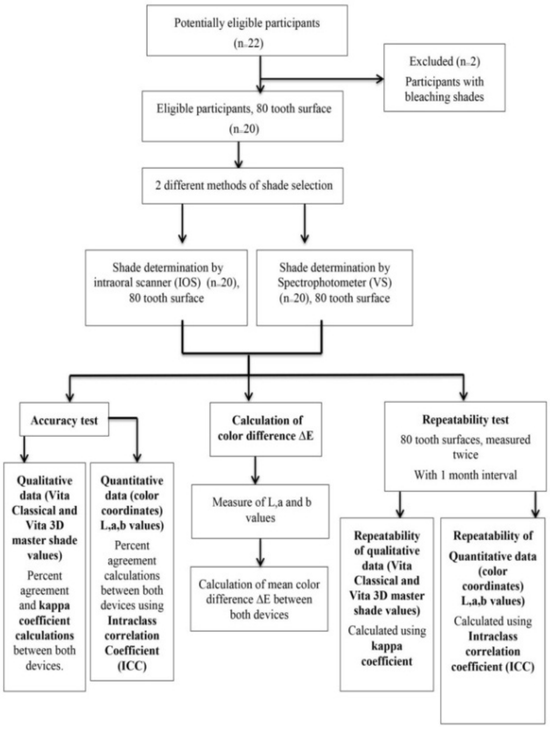

Figure 4: Flow chart.

RESULTS

Patient characteristic

Twenty-two volunteers were evaluated for eligibility (n=22). Upon examination, 2 volunteers were excluded as they had incisors with bleaching shades. A total of 20 participants (6 males, 14 females) with average age 24.5 years were recruited in the study.

Agreement of shade values

The percent agreement of Carestream CS3700 Intra oral scanner when compared with Vita EasyShade spectrophotometer was 50.62% (κ =0.26) and 50.63% (κ =0.26) by automatic and manual methods, respectively when tooth shade was recorded as Vita classical values. While the agreement of the automatic method of CS3700 IOS was 28.6% (κ =0.14) and 34.5% (κ =0.16) by manual method, when shade was recorded in Vita 3D Master values. The percentage of color match between both instruments was higher when tooth shade was recorded in Vita Classical values. (Fig. 5)

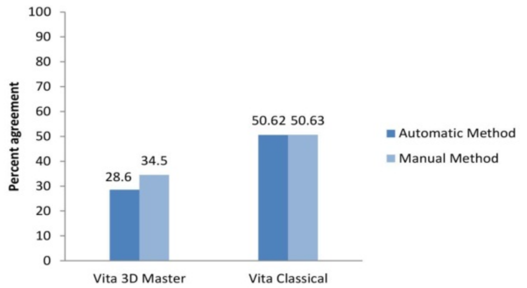

Figure 5: Percent agreement of shade values.

Agreement of color coordinates between Vita EasyShade spectrophotometer and Carestream CS3700 IOS

Statistical analysis revealed a significant agreement of the color coordinates between Carestream CS3700 IOS and Vita EasyShade spectrophotometer ($p < 0.05$). The intraclass correlation coefficient ICC for the automatic and manual methods when shade was recorded as Vita classical values and Vita 3D Master are shown in table 1. The mean color difference values between IOS and VS are shown in table 1.

Repeatability of shade values of Vita EasyShade spectrophotometer and carestream CS3700 IOS

The repeatability of Vita EasyShade spectrophotometer was found to be 73.8% as Vita Classical values, and 69% as Vita 3D Master values. The highest repeatability in this study was observed with the manual method of Carestream CS3700 IOS

DISCUSSION

(75%) as Vita Classical values. When the automatic method was used, the repeatability was 71.4% in Vita Classical values. The repeatability of both automatic and manual methods of IOS was the lowest among all measurements when color was recorded in Vita 3D Master values (54.8%) shown in table 2.

