

# Comparison of Different Digital Color Measurement Methods on Maxillary Anterior and Canine Teeth: A Clinical Observational Study

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## ABSTRACT

*Purpose:* This clinical observational study aimed to determine the reproducibility of digital color measurement methods of different front teeth. *Methods:* Color determination was performed using two spectrophotometric systems (Easyshade Advance; ES and ShadePilot; SP) and digital photography using a camera with ring flash and gray card with subsequent evaluation using computer software (DP; Adobe Photoshop). In 50 patients, at two time points, a digital color determination was performed on maxillary central incisors (MCI) and maxillary canines (MC) by a calibrated examiner. Outcome parameters were: color difference  $E$  based on CIE  $L^*a^*b^*$  values and VITA color match given by spectrophotometers. *Results:* SP showed significantly lower median  $E$  values (<1.2) than ES (<3.5) and DP (<4.4), while no significant differences were found between ES and DP. For all methods, both  $E$  values and VITA color showed lower reliability regarding MC compared with MCI. The  $E$  examination of subareas revealed significant differences in MCI for all devices and in MC only for SP. When comparing VITA color stability, SP showed a significantly higher color match than ES (81% and 57%, respectively). *Conclusions:* Digital color determination methods tested in the current study provided reliable results. However, there are significant differences between the devices used and the teeth examined.

## INTRODUCTION

Determining the correct tooth shade plays a decisive role in esthetic dentistry, as patients increasingly demand natural-looking restorations in the anterior region.<sup>1</sup> It is a particularly challenging task, as the composition of enamel and dentin can vary considerably depending on the tooth and tooth subarea, ultimately influencing the translucency and color appearance. Physical properties such as absorption, scattering, and reflection play a significant role in this process.<sup>1</sup>

The most common method of shade determination for direct and indirect restorations is by visual inspection using dental shade guides.<sup>2</sup> However, this subjective method is prone to inaccuracies caused by general examination conditions (time of day, lighting conditions, environment, or patient's clothing)<sup>2-4</sup> and examiner-dependent factors (experience, age, and gender).<sup>2,4-8</sup> To ensure a more objective method for color matching, the first

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digital devices, such as spectrophotometers, emerged in the 1990s. Previous study results have already advocated the use of spectrophotometers.<sup>9–11</sup> Even though these devices provide significantly better results than visual inspection,<sup>4,12–15</sup> they have poor interdevice reliability<sup>16–19</sup> and cause an additional financial expense for the dentist.<sup>20</sup> In contrast to spectrophotometers, digital photography is part of the standard routine in dental offices to document patient cases or provide the dental technician with photos for the fabrication of indirect restorations.<sup>2,8</sup> However, digital photography can also be used for color determination with standard software programs such as Adobe Photoshop CC (Adobe Systems Incorporated, Delaware, USA).<sup>4,21,19</sup> The tooth color determination of both digital techniques is based on a three-dimensional coordinate system, the CIE L\*a\*b\* system, which was developed by the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination).<sup>2</sup> The three parameters precisely define each color: L\* = L-value along the y-axis defines the perceptual lightness of the color (0 = black, 100 = white), and a\* and b\* = horizontal axes defining the chroma within the green-red range (a-axis) and the blue-yellow range (b-axis).<sup>2</sup> Based on this system, spectrophotometers also provide the corresponding VITA color.<sup>13</sup> Delta E ( $\Delta E$ ) is an established metric for determining the difference between two tooth colors by measuring the distance between the L\*a\*b\* parameters.<sup>22</sup> The higher the value is, the greater the color difference and the more clearly it is perceptible to the human eye. In the literature, the threshold for the acceptable color difference is set at  $\Delta E \leq 3.7$ , while the threshold for perceptibility is set at  $\Delta E = 1$ .<sup>22,23</sup>

