Clinical evaluation of a new software for shade matching

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Digital photography is increasingly used in dentistry, with the indication in case documentation as well as communication with the patient and dental technician. The aim of this study is the clinical evaluation of new software developed for tooth color assessment from digital images, taken in general practice-working conditions. The color parameters generated by the software were compared with the spectrophotometric measurements. Color difference, ΔE* between the color parameters (obtained from images and spectrophotometer) was below the acceptability threshold value in 88% of the cases. Strong Spearman's and Pearson correlation's (0.954, and 0.973 ($p<0.001$)) were obtained when the results were presented in Vita 3D Master shade tab codification. The software was able to match shade tab colors, from the digital images with good accuracy. Further improvements are required in order to increase program performance.

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Keywords: Color matching, Digital images, Dental photography, Spectrophotometer

1. Introduction

Shade matching is a challenging procedure in dentistry. Errors in closely mimic of the optical properties of natural dentition, when dental restoration is aimed, is a source of dissatisfaction, for both patient and dentist. However, tooth multidimensional character is defined not only by color, but also by translucency, opalescence, fluorescence and surface gloss [1-3].

Current technological developments in computers sciences, communication and the Internet have a great influence on modern society. These improvements have translated also in the domain of dental medicine[4]. New generation of technologies focused on analysis, communication and color matching were developed in recent years. Spectrophotometry, colorimetry and computer analysis of digital images are the instrumental methods used in dental practice and in research[5]. Instrumental methods aim to transform a subjective analysis done by the human observer into an objective method, which allows the numerical expression, through different systems, of dental color parameters[6]. Recording CIE L*a*b* values, allows the calculation of color difference ΔE^*_{ab} with application in clinical dentistry and research. 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[7].

Digital photography is increasingly used in dentistry, with the indication in case documentation as well as communication with the patient and dental technician. High-resolution intraoral images are useful documentation tool.

Nowadays the price range for quality digital cameras, lenses and flashes, became affordable for dentists. Middle-end or high-end cameras are constant tool in dental offices [8]. Communication with the dental laboratory it is very important for the outcome of the final result, and sometimes can be a serious problem. Verbal communication of color is limited. A good shade match must be accompanied by information regarding other tooth esthetic parameters (translucency, opacity, gloss, texture, etc.). A good digital photography can transmit the majority of the parameters needed by the dental technician[9].Intra-oral images taken with a shade tab positioned correctly next to the tooth, can be very useful for shade matching [10].

In digital photography, the influence of factors such light, camera technology, and clinical procedures on the pictures' quality can by reduce to minimum but not completely eliminated. Post-processing software is required to calibrate images in order to gain the natural outcome [11].

The Vita 3D-Master shade tab has color samples featuring equidistant distribution in the color space in accordance with the accepted color perception concepts of hue, lightness and chroma. Five different levels of lightness create 5 groups of shade tabs, from 1-5. There are 3 chroma levels, from 1-3 in each group. Chroma are associated with hue variations L (more yellow) and R (more red) [12].

2. Objective

The aim of this study is the clinical evaluation of new software developed for tooth color assessment from digital images, taken in general practice-working conditions. The color parameters generated by the software were compared with the spectrophotometric measurements (Vita Easyshade Advanced 4.0 (VES), Vita, Bad Sackingen, Germany).

3. Materials and methods

50 teeth from 18 patients were measured for this study, in order to compare the software color parameters results with spectrophotometric (VES) results.

Central and lateral incisors were included in this study. Inclusion criteria were represented by: natural teeth, with no lesions, fractures, decay or restorative treatment.

Digital images were taken for each tooth, using a regular dental set-up system: camera body Nikon D600, Nikon AF-S VR 105mm f/2.8G IF-ED lenses, and R1 twin flash. The images were taken under standardized dental camera settings: manual mode ‘M’ which allowed the manual control of exposure’s parameters: F22 aperture value and 1/200 shutter speed; manual focus, magnification ratio 1:2 – for repeatability and maintaining a constant distance between the lens and the object; white balance – flash (color temperature 6500K); ISO 100, Flash Mode Manual at ¼ power ratio, resolution 4928 × 3264 pixels, Fine JPG compression, neutral style picture[10, 11].