Repeatability of color coordinates

The Intraclass correlation coefficient (ICC) revealed good reliability in the L (0.71) and b (0.97) coordinates of the Vita EasyShade. For the Vita Classical measurements by Carestream CS3700 IOS, the Intraclass correlation coefficient (ICC) range was (0.49-0.71) and (0.65-0.76) for the automatic and manual methods, respectively. Repeatability of color coordinates ranged from poor to good repeatability for the IOS and VS. ICC and confidence interval are shown in table 3.

Table (1): Agreement of color coordinates between spectrophotometer and IOS (Vita Classical, Vita 3D Master)

	Spectrophotometer		IOS			ΔE	ICC	95% CI (p value)
	Mean (SD)							
Vita Classical	L*	84.50 (3.11)	Automatic method	L*	79.74 (2.15)	6.77 (2.766)	0.52	0.25, 0.69 (0.001*)
				a*	-0.02 (0.97)		0.49	0.21, 0.67 (0.002*)
	a*	-0.21 (1.07)		b*	17.55 (2.60)		0.52	0.25, 0.62 (0.001*)
			Manual method	L*	79.83 (2.27)	6.90 (2.84)	0.40	0.04, 0.63 (0.02*)
	b*	20.44 (4.29)		a*	-0.09 (0.10)		0.47	0.17, 0.66 (0.003*)
				b*	17.43 (2.64)		0.49	0.21, 0.68 (0.002*)
Vita 3D Master	L*	84.50 (3.11)	Automatic method	L*	79.84 (6.97)	6.45 (2.93)	0.42	0.10, 0.62 (0.008*)
				a*	0.54 (0.65)		0.56	0.32, 0.72 (<0.001*)
	a*	-0.21 (1.07)		b*	17.57 (3.15)		0.59	0.37, 0.74 (<0.001*)
			Manual method	L*	81.07 (2.89)	6.00 (3.16)	0.75	0.61, 0.84 (<0.001*)
	b*	20.44 (4.29)		a*	0.41 (0.65)		0.50	0.22, 0.68 (0.001*)
				b*	17.53 (2.97)		0.51	0.24, 0.69 (0.001*)

ICC: Intraclass correlation coefficient
ΔE: between IOS and spectrophotometer color coordinates
*statistically significant at p value <0.05

Table (2): Repeatability of shade values using spectrophotometer and IOS

		Spectrophotometer		IOS	
		Vita Classical	Vita 3D Master	Vita Classical	Vita 3D Master
Automatic method	Kappa coefficient	-	-	0.56	0.43
	Percent agreement	-	-	60 (71.4%)	46 (54.8%)
Manual method	Kappa coefficient	0.66	0.52	0.67	0.43
	Percent agreement	62 (73.8%)	58 (69%)	63 (75%)	46 (54.8%)

Table (3): Repeatability of color coordinates measurements using spectrophotometer and IOS

			Spectrophotometer	IOS Vita Classical	IOS Vita 3D Master
Automatic method	L*	ICC	0.71	0.49	0.39
		95% CI (p value)	0.56, 0.81 (<0.001*)	0.30, 0.67 (0.002*)	0.05, 0.61 (0.01*)
	a*	ICC	0.27	0.71	0.80
		95% CI (p value)	-0.12, 0.53 (0.08)	0.54, 0.81 (<0.001*)	0.69, 0.87 (<0.001*)
	b*	ICC	0.97	0.60	0.77
		95% CI (p value)	0.95, 0.98 (<0.001*)	0.38, 0.75 (<0.001*)	0.65, 0.85 (<0.001*)
Manual method	L*	ICC	0.71	0.65	0.84
		95% CI (p value)	0.56, 0.81 (<0.001*)	0.44, 0.78 (<0.001*)	0.75, 0.90 (<0.001*)
	a*	ICC	0.27	0.76	0.85
		95% CI (p value)	-0.12, 0.53 (0.08)	0.62, 0.85 (<0.001*)	0.77, 0.90 (<0.001*)
	b*	ICC	0.97	0.73	0.66
		95% CI	0.95, 0.98 (<0.001*)	0.57, 0.83 (<0.001*)	0.47, 0.78 (<0.001*)

