Assessment of a new photographic system used in dentistry

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The aim of this study was to assess the role of a polarizing filter upon the accuracy of shade matching, when digital photography, with a system specifically designed for dentistry was used. CIE L*a*b* color parameters obtained from digital images, taken in two different conditions were compared with the parameters recorded with spectrophotometer Vita EasyShade Advanced 4.0 considered as standard. All the values for ΔE2000 parameter calculated between spectrophotometry and digital photography (with direct and polarized light) were over the acceptability threshold value (ΔE>1.87). The use of digital photography and polarizing filters can be considered as alternatives to the current methods for shade matching.

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Keywords: Spectrophotometer, Color, Digital photography, Shade matching, Polarizing filter

1. Introduction

In esthetic restorative dentistry, accurate shade matching determined visual or with instrumental methods is a very important task for the success of the treatment.

Visual shade matching obtained with shade tabs is considered to be less reliable then the instrumental methods because it can be influenced by external variables such as the factors related to the observer or the illuminants [1].

A clinical study conducted on 3758 anterior teeth of 106 patients regarding evaluation of the visual and spectrophotometric shade analysis shown that the results of spectrophotometry were identical in 89.6% of the cases compared to 49.7% for visual assessment [2].

Instrumental methods for shade matching (spectrophotometers, colorimeters, digital cameras and imaging systems) were developed for accurate shade taking in clinical dentistry.They are considered more effective then visual methods [1,3], but in their review about dental color matching instruments and systems, Chu SJ et al. [4] concluded that whenever possible, both instrumental and visual color matching method should be used, as they complement each other and can lead towards predictable esthetic outcome.

Digital photography in dental medicine has become a useful method for clinical cases illustration, important for patient, dental technician and other practitioners. The details obtained using standardized photos, helps the dentist to understand better the cases and interventions performed, contributing to its professional development.

Using proper techniques, equipment, training and implementation, digital dental photography can be a suitable tool for diagnosis and documentation [5].

Jarad FD et al. [6] found statistically better results for a computer matching method based on digital photography, compared to the conventional matching, with 61% correctly matched shade tabs compared to 43% for the conventional method.

Polarizing filters are lately introduced in dentistry as devices attached to different instruments for dental use, with the aim of reduction the glare from images. In clinical observation, the polarizing filter attached to the color corrected lamp Smile Lite (Smile Line, St-Imier, Switzerland) allows for a better visualization of the translucent areas of the tooth [7].

In addition to lens and flash, polarizing filters are also used with professional digital camera in dentistry.

Clinical relevance: to evaluate the efficiency of shade matching using digital photography taken under two different conditions: a. with polarizing filters and b. without polarizing filters attached to the flash.

The following null hypotheses were tested:

1. There was no difference between L*, a*, b* color values recorded with digital photography in the two different conditions and the coordinates indicated by the Sperctophotometer VitaEasyshade Advanced 4.0, used as reference.

2. There was no difference between ΔE color differences values when comparing spectrophotometric analysis with digital photography in two different conditions.

2. Objective

The aim of this study was to assess the role of a polarizing filter upon the accuracy of shade matching, when digital photography, with a system specifically designed for dentistry was used.

3. Materials and methods

3.1 Set-up used for the measurements

The CIE L*a*b* is a three-dimensional real number space, that contains an infinite possible representations of colors, where CIE L* coordinate (lightness or value) is represented on a vertical axis, with values ranging from 0 (black) to 100 (white). The color channels, a* and b*, represent true neutral gray values at a* = 0 and b* = 0. The red/green opponent colors are arranged along the a* axis, the yellow/blue opponent colors are distributed along the b* axis [8].

The color parameters L*, a*, b* were measured on all the 26 shade samples from a Vita 3D Master shade guide (VITA Zahnfabrik GmbH, Bad Säckingen, Germany). In order to simulate the arrangement of natural dentition, an artificial maxillary arch was used. The shade tabs were placed, one by one, in the position of 1.1; a transparent silicon index was made over the maxillary frontal group with a round opening of 6 mm diameter –corresponding to the central area of the sample (Fig. 1).