In order to reproduce the measurement area of the Vita EasyShade tip and guide the instrument positioning, a hollowed transparent rubber matrix (size 30 mm^2, and the 2.5 mm thickness) was placed on the middle third of the labial surface for the teeth to me measured.[13].A shade tab from Vita 3D Master shade guide (3DM) (Vita, Bad Sackingen, Germany), was added in all the images for image calibration proposes (Fig. 1,2).

Fig. 1. Digital image taken in dental practice conditions, with the area to be measured and the shade tab

Fig. 2. Measurement of the same selected area with Vita EasyShade

The computer analysis of the digital images was performed using the developed shade matching software (TooDent v1.0). The workflow:

Step 1:Image color calibration.

CIE L, a, b values of all shade tab of 3DM shade guide were previously stored in the program. The values were obtained in standardized conditions. Selecting the reference shade tab from the image was the next step. When the shade tab was selected, the image was calibrated by adjusting shade tab L*, a*, b* values determined instantly to the reference ones. The whole image was modified accordingly (fig. 3);

Step 2: Automatic contour area selection

Automatic contour area selection was performed by selecting the tooth to be analyzed. In our study we selected the area of 30 mm^2 corresponding to VES measuring tip. When clinical images are taken in dentistry, light sources as twin flashes are required [14]. Flash reflections appear on tooth surface and can influence the color outcome of the image. Our software provides automatic flash reflection exclusions (fig. 4);

Step 3: Color analysis of the selected area (fig. 5).

The results of the color analysis performed in the selected area were expressed in 3DM shades codification and in CIEL*a*b* values, and were instantly displayed by the software, and marked as L_1, a_1, b_1, values for our study.

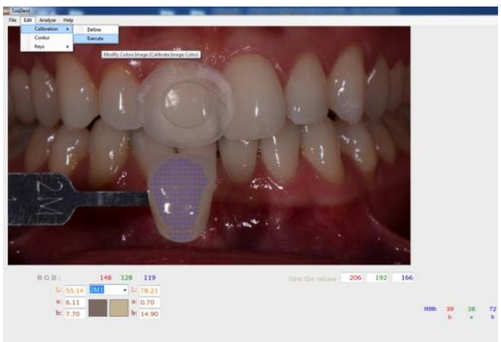

Fig. 3. Image calibration

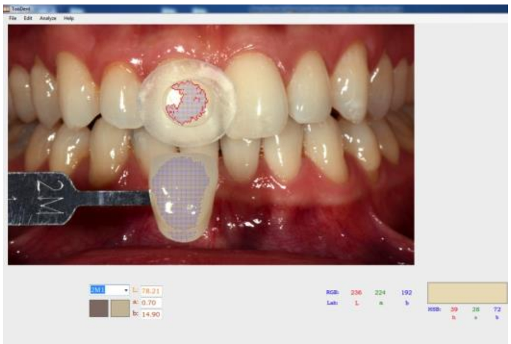

Fig. 4 Calibrated Image with Automatic contour area selection

Fig. 5. Color analysis of the selected area

The results expressed in 3DM shade tabs coding and L_2, a_2, $b_2$values provided by spectrophotometric measurements with Vita EasyShade in the same dental area were used as reference.

ΔE* from CIE*1976 color space was calculated using L*, a*, b* values obtained from the images and spectrophotometer, for the same tooth/areas. A difference below 3.2ΔE* units was considered acceptable[15].The following formula was used:

$$\Delta E_{12}^{*} = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

The statistical analysis was performed using SPSS 16.0 for Windows, software. Pearson, Spearman and Kendal correlation coefficients were used to assess the correlation between the two different types of measurements. Pearson coefficient for the correlation between global color difference ΔE_{ab*} and his components ΔL^*, Δa^* and Δb^*. T-test for medium vales comparison, and for testing the statistical signification of correlation coefficients (Pearson, Spearman, Kendall)

4. Results

In order to evaluate the accuracy of the program in determining results that match the Vita 3D Master Shade tabs, each shade tab was coded with numbers from 1-26 (Table 1)[16]. A database with the measurements was created (Table 2).