		(p value)			

ICC: Intraclass correlation coefficient
*statistically significant at p value <0.05

In the present study, the accuracy of Carestream CS3700 intraoral scanner was measured when compared to Vita EasyShade spectrophotometer as a reference. The repeatability of both devices was also tested. Accuracy is how close the CS3700 IOS measures the shade of the teeth compared to the measurements obtained by the reference EasyShade Spectrophotometer. While repeatability is the consistency of both instruments to produce similar results upon multiple tests. The percent agreement (accuracy) of CS3700 IOS when compared to Vita EasyShade as a reference was considered fair when tooth shade was recorded in Vita Classical values, and poor agreement was found when shade was recorded in Vita 3D Master values (κ= 0.14 automatic method), (κ= 0.16 manual method). Therefore, the first null hypothesis was rejected. The secondary null hypothesis was also rejected as the repeatability of both instruments was considered moderated to good.

The agreement was better when shade was recorded in Vita classical (Moderate agreement) than 3D Master shade values. This could be attributed to narrower range of coverage in the color space of the Vita Classical shade tabs in comparison to the Vita 3D Master. Therefore, matching to 16 tabs will have the chance to be matched higher than 29 shade tabs.

Interdevice agreement (accuracy) was also calculated using Intraclass correlation coefficient ICC when L, a, and b coordinates were analyzed. The results revealed poor to moderate reliability when shade was recorded as Vita classical and Vita 3D Master values. The highest agreement was found in the L value between the manual method in CS3700 IOS and the EasyShade, ICC= 0.75 which is considered the lower margin of moderate agreement (28). Estimating the agreement of color coordinates between Carestream CS3700 IOS and Vita EasyShade spectrophotometer is not an indication of the scanner's accuracy, as CS3700 IOS cannot generate Lab coordinates which were derived from a conversion table (27). However, interpreting ICC ended up with the same results; poor to moderate/fair agreement. Hence, relying on IOS for color selection is questionable.

The truth behind this high level of disagreement might be the different technologies of both devices to detect the color of natural teeth (29). The CS3700 IOS rely on triangulation technique combined with bidirectional reflectance distribution function (BRDF) for 3D colored image construction. Using BRDF function can detect shades from different angles and along different paths regardless of tooth surface texture, anatomy or curvatures (22,23,30). While EasyShade is based on the conversion of the reflected light from an object into tristimulus parameters based on a D65 illuminant, with the unit itself uses a 20 W halogen bulb (31).

The percent agreement of different intraoral scanners in literature ranges 43- 66 %. The results in this study suggests that CS3700 IOS falls within the same range of percent agreement with easyshade spectrophotometer (7,32). These different results could be referred to the different working principle of each digital intra oral scanner. The 3shape Trios depend on advanced parallel confocal imaging technology with rapid point and stitch reconstruction (19), while mode of acquisition of Omnicam and Primscan depends on a continuous video capturing technology to reconstruct a 3D colored image (7). Additionally, the wide range of accuracy of color determination by different IOS is probably due to the use of different reference devices including different version of Easyshade and other types of spectrophotometers (33). Different light sources of color measuring instruments and IOS might affect the color measurements and lead to different shade values (32).

The mean color difference **ΔE** between Carestream CS3700 IOS and Vita EasyShade spectrophotometer was calculated in this study and was found to be 6 and 6.9. In literature, various studies have reported the threshold for acceptable color difference ranging between 2.72-6.8 (34-37). However, a widely accepted acceptability threshold is 3.7 which lies way below color difference in this study, supporting the poor to medium accuracy of the CS3700 IOS.