Although color determination using digital methods is already well established and has good reliability,<sup>2</sup> no gold standard has been defined. This could be due to the current lack of comparisons between different teeth and tooth areas. Therefore, this clinical study aimed to determine whether digital spectrophotometry and photography allow reliable and reproducible determination of tooth color based on the parameters  $\Delta E$  and VITA color. Furthermore, differences depending on the type of tooth (maxillary central incisor [MCI] or maxillary canine [MC]) or labial subareas (cervical, central, incisal, and total) were investigated. The hypothesis of this study comprised two parts:

1. Both digital methods provide reproducible results ( $\Delta E < 3.7$ ), regardless of the teeth or subareas examined.
2. The VITA colors determined by the spectrophotometers are consistent between the two measurements and show no significant differences between the devices.

## METHODS

### STUDY DESIGN AND PARTICIPANTS

This clinical observational study was performed in full accordance with the Declaration of Helsinki and reviewed as well as approved by the ethics committee of the University Medical Center

Goettingen, Germany (application No. 19/5/12). All patients were informed verbally and in writing and signed informed consent.

Fifty patients (31 females) participated in the study with an average age of 32.7 (SD  $\pm$  11.47). Fourteen subjects were current smokers. All examined teeth and their neighboring teeth were free of restorations and carious lesions. The teeth to be examined were regularly positioned in the dental arch. Patients with rotated or displaced teeth were excluded. Both maxillary canines (MC; World Dental Federation notation [FDI] tooth codes: 13 and 23), and the maxillary central incisors (MCI; FDI codes: 11 and 21), were included.

### COLOR MEASUREMENT METHODS AND PROCEDURE

Color measurements were performed with two digital methods: spectrophotometry and digital photography. This study included two different spectrophotometry systems: VITA Easyshade Advance (ES, VITA Zahnfabrik, Bad Säckingen, Germany) and Degudent Shadepilot (SP, Dentsply Sirona, Konstanz, Germany). The devices were calibrated and adjusted according to the manufacturers' specifications before the measurements. Digital photography (DP) was executed with a digital SLR camera (Canon Eos 500D, Tokyo, Japan) with a ring flash (Soligor AR-40 AF/MF-TTL; Soligor GmbH, Leinfelden-Echterdingen, Germany); all photographs were taken in automatic mode. A vestibular tensioner was inserted, and a gray patch was placed on the gingiva above the incisors (4 x 4 mm, medium gray (18%; L = 54, a = 0, b = 0), type QP Card 101; QPcardAB, Gothenburg, Sweden). For all photographs, the subject's head was positioned with a chin and forehead support at a fixed distance of 50 cm from the camera. Before the measurements, all teeth were cleaned with ultrasound scalers and hand scalers and then polished with a rubber cup (Pro-Cup soft at U=5000/min; (KerrHawe, Bioggio, Switzerland) and polishing paste (Cleanic Prophy Paste, RDA=27; (KerrHawe, Bioggio, Switzerland). Color determination was performed by an experienced and calibrated examiner (calibration: clinical use and analysis of all devices with five different front teeth prior to the clinical study: kappa > 80% for each method) twice per method, 30 minutes apart each time (t1 and t2). The treatment room was darkened, and the ceiling light, according to daylight standard D65, served exclusively as the light source in the room (6 halogen tube lamps, OSRAM Lumilux T8 L 58W/865, 6500K color temperature; OSRAM Licht AG, Munich, Germany) (Strub, JR 2005; DIN 6173-2: 1983-10). The examination lamp of the treatment chair was switched off. The interior design was simple in color (white and gray). The treatment chair was in the same position at all times. In addition, a steady head position was ensured by using a head and chin support.