Table 1. Number codification of 3DM shade guide

3DM	Codification	3DM	Codification
1M1	1	3L2.5	14
1M2	2	3M3	15
2M1	3	3R2.5	16
2L1.5	4	4M1	17
2M2	5	4L1.5	18
2R1.5	6	4M2	19
2L2.5	7	4R1.5	20
2M3	8	4L2.5	21
2R2.5	9	4M3	22
3M1	10	4R2.5	23
3L1.5	11	5M1	24
3M2	12	5M2	25
3R1.5	13	5M3	26

Table 2. The database with L, a*, b* values and number coded 3DM results both from software and VES measurements*

EasyShade values				Software measurements			
3DM	L_1*	a_1*	b_1*	3DM	L_2*	a_2*	b_2*
8	83.2	0.9	25.7	8	84.4	0.8	23.2
15	75.8	4.1	32.2	14	76	3	30.08
9	81.3	2	20.1	7	82.2	1.1	20.12
8	78.3	3.2	25.7	8	78.4	2.3	23.2
2	86.5	-0.7	18.1	5	85.4	1.2	20.1
9	81.7	0.1	16.2	8	80.3	1	15.2
4	82.5	-0.6	16.2	5	83.3	1	18.3
9	85.8	-0.2	19.2	9	84.2	2.2	19.5
4	84.4	-1.4	16.6	4	85.2	1.1	17.5
4	82.2	-0.9	16.2	5	81.02	0.94	17.93
8	84.2	0.8	28.7	7	84.4	1.4	26.2
4	83.4	-1	17.4	6	84.2	1	17
5	82.6	0.3	25.2	4	83	0.9	23.2
8	82.2	1	28.3	8	82.2	-1.2	26.3
2	86.3	-1.9	17.1	2	86.7	0.1	18.2
2	84.6	-1	17.1	2	83.2	1	18.2
9	80.3	0.3	24.2	8	81.1	0.5	22.1
23	70	3.8	28.4	22	71.1	2.8	25.3
15	74.5	2.1	31.4	13	72.2	2.4	29.4
5	80.5	-1.1	21.7	5	81.2	1	19.8
5	77.6	-0.4	19.6	5	78.9	1	18.9
15	71.6	2.4	30.2	15	72.2	2.1	28.21
20	71.5	2.9	29.2	17	72.2	3	25.1
14	75.9	0.3	26.4	12	73.2	1	23.2
7	85.7	0.7	22.3	12	81.68	2.14	22.49
9	79.5	0.9	20.1	9	78	0.2	17.1
7	88.8	0.1	23.5	8	88.6	0.61	24.35
8	80.5	1.8	25.8	8	80.3	1.2	24.2
1	85.2	-2.2	12.4	2	82.2	-1.9	13.2
1	84.2	-1.7	13.5	1	81.2	-2.1	14.2
3	82.5	-1.8	14.4	2	79.2	1.1	12.1
5	79.2	-0.05	20.4	4	77.4	0.4	21.1
5	84.4	-1	18.4	4	83.2	-0.2	19.2
2	84.4	-1.5	15.8	3	85.4	1.2	16.9
24	63.9	-1.4	20.3	24	64.2	1.2	21.2
17	64.4	-0.6	17.5	16	64.21	-0.8	20.2
17	66.5	0.1	20	17	65.5	0.2	18.7
17	65.6	1.3	21	17	65.2	0.2	18.34
15	78.1	-0.1	32.2	14	78.3	0.2	31.3
8	77.6	0.5	27.2	8	78.2	1.2	28.2
9	70.3	1.1	15.6	9	71.03	1.3	18.1
9	67.9	1.7	14.5	9	69.3	2.1	15.5
17	64.8	1.2	13	17	64.2	2.2	14.3
6	73.5	-0.4	14.7	7	72.1	1.2	15.2
6	70.6	0.4	11.1	7	72.1	1.2	12.2
9	69.8	0.8	13.6	9	70.2	2.1	14.3
16	74.4	3.5	27.9	15	72.2	4.5	28.1
8	79	1.6	26.3	8	80.2	2.3	25.2
5	83.2	-1.4	20.4	7	82.54	1.33	21.8
16	76.1	2.8	26.2	19	75.2	3.4	23.2

Spearman's rank correlation, and Pearson correlation coefficient were applied between the results obtained by the program measurements and the shade tab values obtained with VES (Fig. 6). A very strong correlation was obtained: Spearman's rank correlation=0.954 ($p<0.001$), Pearson correlation coefficient=0.973 ($p<0.001$). These results suggest a good accuracy of the program when the results were presented in Vita 3D Master codification.