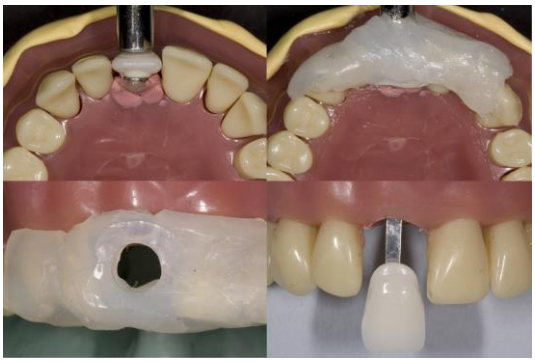

Fig. 1. Set-up used for the measurements

3.2 Spectrophotometric measurements

The spectrophotometric measurements were performed with a Vita EasyShade Advanced 4.0 spectrophotometer (VITA Zahnfabrik GmbH, Bad Säckingen, Germany), under D65 illuminant provided by the color viewing box LED Color Viewing Light (JUST Normlicht Inc., Langhorne, USA). The spectrophotometer was calibrated at the beginning of each color measurement.

The tip of the spectrophotometer supported by the silcon index, was introduced throuh the round opening, perpendicularly to the labial surface of the shade tab in order to measure the values of color parameters L*, a*, b* (Fig. 2).

The values obtained were considered as reference for this study.

Fig. 2. Measurement with Vita EasyShade Advanced 4.0

3.3 Digital imaging

The digital images were taken in the same conditions (CIE Standard Illuminant D65), with the following equipment: Canon 60D body, Canon EF-S 60mm f/2.8 USM Macro (1:1) lens, Sigma EM-140 DG E-TTL II - macro ring flash and Polar_eyes filter (polarizing filter, Emulation, Frankfurt, Germany).

a. Calibration of the camera

Before taking the images, an exposure test was made to decide which settings are appropriate for the correct exposure of the images. Six shade samples from Vita 3D Master shade guide (1M2, 2M2, 2R2.5, 3L1.5, 4L2.5, 5M2) were photographed in different conditions, modifying the aperture and the power of the flash. The test began with calibration of the flash using the following settings: aperture value F22, shutter speed 1/200 sec and the flash on manual mode, ½, ¼ respectively 1/8 from its full power.

The comparison between the values obtained and the standard values given by the spectrophotometer was made using ΔE (color differences) parameter in CIEDE 2000 system. The best value for ΔE was obtained when the flash was set on ¼ from its full power.

Secondly, with the flash set on ¼ from its full power, aperture of the lens was calibrated. It was set on F22, F25 respectively F29 for normal photography (direct light) and F10, F11, F13 respectively F14 for polarized photography. We observed that the closer values to ΔE acceptability threshold were obtained when the aperture was set on F25 for normal photography (direct light) and F10 for polarized photography.

The final camera settings were set on manual mode (M) program, which allowed free control of the shutter speed, aperture size and most of the camera settings. The shutter speed was set at 1/200 sec, with an aperture of F25 for direct light, F10 for polarized light and ISO 100 sensitivity. The white balance was set on flash mode, picture style neutral, image quality Fine, Jpg format. The focal length of the lens was 60mm with a magnifying ratio of 1:1. The Sigma EM-140 DG E-TTL II ring flash attached to the lens was set on manual mode, ¼ from it full power. The digital camera was mounted on a tripod and a grey background was used when taking the photos.

b. Experimental digital images

The artificial maxillary arch with the shade sample in position was photographed 3 times for each shade sample: one picture was made with the silicon index attached over the arch and a piece of millimetric paper placed laterally, both used as a guide, one picture without the silicon index with direct light and one with polarized light (Fig. 3).

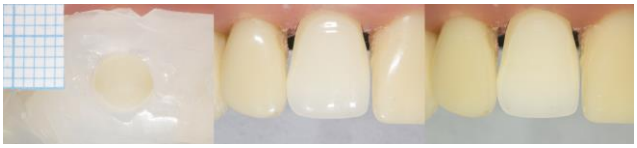

Fig. 3. Digital images taken in different conditions a. picture with the silicon index and milimetric paper, b. picture with direct light, c. picture with polarized light

Then the images obtained for all the shade samples of Vita 3D Master shade guide were edited in the Adobe Photoshop CS4 (Adobe system Inc., California, USA) software program (Fig. 4).

The images were cropped using a circular shape tool guided by the image with the silicon index and millimetric paper. Thus we have separated a 6mm diameter circle to be analyzed and compared with the standard values. After processing, for each shade sample two images were obtained: one with direct light and one with polarized light. Histogram function allowed us to measure Red, Green, Blue (RGB color model) values for each image of the samples (Fig. 4). A converter (Colormine Org., Atlanta, USA) was used to transform RGB values into L*, a*, b* values.