### COLOR MEASUREMENT ANALYSIS

Both digital methods were used to evaluate the entire labial tooth surfaces (total; DP, and SP) as well as the cervical, central, and incisal subareas (DP, SP, and ES). In contrast to the spectrophotometer SP, ES only allows the evaluation of tooth subareas. Therefore, the total surface was only evaluated with

SP and DP. For ES, the individual measured values were recorded and stored within the device for each subarea. In the case of SP, total images of the teeth were taken, and a subsequent evaluation of the subareas (cervical, central, and incisal) was performed with the aid of the device software, in which the individual measured values were recorded. Both spectrophotometers supplied L\*a\*b\* values as well as corresponding VITA colors. Regarding DP, digital image processing and color determination were performed with Adobe Photoshop CC (Adobe Systems Incorporated, Delaware, USA) following the procedure described by Knösel *et al.*<sup>21</sup>. The Adobe L\*a\*b\* values of the defined areas (cervical, central, and incisal) and the entire labial tooth surface (total) were determined. To enable comparison of the L\*a\*b\* parameters between DP and the spectrophotometers ES and SP, the Adobe L\*a\*b\* values were converted to the standardized CIE L\*a\*b\* values using the following equations:  $L^* (CIE) = L(Adobe) * 100/255$ ,  $a^* (CIE) = (a(Adobe)-120) * (240/255)$  and  $b^* (CIE) = (b(Adobe)-120) * (240/255)$ . To evaluate the reproducibility,  $\Delta E$  values were calculated according to the equation  $\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}$ .

## STATISTICAL ANALYSIS

The statistical analysis was performed using SPSS for Windows, version 24.0 (SPSS Inc., U.S.A.). The level of significance was set at  $p < 0.05$ . The tested variables showed no normal distribution (Kolmogorov-Smirnov test); therefore, nonparametric tests were used throughout this study. The Wilcoxon signed-rank test was used when comparing the measured CIE L\* parameters between two points in time (t1 and t2) divided according to methods, tooth subarea, and tooth type. When comparing  $\Delta E$  within each method and focusing on the subareas (cervical, central, incisal and total), the Friedman test was used. When comparing  $\Delta E$  among methods, the Mann-Whitney U test was chosen whenever two methods were compared and the Kruskal-Wallis H test when more than two methods were compared. VITA color stability was analyzed using the Fisher's exact test.

## RESULTS

### REPRODUCIBILITY ( $\Delta E$ )

SP showed a significantly higher reproducibility ( $\Delta E$ ) for all teeth and subareas (cervical, central, incisal, and total) compared with ES and DP, while these two methods did not differ significantly (*Figure 1*). The assessment of the total labial surfaces showed median  $\Delta E$  values for SP well below the visible color difference (MC and MCI  $\leq 1.2$ ), while  $\Delta E$  for DP was above the threshold regarding canines (MC  $\leq 3.4$ /MCI  $\leq 3.9$ ) (*Table 1*). For the subareas, slightly higher  $\Delta E$  values were found on average for the canines than for the central incisors. While median  $\Delta E$  values of 2.3-3.4 (MCI) and 3.0-4.4 (MC) were calculated for ES and DP, the measured color differences of SP were very close for MCI and MC in a narrow  $\Delta E$  range of 0.8-1.1 (*Table 1*). The comparison of the subareas did not show

a clear trend regarding  $\Delta E$  (*Table 1*). In the three CIE L\*a\*b\* parameters, only the L\* values showed significant differences between measurements t1 and t2 (*Table 2*). The parameter for lightness L\* decreased from cervical to incisal across all methods and teeth. The L values ranged from 70-83 for incisors and 65-77 for canines. The incisors showed higher L values than the canines in the subareas and the entire labial surface. Significant differences were found between measurements t1 and t2 for all teeth using SP. The other two methods (ES and DP) showed significant differences in the subareas of the incisors (*Table 2*).