The results of the present study revealed good repeatability of both CS3700 IOS and Vita EasyShade spectrophotometer (60%). This is in close approximation with previous in vivo study by Brandt et al, who evaluated the repeatability of Trios scanner (78.3%) and the repeatability of Vita EasyShade which was 76.6% (38). The CS3700 IOS showed a slightly lower repeatability when shade was recorded as Vita 3DMaster values (54.8%) in both manual and automatic methods. This finding is similar to a previous study by Ebeid et al, who reported a slightly lower repeatability of different devices which was 51.7% for 3 shape Trios, 51.9% for CEREC Omnicam, 48.4% for CEREC Primscan, and 44.3% for Vita EasyShade (7).

Intradevice repeatability was also calculated using Intraclass correlation coefficient ICC when shade was recorded as L, a, and b coordinates. The highest repeatability was found in the b value for the spectrophotometer ICC= 0.97, followed by L and a values by manual method of CS3700 IOS, ICC= 0.84, ICC= 0.85 respectively, which is considered highly reliable. However, other studies showed higher repeatability, because it was performed in the laboratory without considering clinical conditions. Moreover, spectrophotometer may produce incorrect color measurements due to loss of light fraction because of natural tooth size compared to the instrument measuring tip and natural tooth anatomy and curvatures (18).

In the present study, the Vita EasyShade spectrophotometer was selected as a reference device due to its high level of accuracy based on results obtained by Kim-pusateri et al (13), who evaluated the accuracy of Vita Easy shade when compared to SpectroShade, ShadeVision, and ShadeScan which was 92.6% in vitro study. Another in vivo study also suggested an accuracy of 83.3% of Vita Easy shade when compared to visual method by Paul et al. (39). These high findings were not in agreement with a study by Mehl et al, who reported an accuracy of 59.2% for the Vita EasyShade spectrophotometer in comparison to intra oral scanner and visual shade matching (33). While some researchers have assumed that both visual and instrumental shade methods could complement each other; hence optimize shade selection procedure (10). Another study by Czigola et al, who evaluated the accuracy and the repeatability of Trios scanner, EasyShade spectrophotometer, Vita Classical and Linearguide-3D Master guides. The supervisor's best match was the reference. The research group reported an accuracy of 21.64% and a repeatability of 56% of the Trios scanner which is in close approximation with the outcome of the present study when shade was recorded in Vita 3D Master values by CS3700 IOS (16). These variations maybe attributed to different soft wares of the color measuring devices, surrounding environment, multilayer nature of the teeth and the human factor error.

In the present study, visual shade matching was excluded since it is affected by several confounding factors such as gender, eye fatigue, lighting conditions (40), and others. This study was carried out to evaluate shade under standardized clinical conditions to minimize errors during shade measurements. Meanwhile, clinical study settings also created a realistic environment for shade measurement, rather than a light box measuring color of extracted teeth or ceramic specimens.

The shade of central and lateral incisors were selected in this study due to its accessibility and to narrow down the possible errors that might come from shadows from oral structures. Choosing the middle third of the teeth for shade selection procedure to ensure more accurate representation of the natural color, as the cervical third may be influenced by the color of the gingival margin and the incisal third may be affected by its translucency, which may not reflect the true color of the tooth.

Factors that may affect the in vivo performance of the shade matching devices include translucency and curvatures of natural teeth, surrounding environment and patient position. Moreover, the use of a conversion table because the scanner cannot produce L, a, and b values which might be less accurate to calculate color difference ΔE. Another limitation of the present study is that repeatability was measured twice while optimizing repeatability could be done by measuring color more than twice.

CONCLUSIONS

The Carestream CS3700 intraoral scanner (IOS) was found to have fair accuracy in determining tooth shade when compared to the Vita EasyShade spectrophotometer. Both instruments showed moderate to good repeatability.

Clinical implications

The results of this study suggest that dentists should not completely rely on the shade generated by CS3700 IOS software, and should use other methods to confirm the nearest shade tab.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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