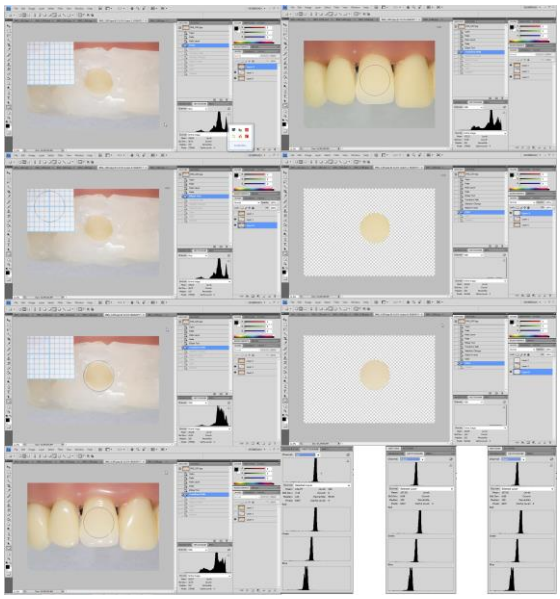

Fig. 4. Protocol for digital images processing in Adobe Photoshop CS4 (the use of circular shape tool to crop a 6mm diameter circle on the images obtained and histogram function to measure Red, Green, Blue (RGB color model) values for each image)

The color difference between the values obtained with the methods described in the study was calculated using ΔE CIEDE2000 formula [9], [10]:

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

$$\Delta L' = L_2^* - L_1^*$$

$$\bar{L} = \frac{L_1^* + L_2^*}{2} \quad \bar{C} = \frac{C_1^* + C_2^*}{2}$$

$$a_1' = a_1^* + \frac{a_1^*}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right) \quad a_2' = a_2^* + \frac{a_2^*}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right)$$

$$\bar{C}' = \frac{C_1' + C_2'}{2} \text{ and } \Delta C' = C_2' - C_1' \quad \text{where } C_1' = \sqrt{a_1'^2 + b_1^{*2}} \quad C_2' = \sqrt{a_2'^2 + b_2^{*2}}$$

$$h_1' = \operatorname{atan2}(b_1^*, a_1') \mod 360^\circ, \quad h_2' = \operatorname{atan2}(b_2^*, a_2') \mod 360^\circ$$

$$\Delta h' = \begin{cases} h_2' - h_1' & |h_1' - h_2'| \le 180^\circ \\ h_2' - h_1' + 360^\circ & |h_1' - h_2'| > 180^\circ, h_2' \le h_1' \\ h_2' - h_1' - 360^\circ & |h_1' - h_2'| > 180^\circ, h_2' > h_1' \end{cases}$$

$$\Delta H' = 2\sqrt{C_1' C_2'}\sin(\Delta h'/2), \quad \bar{H}' = \begin{cases} (h_1' + h_2' + 360^\circ)/2 & |h_1' - h_2'| > 180^\circ \\ (h_1' + h_2')/2 & |h_1' - h_2'| \le 180^\circ \end{cases}$$

$$T = 1 - 0.17\cos(\bar{H}' - 30^\circ) + 0.24\cos(2\bar{H}') + 0.32\cos(3\bar{H}' + 6^\circ) - 0.20\cos(4\bar{H}' - 63^\circ)$$

$$S_L = 1 + \frac{0.015\left(\bar{L} - 50\right)^2}{\sqrt{20 + \left(\bar{L} - 50\right)^2}} \quad S_C = 1 + 0.045\bar{C}' \quad S_H = 1 + 0.015\bar{C}'T$$

$$R_T = -2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}}\sin\left[60^\circ \cdot \exp\left(-\left[\frac{\bar{H}' - 275^\circ}{25^\circ}\right]^2\right)\right]$$

Compensation for lightness (S_L), chroma (S_C) and hue (S_H); hue rotation term (R_T); parametric factors k_L, k_C, and k_H

Multivariate analysis of variance was used for assessing the differences between color parameters recorded with the three measurement systems. Numerical data obtained from the study were analyzed using the Bland-Altman method. Statistical software (IBM SPSS Statistics v20.0.0, Chicago, Illinois, USA) was used for the analysis and α=0.05 values were considered statistically significant.