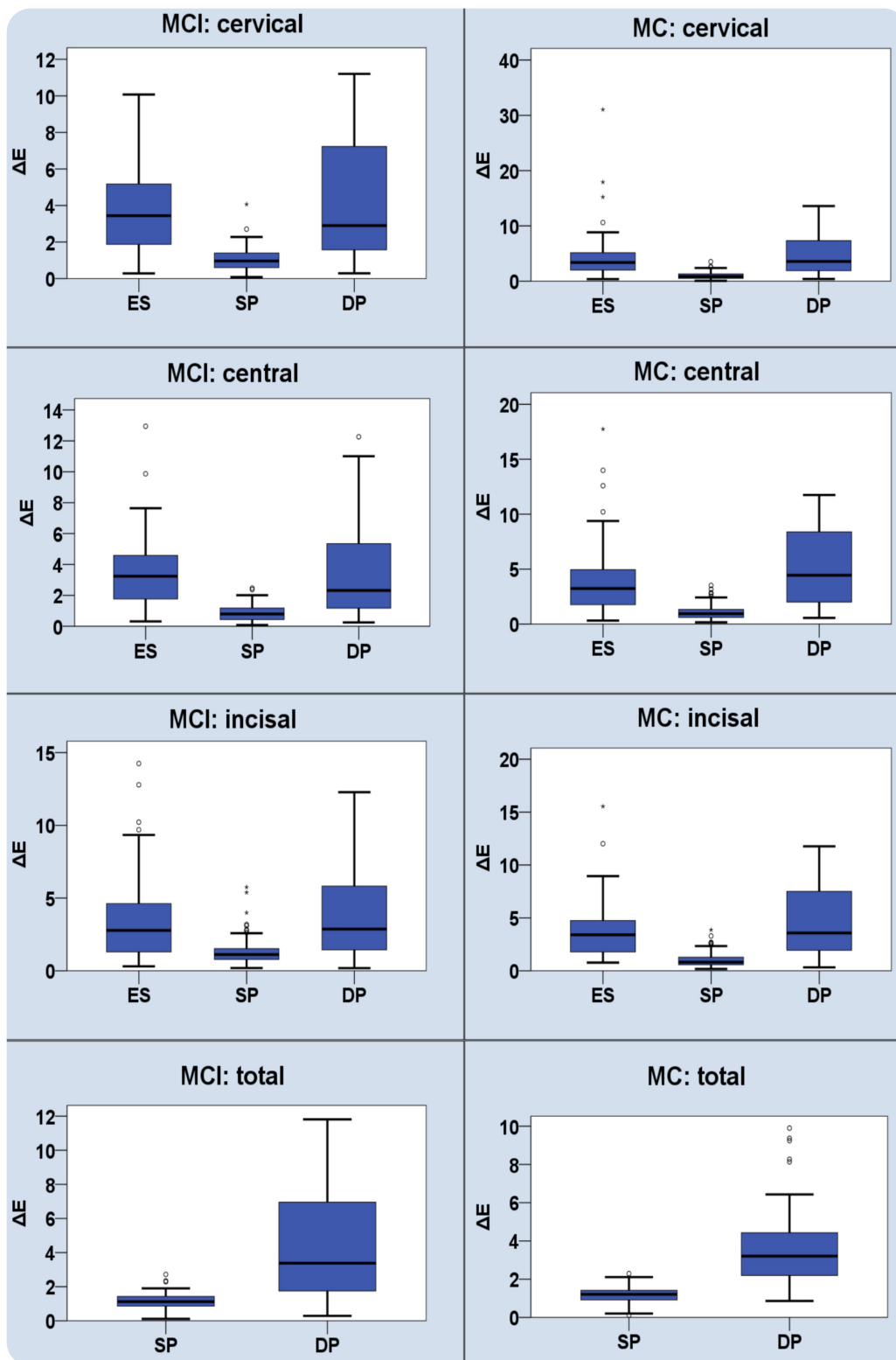
## VITA COLOR DETERMINATION

Significant differences in Vita color determination were found between the two spectrophotometers, with significantly higher matches achieved by SP (*Table 3*). While SP reached an average consistency within the subareas of 81%, the values for ES were about 57%. In comparison, a high level of consistency was achieved when considering the total areas in relation to the subareas as well as MCI in relation to MC. Incisal color determinations were less consistent for both canines and incisors than for the other two subareas (*Table 3*).