The color difference, ΔE* between the color parameters L_2*, a_2*, b_2* and L_1*, a_1*, b_1* was below the 3.2 acceptability threshold value in 88% of the cases. ΔE* values distribution is presented in Fig. 7.

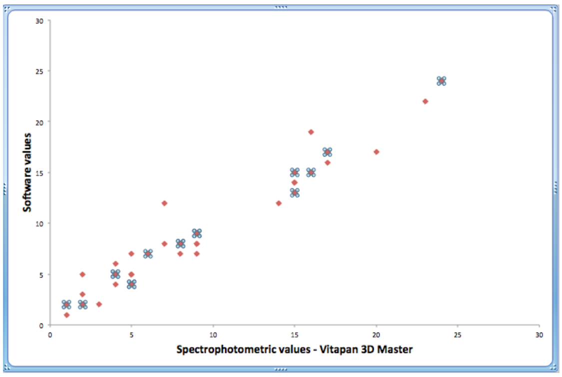

Fig. 6. Data correlation

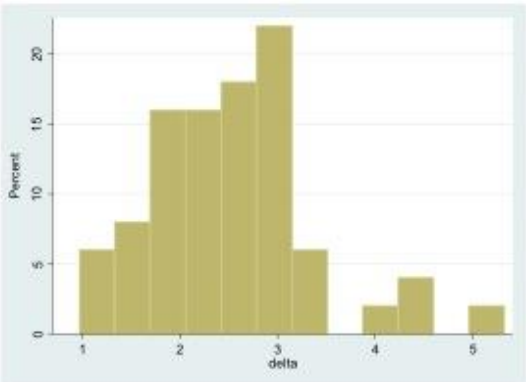

Fig. 7. ΔE values distribution*

T-test was used in order to evaluate the correlations between program's and spectrophotometric L_1*, a_1*, b1*, and L_2*, a_2*, b2* values (Table 3).

Table 3. Correlation between program's and spectrophotometric L, a, b values

	L*		a*		b*	
	Coef.	p-value	Coef.	p-value	Coef.	p-value
Pearson Correlation	0.979	0.000	0.676	0.000	0.961	0.000
Spearman Correlation	0.958	0.000	0.581	0.000	0.962	0.000
Kendall Correlation	0.854	0.000	0.418	0.000	0.840	0.000

Pearson, Spearman, Kendall coefficients indicates that all correlations between L, a, b values are statistically significant (p=0.000). However, for the a* axis, the correlations are not as strong as for L*, and b*.

Fig. 8, 9, 10 Graphic representation of the correlations for L*, a* and b* axis respectively, between program and spectrophotometric measurements