4. Results

The recorded values for L*, a* and b* parameters, measured with spectrophotometric and digital imaging methods (under two different conditions) are included in Table 1.

Table 1. L, a*, b* values measured in three different conditions*

L* values							
	Sp.	D. l.	P. l.		Sp.	D. l.	P. l.
1M1	82.7	82.56	84.42	**3M3**	74.1	72.29	72.24
1M2	83.5	82.7	81.16	**3R1,5**	74.7	73.93	74.3
2L1,5	79.3	76.31	79.14	**3R2,5**	73.4	75.28	74.03
2L2,5	79.1	77.33	81.32	**4L1,5**	68.7	68.89	71.11
2M1	79.2	79.23	79.4	**4L2,5**	69.1	69.78	70.66
2M2	79,2	77.14	78.63	**4M1**	68.1	70.52	73.26
2M3	78.7	75.72	80.24	**4M2**	68.8	70.8	70.64
2R1,5	77.9	78.37	79.11	**4M3**	68.2	69.83	70.76
2R2,5	78.4	79.88	78.72	**4R1,5**	69.1	71.02	70.8
3L1,5	72.7	75.95	73.41	**4R2,5**	68.9	69.96	71.61
3L2,5	73.9	73.5	75.45	**5M1**	62.6	66.52	66.63
3M1	73.9	73.4	74.87	**5M2**	64	66.25	67.51
3M2	74.2	71.89	73.15	**5M3**	64.5	63.15	67.97
Sp. – spectrophotometry , D. l. – Direct light, P.l. – Polarized light							
a* values							
	Sp.	D. l.	P. l.		Sp.	D. l.	P. l.
1M1	0.1	0.09	-1.74	**3M3**	3.1	1.04	-0.75
1M2	0	-0.72	-2.32	**3R1,5**	2.9	1.61	-0.09
2L1,5	0.2	-0.23	-2.16	**3R2,5**	3.6	1.02	-0.65
2L2,5	0.9	-0.24	-2.75	**4L1,5**	3.1	1.97	-0.28
2M1	0.7	0.25	-1.78	**4L2,5**	4.4	1.52	-0.44
2M2	1.5	0.31	-1.66	**4M1**	3	2	-0.24
2M3	1	0.06	-2.5	**4M2**	4	1.95	0.28
2R1,5	1.4	0.39	-1.51	**4M3**	4.9	1.97	0.008
2R2,5	1.5	-0.04	-1.71	**4R1,5**	4.3	2.36	0.56
3L1,5	1.8	0.49	-1.39	**4R2,5**	5.1	2.34	0.48
3L2,5	2.3	0.78	-1.4	**5M1**	4.6	2.81	1.23
3M1	1.9	1.29	-0.91	**5M2**	6.4	3.02	1.2
3M2	2.6	1.58	-0.6	**5M3**	7.9	3.28	1.46
Sp. – spectrophotometry , D. l. – Direct light, P.l. – Polarized light							
b* values							
	Sp.	D. l.	P. l.		Sp.	D. l.	P. l.
1M1	13.2	6.67	10.59	**3M3**	30.7	23.26	28.2
1M2	19.5	11.16	16.21	**3R1,5**	20.3	14.35	18.9
2L1,5	18.8	13.03	16.99	**3R2,5**	27.6	19.73	25.3
2L2,5	26.8	17.98	21.56	**4L1,5**	23.7	18.13	22.91
2M1	15.1	9.13	14.2	**4L2,5**	30.5	22.36	27.52
2M2	21.7	14.42	18.84	**4M1**	18.5	13.6	17.84
2M3	25.2	17.16	21.05	**4M2**	26	20.14	25.12
2R1,5	16.9	11.4	15.79	**4M3**	32.3	23.65	28.51
2R2,5	22.7	15.11	19.94	**4R1,5**	22.4	16.46	21.71
3L1,5	21.7	15.2	20.22	**4R2,5**	27.9	21.58	26.46
3L2,5	28.6	20.38	25.03	**5M1**	21	17.5	22.67
3M1	16.8	12.08	16.15	**5M2**	30.2	25.27	30.32
3M2	24	16.95	22.02	**5M3**	37.1	32.04	35.52
Sp. – spectrophotometry , D. l. – Direct light, P.l. – Polarized light							

Further, two pairs ΔE were calculated, based on:

a. Spectrophotometric measurements vs. digital photography with direct light (without filter) – ΔE1

b. Spectrophotometric measurements vs. digital photography with polarized light (with filter) – ΔE2

The results obtained are shown in Tabel 2.