## DISCUSSION

The hypothesis that spectrophotometry [ES, SP] and digital photography [DP] provide reproducible results based on  $\Delta E$  was partially rejected as differences were found depending on the teeth examined: Overall, the reproducibility of SP was better than ES and DP. While all digital methods (SP/ES/DP) provide reproducible results based on  $\Delta E$  for the maxillary central incisors, for the maxillary canines, the threshold for the visible color difference ( $\Delta E > 3.7$ ) was partially crossed using DP. SP showed significantly lower values at the threshold of perceptibility ( $\Delta E = 1$ ) than ES and DP (*Figure 1, Table 1*). Spectrophotometers provide different results regarding VITA color stability depending on the device, with SP being preferable to ES. The examination of the subareas revealed significant differences depending on the parameter used. When referring to VITA color stability, the total area should be used for evaluation; for  $\Delta E$ , the subareas seem to provide more accurate results.

Heterogeneous results were observed for the two spectrophotometers investigated in this study. While very low median  $\Delta E$  values between 0.8 and 1.1 were obtained for the SP device, ES showed significantly higher median  $\Delta E$  values ranging from 2.8-3.4. Even though the median values were below the threshold of acceptable color differences for all teeth, the high interquartile range must be taken into account. Therefore, based on the current study results, the ES device can only be considered reliable to a limited extent. In other studies, however, ES proved to be an accurate and reliable color determination device.<sup>10,11,18</sup> Mean  $\Delta E$  values of 2.1 were reported by Olms *et al.*, where, in contrast to the current study, indirect metal-ceramic



**Figure 1:** Comparison of  $\Delta E$  between all digital color-measuring methods (ES, SP, and DP) subdivided according to maxillary central incisors (MCI) or maxillary canines (MC) and the areas (cervical, central, incisal, and total) examined. The statistical analysis was carried out using the Kruskal-Wallis test (cervical, incisal and central) and Mann-Whitney U test (total). While the median and the 25th-75th percentiles are plotted in the boxes, the T-bars correspond to the smallest and largest values. The outliers are values that were between  $1\frac{1}{2}$  - 3 box lengths outside the box. They are shown as circles in the graphs, while extreme values that were measured more than three box lengths outside the box are plotted as crosses.

restorations were investigated.<sup>11</sup> Therefore, it is questionable whether comparing the  $\Delta E$  values between natural and artificial teeth is useful as light absorption and scattering differ greatly in these cases. Their study reported mean values for the two ES

devices between 3.73 and 4.06 and considered them acceptable.<sup>10</sup> Although the measurement results were similar to the results of the present study (Table 1), the author groups interpreted the results differently because of the different threshold

**Table 1. Reproducibility ( $\Delta E$ ) from t1 to t2 within each methods for all subareas and teeth. The mean  $\pm$  standard deviation and median [interquartile range] were calculated. Statistical analysis was performed using the Friedman test.**

Type of teeth	Method	Cervical	Central	Incisal	Total labial surface	p value
MCI	DP	4.16 $\pm$ 3.21	3.48 $\pm$ 2.98	3.66 $\pm$ 2.89	4.24 $\pm$ 2.70	0.005*
		2.90 [1.57; 7.25]	2.32 [1.17; 5.42]	2.87 [1.40; 5.94]	3.38 [1.75; 6.96]	
	ES	3.76 $\pm$ 2.35	3.53 $\pm$ 2.14	3.36 $\pm$ 2.76		0.007*
		3.44 [1.88; 5.18]	3.24 [1.76; 4.59]	2.78 [1.30; 4.62]		
MC	SP	1.07 $\pm$ 0.64	0.86 $\pm$ 0.50	1.32 $\pm$ 0.92	1.13 $\pm$ 0.51	<0.001*
		0.97 [0.60; 1.40]	0.80 [0.44; 1.18]	1.12 [0.78; 1.59]	1.12 [0.86; 1.43]	
	DP	4.01 $\pm$ 2.55	5.02 $\pm$ 3.39	4.67 $\pm$ 3.15	4.85 $\pm$ 2.92	0.181
		2.98 [2.01; 6.04]	4.39 [1.78; 7.95]	3.63 [2.06; 7.46]	3.94 [2.39; 7.79]	
ES	4.40 $\pm$ 4.03	3.84 $\pm$ 2.88	3.91 $\pm$ 2.96		0.227	
	3.34 [2.26; 6.04]	3.23 [1.92; 5.22]	3.43 [1.71; 4.94]			
	SP	1.09 $\pm$ 0.63	0.88 $\pm$ 0.53	1.25 $\pm$ 0.76	1.10 $\pm$ 0.48	<0.001*
		0.96 [0.60; 1.42]	0.81 [0.48; 1.10]	1.07 [0.72; 1.51]	1.13 [0.75; 1.38]	