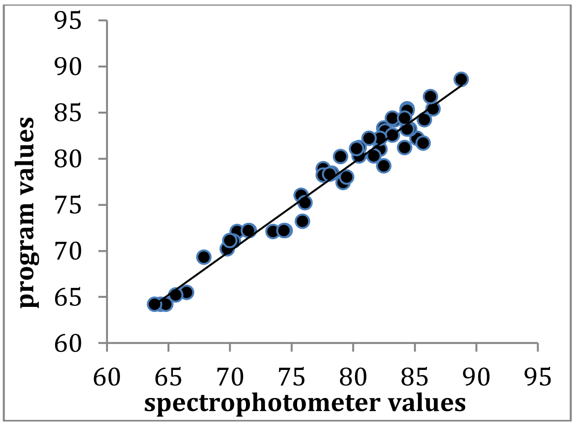

Fig. 8. Correlation for L axis*

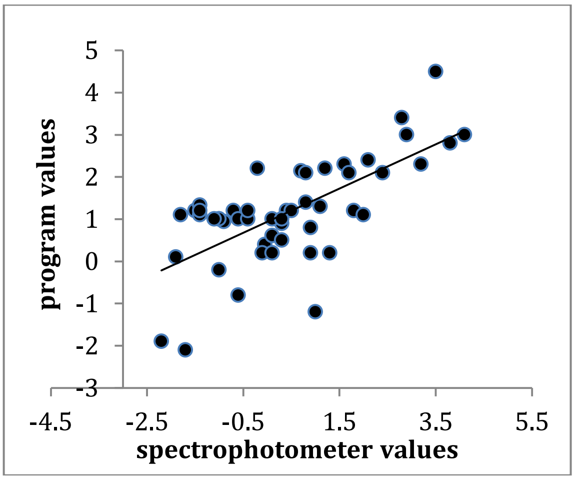

Fig. 9. Correlation for a axis*

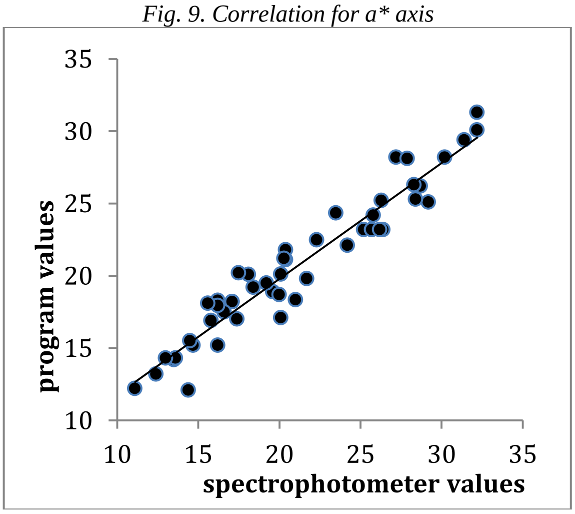

Fig 10. Correlation for b axis*

Table 4 presents the differences of mean values for L*, a* and b*.

Table 4. Differences for mean values

	$L*$	$a*$	$b*$
Mean value spectrophotometer	78.14	0.427	21.18
Mean value program	77.76	1.162	20.74
p-value	0.029	0.999	0.041

The differences between the mean values were not statistically significant for L* and b* ($p<0.041$), but with systematic deviations for the a* component, even it is not statistically significant ($p<0.999$)

The correlation between ΔE_{sp} and its components ΔL*, Δa*, Δb* was made using the following formulas:

$$\Delta E_{sp} = \sqrt{(L_s - L_p)^2 + (a_s - a_p)^2 + (b_s - b_p)^2}$$

$$\Delta L = |L_s - L_p| \ , \ \ \Delta a = |a_s - a_p| \ , \ \ \Delta b = |b_s - b_p| \ ,$$

where *s* and *p* are indicators for the spectrophotometer and the software

Table 5. Correlation between ΔE_{sp} and its components ΔL_{sp}, Δa_{sp}, Δb_{sp}

	Correlation with ΔL	Correlation with Δa	Correlation with Δb
Pearson coefficient	0.521	0.315	0.504
p – value	0.000	0.000	0.000

ΔE_{ab} was significantly correlated with all its components. The correlation with the a component was weaker (Fig. 11, 12, 13).