Table 2. Values for ΔE1 and ΔE2

	ΔE1	**ΔE2**		**ΔE1**	**ΔE2**
1M1	4.51	3.24	**3M3**	3.91	3.62
1M2	5.07	3.69	**3R1,5**	3.54	3.33
2L1,5	4.01	2.95	**3R2,5**	4.53	3.9
2L2,5	4.69	4.63	**4L1,5**	2.97	3.8
2M1	3.89	3.16	**4L2,5**	4.27	4.35
2M2	4.42	3.75	**4M1**	3.49	5.43
2M3	4.71	4.2	**4M2**	3.61	3.68
2R1,5	3.54	3.66	**4M3**	4.46	4.63
2R2,5	4.51	3.65	**4R1,5**	3.8	3.99
3L1,5	4.46	3.49	**4R2,5**	3.69	4.53
3L2,5	4.08	3.8	**5M1**	4.04	4.96
3M1	2.92	3.46	**5M2**	3.75	5.16
3M2	4.1	3.36	**5M3**	3.86	5.6
ΔE1 – between spectrophotometric method and digital photography with direct light **ΔE2 – between spectrophotometric method and digital photography with polarized light**					

No significant difference was found for L* parameter recorded overall with the three measurement methods ($p>0.05$). However, when pairwise comparisons were analyzed a significant difference was found only for lightness groups 2 and 4. The differences between L* parameter values recorded with digital photography and the dental spectrophotometer are plotted against the average measurements using the dental spectrophotometer. Bland-Altman plots show that measurements follow an ascending trend, for lower values of the L* parameter the difference having negative values, while for higher values for L* parameter, the difference having positive values. This means that digital photography provides higher values than the dental spectrophotometer for L* values lower than 75, and lower L* values above 75. However, all the values are between the 95% confidence interval (Fig. 5, 6).

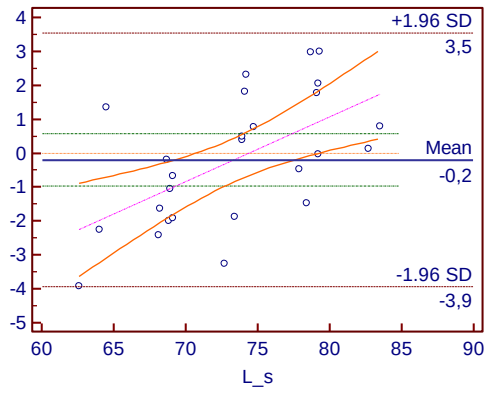

Fig. 5. Bland-Altman plots for L parameter (spectrophotometry vs. digital photography with direct light)*

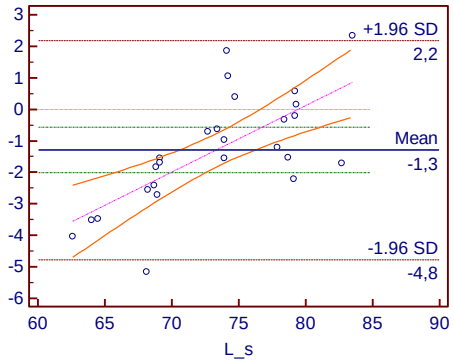

Fig. 6. Bland-Altman plots for L parameter (spectrophotometry vs. digital photography with polarized light)*

There was a significant difference for a* parameter recorded overall with the three measurements methods ($p<0.05$). However, when pairwise comparisons were analyzed a significant difference was found for all the lightness groups. The differences between a* parameter values recorded with digital photography and the dental spectrophotometer are plotted against the average measurements using the dental spectrophotometer. Bland-Altman plots show that measurements follow an ascending trend, for lower values of the a* parameter the difference having smaller values, while for higher values for a* parameter, the difference having higher values. This means that digital photography provides lower values than the dental spectrophotometer for a* values higher than 0. However, all the values are between the 95% confidence interval (Fig 7, 8).