MCI: maxillary central incisors; MC: maxillary canine; ES: Easyshade Advance; SP: Shadeplot. Statistical analysis was performed using the Friedman test. \*Significantly associated ( $p < 0.05$ ).

definitions, as the defined threshold would have been exceeded in this study. When comparing the two spectrophotometry devices, SP achieved significantly lower  $\Delta E$  values than ES. In contrast, in a study by Ali *et al.*, both devices (SP/ES) resulted in similar  $\Delta E$  values of approximately 3.6 but revealed poor inter-device reliability.<sup>18</sup> While the conclusion, according to Ali *et al.*, is primarily based on not interchanging the devices between measurements, the present study indicates a benefit of the SP device compared with the ES device. However, only the central region of the maxillary central incisor was included in the study of Ali *et al.* The current study was able to show significant differences between the subareas investigated (Table 1), but a clear trend could not be identified based on the data obtained. The consideration of the total area, however, seems to result in higher  $\Delta E$  values.

In the present study, the  $\Delta E$  comparison between incisors and canines provided reliable results for both spectrophotometry devices. This is consistent with the results of Klotz *et al.*, who came to similar findings when comparing incisors and premolars.<sup>9</sup> Apart from this study, previous studies focused on maxillary (central) incisors.<sup>12,14,15</sup> Even though these teeth are of particular interest to patients, the reliability of digital color measurement devices for different teeth and tooth subareas should be verified in further studies.

In the current study, digital photography was performed with the use of a ring flash and a gray reference card to improve consistency when recording colors. Other studies support the benefit of color matching using a gray card.<sup>8,20</sup> Jorquera *et al.* recommend the use of a gray card to enable standardized color determination,<sup>15</sup> resulting in acceptable  $\Delta E$  values of 2.75 when using a digital camera.<sup>15</sup> Comparing the results with the median values for incisors of this study,  $\Delta E$  values were similar (2.32–3.38). Furthermore, the present study showed that higher  $\Delta E$  values were measured for all areas when DP was used to examine maxillary canines. This could be because digital photography does not allow images to be taken in the tooth axis regarding canines, which may have led to inaccuracies and thus higher  $\Delta E$  values. While other studies have identified an influence of lighting conditions, camera settings, tooth hydration, or patient positioning,<sup>4</sup> little attention has been given to differences depending on tooth position in the dental arch and associated variations such as light and shade conditions or the positioning of the devices. While one study compared anterior and posterior teeth for spectrophotometry,<sup>9</sup> this does not seem to be the case for digital photography concerning  $\Delta E$ . For canines, it, therefore, seems reasonable to combine digital photography with visual color determination,<sup>2</sup> until further study results are available.

**Table 2.** Results of the measured CIE L\* parameter divided according to methods, tooth subarea, and tooth type. The mean ± standard deviation and median [interquartile range] were calculated.