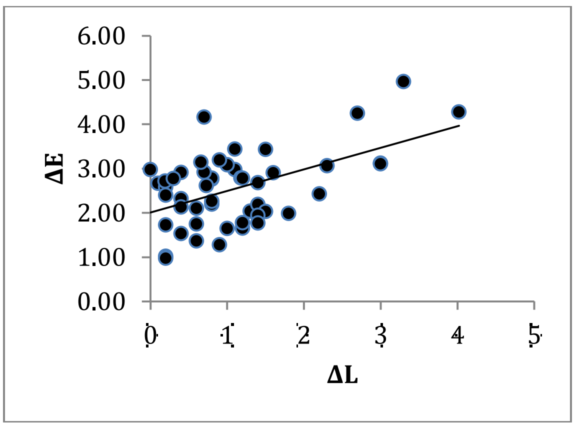

Fig. 11. Correlation between ΔE_{sp} and ΔL_{sp}

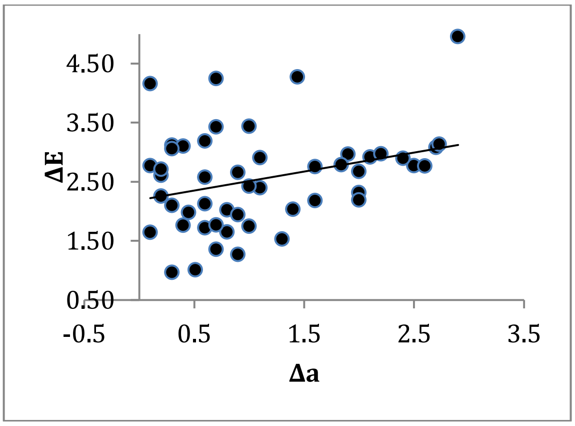

Fig. 12. Correlation between ΔE_{sp} and Δa_{sp}

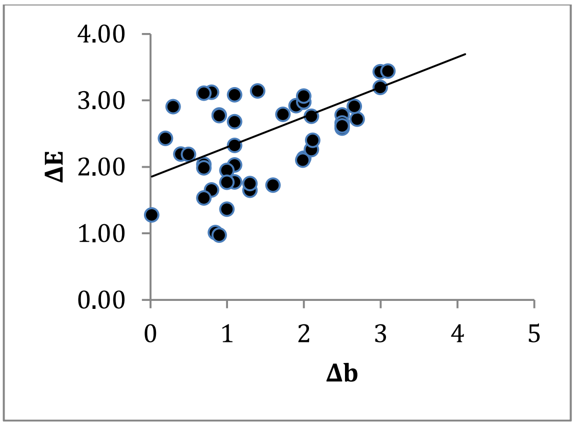

Fig. 13. Correlation between ΔE_{sp} and Δb_{sp}

5. Discussion

The development of easy to use open source software for dental color matching, aimed to generate predictable results, can improve the performances in color selection and communication for both the clinicians and the dental technicians.

Studies having computer analysis of digital images as a topic, are usually using Abobe Photoshop (Adobe system Inc, California, USA) or other commercials editing software [17]for obtaining color parameters. R, G, B or CIE L*, a*, b* values are obtained, important for research but without significance for the clinicians [9].

TooDent software was intended for clinical use. Digital images were analyzed and the results presented both in Vita 3D Master shade tabs codification, and CIE L*, a*, b* values. The first ones were intended for clinical use, and CIE_L*a*b*color parameters for control. Vitapan 3D Master shade tab contains 26 shade tabs that are equally distributed in the color space, within the limits of dental color range[12]. TooDent software calculates ΔE* between the CIE L*a*b* values measured on the digital image and the shade tabs values (already implemented in the program). The shade tab that generates the lowest ΔE^* represents the final result. Within the limits of this study 88% of the cases were in the acceptability threshold limits. When tooth color from a digital image is analyzed, an exact match ($\Delta E^*=0$) with the shade tab is never possible.

It will always be a color difference between the selected dental color and standard shade tabs. The 88% of ΔE*<3.2 must be analyzed together with the strong Spearman's and Pearson correlation coefficient that suggests (0.954, and 0.973 (p<0.001) a good accuracy of the program when the results were presented in Vita 3D Master codification.

Tam, Takatsui and Wee [8, 16, 18] obtained inconsistent results or weak correlations between spectrophotometric measurements and digital images when flashes were used. Electronic flashes used in TTL measurement mode, the influence of the surrounding light, automatic white balance of the camera, flash color temperature, lead to inconsistent results in terms of lighting. Image calibration is mandatory in order to obtain natural colors.

In clinical images, a shade tab positioned parallel, and in the same plane with the tooth[19] offers valuable information to the dentist and dental technician. The program reads from the image shade tab's L*, a*, b* values and calibrate the image to match the standard one (already implemented).

In our study we obtained ΔE* values above the reference value of 3.2 (12%). Strong correlations were obtained between L*, b* values obtained with both methods. Weaker correlations were obtained for a* component, when values were analyzed. Mean value differences were not statistically significant for L* and b*, showing no systematic program tendencies to over or under evaluate light or green/blue axis. However, systematic deviations towards higher values (to red) were observed for the a* axis.

a* axis represents red/green opponent colors, the measure of redness (positive value) or greenness (negative value). The increase of a* mean values suggest a slight variation to red of the digital images after calibration. Image calibration is critical, different CCD or CMOS sensors, together with various cameras technologies, lead to inconsistent color results in photography. A calibration of a* and b* axis to a neutral (gray) may improve image color.

Teeth are usually polychromatic, and various shades can be found in a reduced surface. The program is performing an overall analysis of the selected area, but a color chart is also possible to obtain.

6. Conclusions

An experimental software for color selection was developed in the presented research that can be used for clinical color matching.

The program was able to match the shade tab colors, from the digital images; the statistical analysis indicated a good accuracy when the results were presented in Vita 3D Master codification.

However, only 12% of the ΔE* values were above the reference value of 3.2. Further improvements are required in order to increase program's performance.

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