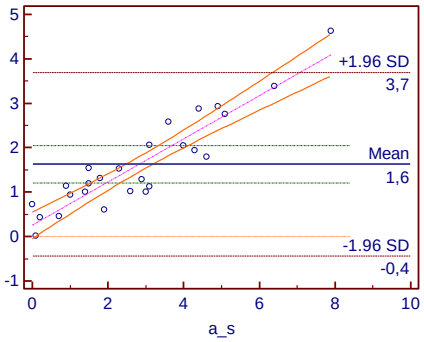

Fig. 7. Bland-Altman plots for a parameter (spectrophotometry vs. digital photography with direct light)*

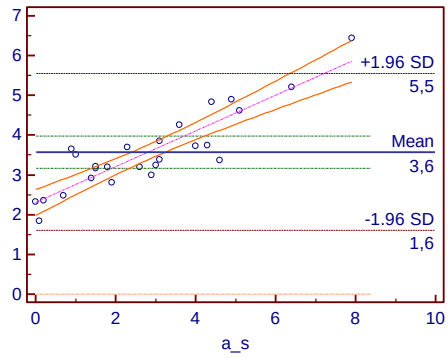

Fig. 8. Bland-Altman plots for a parameter (spectrophotometry vs. digital photography with polarized light)*

No significant difference was found for b* parameter recorded overall with the three measurement methods ($p>0.05$). However, when pairwise comparisons were analyzed a significant difference was found only for lightness groups 3 and 4. The differences between b* parameter values recorded with digital photography and the dental spectrophotometer are plotted against the average measurements using the dental spectrophotometer. Bland-Altman plots show that measurements follow an ascending trend, for lower values of the b* parameter the difference having smaller values, while for higher values for b* parameter, the difference having higher values. This means that digital photography provides lower values than the dental spectrophotometer. However, all the values are between the 95% confidence interval (Fig. 9, 10).

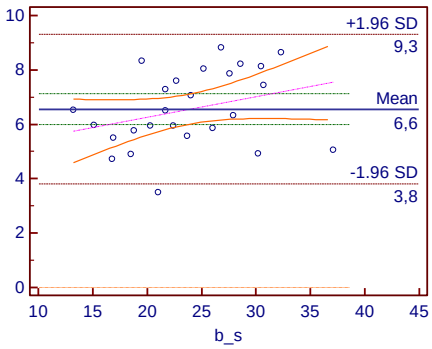

Fig. 9. Bland-Altman plots for b parameter (spectrophotometry vs. digital photography with direct light)*

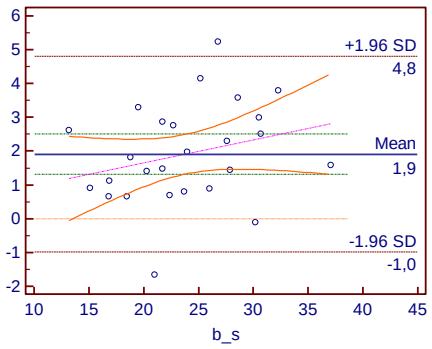

Fig. 10. Bland-Altman plots for b parameter (spectrophotometry vs. digital photography with polarized light)*

There was no significant difference $p>0.05$ when comparing overall ΔE1 (the difference between spectrophotometer and digital photography with direct light) and ΔE2 (the difference between spectrophotometer and digital photography with polarized light). However, when assessing the pairwise comparisons it was observed that this lack of significance was only found for lightness group 3. Analyzing the averages of the two methods, for each lightness group, it was found that for lightness group 1 and 2 the digital photography with polarized light provides values closer to the reference method (dental spectrophotometer), while for lightness groups 4 and 5 the

digital photography with direct light provides closer values to the reference method (Table 3).

Table 3. Mean values and pairwise comparison between ΔE1 and ΔE2

Lightness group	ΔE1	ΔE2	p-value
1	4.790	3.465	0.008
2	4.253	3.714	0.040
3	3.934	3.566	0.154
4	3.756	4.344	0.025
5	3.883	5.240	0.001

5. Discussion

The first null hypothesys of this study was accepted only for L and b* parameters since no significant difference was found for these parameters recorded overall with the three measurement methods (p>0.05).

The second null hypothesys of this study was accepted since there was no significant difference p>0.05 when comparing overall ΔE1 (the difference between spectrophotometer and digital photography with direct light) and ΔE2 (the difference between spectrophotometer and digital photography with polarized light).

In the present study it was shown that both methods: digital photography with direct light and polarized light generate differences from spectrophotometric method considered as standard. The color differences were calculated using ΔE2000 formula which is considered more suitable for instrumental color analysis then the ΔE*ab formula [9].