Parameter	Tooth subarea	Type of teeth	Method								
			ES		SP		DP				
	t1	t2	p	t1	t2	p	t1	t2	p		
L*	cervical	MCI	81.79 ± 4.67 82.06 [79.13; 84.94]	82.67 ± 4.64 83.39 [79.35; 86.26]	0.010*	74.79 ± 2.43 75.08 [73.31; 76.47]	75.15 ± 2.61 75.22 [74.10; 76.51]	<0,001*	78.62 ± 4.07 78.90 [76.22; 82.11]	79.19 ± 4.21 78.94 [76.91; 82.08]	0.132
		MC	76.89 ± 4.75 77.42 [74.01; 80.38]	76.32 ± 5.60 77.04 [73.59; 80.09]	0.356	71.26 ± 2.80 71.69 [70.14; 72.91]	71.45 ± 2.89 71.90 [70.26; 73.41]	0.013*	65.08 ± 5.26 65.39 [61.34; 68.82]	65.86 ± 5.42 66.11 [62.41; 69.12]	0.081
	central	MCI	78.96 ± 4.67 79.32 [75.71; 81.92]	79.76 ± 4.64 80.05 [76.55; 83.66]	0.013*	76.02 ± 2.97 76.09 [74.46; 78.04]	76.33 ± 3.11 76.39 [74.74; 78.08]	<0,001*	80.17 ± 4.10 79.78 [77.69; 82.98]	80.88 ± 4.30 80.36 [78.41; 83.56]	0.038*
		MC	74.93 ± 4.80 75.58 [71.53; 78.54]	75.05 ± 5.20 75.57 [72.15; 78.11]	0.686	71.95 ± 2.70 72.00 [70.49; 73.45]	72.24 ± 2.71 72.25 [70.93; 73.76]	<0,001*	68.00 ± 4.73 68.00 [64.15; 71.51]	68.85 ± 5.12 68.84 [66.05; 72.68]	0.055
	incisal	MCI	74.34 ± 3.97 74.24 [72.25; 76.94]	75.50 ± 4.4 75.81 [72.79; 78.57]	0.007*	70.10 ± 3.27 69.96 [68.26; 71.94]	70.47 ± 3.83 70.39 [68.50; 72.12]	0.005*	76.76 ± 4.60 77.11 [74.11; 79.62]	77.59 ± 4.86 77.30 [74.72; 80.40]	0.026*
		MC	72.14 ± 4.22 72.86 [68.91; 75.15]	72.48 ± 4.97 72.47 [69.81; 75.47]	0.586	67.51 ± 2.93 67.07 [65.63; 68.92]	67.83 ± 2.92 67.35 [66.08; 69.32]	0.001*	65.33 ± 4.90 64.97 [61.39; 68.44]	66.23 ± 5.24 65.64 [62.38; 70.37]	0.050
	total	MCI	-	-	-	74.91 ± 2.81 74.85 [73.36; 76.71]	75.21 ± 3.04 75.23 [73.59; 76.96]	<0,001*	78.60 ± 4.10 78.25 [76.20; 81.24]	79.32 ± 4.29 79.12 [76.80; 81.84]	0.056
		MC	-	-	-	71.27 ± 2.65 71.25 [69.81; 72.72]	71.55 ± 2.65 71.51 [70.19; 73.14]	<0,001*	66.48 ± 4.75 66.23 [62.30; 69.58]	67.34 ± 5.06 66.97 [64.63; 71.48]	0.050

MCI: maxillary central incisors; MC: maxillary canine; ES: Easysshade Advance; SP: ShadePilot; DP: digital photography. Statistical analysis was performed using the Wilcoxon signed rank test. \*Significantly associated (p<0.05).

**Table 3. VITA color stability of the spectrophotometers used between measurements t1 and t2 for all labial subareas of the maxillary central incisors and canines.**

Type of Teeth	Tooth subarea	ES (%)	SP (%)	p value
MCI	cervical	62.0	86.0	< 0.001*
	central	64.0	85.0	0.001*
	incisal	57.1	84.0	< 0.001*
	total	-	88.0	-
MC	cervical	61.0	84.0	< 0.001*
	central	59.0	77.0	0.010*
	incisal	38.0	70.0	< 0.001*
	total	-	84.0	-

MCI: maxillary central incisors; MC: maxillary canine; ES: Easyshade Advance; SP: ShadePilot. Statistical analysis was performed using the Fisher's exact test. \*Significantly associated ( $p < 0.05$ ).

However, the fact that the  $\Delta E$  values in the present study were generally slightly higher than those in other studies may be due to differences in the camera settings. In a study by Sampaio *et al.*, different camera settings were tested, showing very high  $\Delta E$  values of 7.5 when using a digital camera with ring flash.<sup>20</sup> It was concluded that acceptable  $\Delta E$  values of 3.4 could only be achieved when a cross-polarizing filter was used. This is also consistent with previous studies, which have noted the advantage of using a cross-polarization filter to minimize reflections caused by the camera flash.<sup>2,4,15</sup> Presumably, more satisfactory results could have been obtained for canines using an additional polarizing filter, as in the present study most  $\Delta E$  values were already just below this threshold (Table 1).

Regarding the general comparison of color determination methods, a systematic review has already concluded that both digital photography and spectrophotometry are superior to visual color determination.<sup>2</sup> In addition, two studies showed no significant differences when comparing these digital methods to each other.<sup>14,19</sup> This was also evident in this study as spectrophotometry using ES, and digital photography showed no significant differences (Figure 1).

Whereas the comparison of the  $L^*a^*b^*$  parameters between methods is not possible because spectrophotometers do not provide standardized coordinates to compare with CIE  $L^*a^*b^*$ ,<sup>24</sup> the analysis between measurements within each method was possible. In the present study, only the L value showed significant differences, with incisors being more susceptible to change than canines (Table 2). This has also been confirmed by other research groups, who consider luminosity a decisive factor for accepting color differences.<sup>19,20,25</sup> The

present study showed that spectrophotometry devices differ regarding reproducibility based on the VITA color; therefore, the second hypothesis must be rejected. The consistency of the VITA color is significantly higher for the SP device than for the ES device (Table 3). Similar values for ES were obtained in a study by Khurana *et al.* with a VITA shade match of 50%.<sup>26</sup> In the current study, the incisal area showed lower stability than the other subareas. It could be explained by the higher translucency and differences in enamel and dentin proportions in this area. In contrast to the results based on the  $\Delta E$  values, the VITA shade showed good agreement in the assessment of the total labial surface, which could be because each VITA shade extends over a wide  $L^*a^*b^*$  range.

A limitation of this study was the lack of inclusion of different light-correction devices. Only one digital camera with a ring flash but without a cross-polarizing filter was used. Inclusion could have improved the results for DP, especially for the canines. In addition, the study was conducted by only one examiner who was experienced and calibrated with the methods / devices. A strength of this *in vivo* study was the inclusion of incisors and canines as well as different labial subareas for assessing the reliability of digital color determination methods. Further studies should be conducted focusing on this aspect, and they should include smartphones as the most recent implementation in the dental digital field. Although this study included mostly young patients (32.7 years  $\pm$  11.47) and fourteen smoker; the aspect of a potential influence of age as well as smoking on tooth color was not considered separately. This aspect should be include and regard in future studies.

As the values in this study were not normally distributed, the median was chosen as the primary reference value. However, as the mean value was given as a standard in previous studies, the mean values were also displayed in Tables 1 and 2. Considering the mean  $\Delta E$  values in the present study, both ES and DP showed unsatisfactory results, especially regarding the canines (Table 1). The differences in the outcome of our study when the median or mean was used indicate how important it is to use the correct statistical reference value.

## CONCLUSIONS

Considering the limitation of this study, digital color determination methods provide reliable results. However, there are significant differences between the devices used and the teeth examined. Thereby, the results on incisors were more reliable compared with canines, especially regarding digital photography. Therefore, digital examination methods can't be unrestricted recommended for color determination in clinical practice. Visual color determination is still the gold standard in clinical practice; digital methods could be considered in addition to the standard.

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