The values for ΔE1 (the difference between spectrophotometer and digital photography with direct light) and ΔE2 (the difference between spectrophotometer and digital photography with polarized light) were higher then 1.87, which is considered the 50:50% acceptability threshold for colour difference ΔE when using CIEDE2000 formula [10].

The differences result from differences in recording the parameter a *, while between brightness values L* respectively b* values recorded using three methods there is no statistically significant difference (p>0.05).

When comparing digital photography with direct light and polarized light, no statistically significant difference was found between the two methods, based on ΔE2000 values (p> 0.05).

The Vita 3D Master shade guide is divided in 5 groups of value (or lightness), from 1 to 5. The central area of the shade guide (group 3 of value) represents the zone of maximum precision for both modes of photography (the lowest values of ΔE 1 and ΔE 2) compared to the spectrophotometer. In the high lightness areas (group 1 and 2 of lightness) the photography mode with polarized light is closer to the reference value, while in the low lightness areas (groups 4 and 5 of lightness) photography mode without filter (direct light) is closer to the standard value. Tam et al. [11] also reveled in their study that darker shades could be matched with higher accuracy when using digital photography with direct light from flashes.

Similar studies regarding dental shade matching using a digital camera were conducted before the present study in which the color analysis was made using versions of Adobe Photoshop software (Adobe system Inc., California, USA) [4], [6], [12].

In their attempt to quantify the CIELAB color values of shade tabs (Vita Lumin, VITA Zahnfabrik, Germany) using the digital camera and compare them to the spectrophotometer, Jarad FD et al. [6] found that a very high and statistically significant correlation exists between the spectrophotometer and digital camera for all CIE L*, a*, and b* color coordinates (p<0.001).

In their study, Tung OH et al.[12], photographed 15 disks from a custom ceramic shade guide under light-emitting diode (LED) and an electronic ring flash and compared the L*, a*, b* values obtained from the photos with the values measured with the spectrophotometer. L*, a*, b* values of these images showed significantly high correlations to the spectrophotometric values considered as standard. Due to the inconsistent performance of the flashlight and specular reflection, the digital images captured under LED illuminants performed better.

Wee AG et al. [13] compared the CIE L*, a*, b* digital images values for shade tabs taken with three commercial digital cameras and the CIE L*, a*, b* values measured with a spectroradiometer. They found a statistically significant difference between the methods.

Tam et al. [11] proposed a method for shade matching using digital cameras through the comparisons of the color patterns on the shade tab surfaces of a Vita 3D Master shade guide and considered that digital camera might be a tool for dental shade matching.

The major effect of a polarizing filter attached to the flash is the reduction of reflections from the surface photographed.

Some authors found limitations for the use of polarized light. Robertson and Toumba [14] considered that the reduced amount of light that enters through the lens, requires a larger aperture for acceptable pictures. A larger aperture will reduce the depth of field creating images less sharper on the edges. In the present study we used an aperture of F10 for polarized light and F25 for direct light which allows us to have the same depth of field and sharpness for the 6mm diameter region analyzed for each shade sample. The modifications given by a larger aperture are visible when comparing larger regions. We observed that the reduction of light gives difficulties for camera to easily focus, therefore a larger amount of time is needed compared to digital photography without polarizing filters.

Apart from using cross polarization when chosing dental color, this technique can be used for assesing enamel defects [14], dental fluorosis [15] or demineralized lesions surrounding an orthodontic brackets [16].

A previous study [17] considered that cross polarized light is very useful in dental shade selection, plaque

detection and tooth withening by minimizing artefacts in the quantitative image analysis.

6. Conclusions

Digital photography with direct light and polarized light generate differences from the spectrophotometer considered as standard for this study. The central area of the Vita 3D Master guide (group 3 of value) was the zone of maximum precision for both modes of photography compared to the spectrophotometer.

In the high lightness areas (group 1 and 2 of lightness) the photography mode with polarized light was closer to the reference value, while in the low lightness areas (groups 4 and 5 of lightness) photography mode without filter (direct light) was closer to the standard value.

Digital photography with direct light and polarized light generated different values as compared to the dental spectrophotometer considered as standard for this study. However, the use of digital photography and polarizing filters under standardized conditions can be considered as alternatives to the current methods for shade matching

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