Comparison of two instrumental methods for dental colour selection

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1. To assess the colour parameters recorded by two instrumental methods on extracted teeth 2. To compare the data recorded by the two systems. Experimental: The color parameters CIE L*a*b* were recorded on the buccal surface of 15 extracted teeth, by using: dental spectrophotometry (Vita Easyshade -Vita®) and digital analysing of the dental image (experimental software- DetColorDent 1.1), before and after accelerated staining in a coffee infusion; the ΔE*was calculated in each case. Statistic analyse was performed using Bland-Altman plots, paired Student's t-test and Wilcoxon's signed ranks test. Conclusions: The recorded values of L*, a*, b* are included into the intervals reported by other authors. Decreasing in lightness L* and increasing in redness (a*), as a result of accelerated staining was registered. Consistently lower readings of all colour parameters when using digital image analysis, compared to spectrophotometry were obtained; however, the results indicate no statistic significant difference between ΔE* values recorded by the two methods. The experimental software may be used in order to monitor the variation in the dental shade, but it needs further improvements for the accuracy of CIE L*a*b* values.

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1. Introduction

Color measurement and matching represent one of the most important procedures during the dental treatments, when it is aimed to restore the tooth structure using esthetic materials (mainly composite resins or ceramics). The complex optical properties of the dental structures are influenced by local and systemic factors [1,2].

There are two groups of methods currently used in order to record the dental shade: visual selection of the dental color, which use shade tabs organized to form color standards (shade guides) that are compared with the tooth surface by the clinician and instrumental methods, based on spectophotometric or colorimetric measurements, digital color analyzers or instruments that combine these technologies [3,4].

Although the visual methods are largely used, they are recognized as being subjective alternatives; their results vary according to the color perception and experience of the observer in this field, but also the incidental light, the optical properties of the shade tabs used as reference, the environmental shades, play an important role [1,2,5,6].

In order to eliminate these shortcomings, instrumental methods were introduce into practical activity, devices which incorporate several color order systems and convert the data obtained into tooth color measurements [5]. These instrumental shade analysis devices allow for standardized, repeatable shade determinations for increased accuracy, by placing technology in the role of "observer" in the light – object - observer - triad required for color perception [2].

Among these systems, dental spectrophotometers are used by the dentists and dental technicians, and Vita Easyshade® (Vita) is one of the most known due to it's compact structure, easy handling and multitude of recorded data. In a study which aimed to compare the result of shade selection by using several types of instrumental methods, Đoziç et al [4] found Vita Easyshade as the most reliable instrument, in both in vitro and in vivo circumstances.

On the other hand, two major disadvantages are associated with this type of instruments: edge – loss error, generated by the contact of the plane surface of the recording system to the convex portion of the tooth (which will cause an important fraction of the light entering tooth to be lost) and the difficulties in obtaining a reproducible position of the instrument on the tooth surface [3,7].

Another types of instruments, colorimeters, were reported as being unsuitable for routine clinical dental application, with the limitation in measuring translucent objects; under this circumstances, more advanced instruments are required to measure the non - uniform color properties of teeth which involve multilayered tooth structure and subtle color changes [8, 9]. The results generated by the colorimetric devices can be altered because the standardized illuminating light emitted by the

device may be scattered, absorbed, transmitted, reflected and even displaced in a side ways direction, due to the translucent optical properties of the dental tissues and of the dental ceramics [10].

Digital analyzing of the dental image may be taken into account, not only when information related to the dental shade are to be transferred from the dentist to dental technician in order to reproduce the optical properties of the dental structures using esthetic dental materials, but also when color parameters need to be recorded in order to monitories the changes in the dental shade generated to some extrinsic factors (dental staining or dental bleaching). The use of commercial digital cameras to capture accurate color in dentistry is advantageous, but in order to be relevant to clinical research it is important to define the color difference parameters [11].

Digital methods of color analyis have been more widespread lately, their use being extended into the dental research mainly in order to follow the results of a treatment which involves the changing of the dental shade or as a complementary instrument for dental color selection.

2. Objectives

1. To assess the color parameters recorded by two instrumental methods: spectrophotometry (Vita Easyshade®-Vita) and digital analyzing of the dental image (using an experimental software- DetColorDent 1.1) on a sample of 15 human permanent extracted teeth, before and after accelerated staining, in a coffee infusion;

2. To compare the data recorded by the two systems, in order to assess the precision of the experimental software in evaluation of L*, a*, b* and ΔE.

The null hypothesis were:

1. The numeric values of the Cielab color`s paramether recorded using the two instrumental methods were within the values reported by other authors and included into the dental color space.

2. There is no difference between the numerical values of the color parameters (L1*,a1*,b1*, L2*,a2*,b2*) and between the color differences (ΔE*) recorded under similar circumstances, using the two methods, which suggest the possibility to use the program DetColorDent as an appropriate instrument for dental color measurements.

3. Experimental

3.1 Color measurements before staining

The color parameters were recorded on the buccal surface of 15 permanent extracted teeth, by using two methods:

a. Dental spectrophotometry was performed with Vita Easyshade. This instrument is a dental spot measurement spectrophotometer, it's handpiece ends in a 5 mm fiber optic tip, containing 19 - 1 mm diameter fiber optic fibers [3,12].

The lightsource, represented by a halogen- stabilized lamp, is located in the base unit. This lightsource is monitored by several spectrophotometers, which also aim to measure the scattered light at 2 different distances from the tooth surface. These readings are combined in order to produce a „ principal spectrum" for the tooth [3].

In our study, the instrument was used in a „global mode", which indicate a basic shade for the evaluated surface; a „tooth area" mode is also available in the menu. The tip was located in the middle of the buccal surface and the CIElab parameters: L_1*, a_1*, b_1*, were recorded, for each tooth (Fig. 1).

*Fig. 1. Vita Easyshade indicating the CIE L*a* *b parameters of dental shade.*

b. Dental imaging methods. The digital images of the teeth before and after the staining process were obtained using the following photographic system: Canon 400D (body) with Canon 100mm f2.8 USM macro lenses and MR-14EX flash

The images were taken under the following standardized camera settings (fig. 2)

- Manual mode M which allowed to set the shutter speed to 1/125s and to close the diaphragm to F22 in order to avoid image distortions;
- Magnification ratio 1:2. This rate was chosen in order to maintain the same distance between the lens and the buccal surface of the teeth while photographing;
- White Balance (WB) was set to flash mode - to obtain a color temperature of 5500K from the xenon ring flash lan.ps,
- TTL II, exposure compensation 2/3 – for an exact quantification of the quantity of light necessary for natural color appearance of the teeth;
- ISO 100;
- Resolution 3888x2595 pixels;
- Manual focus – focus on the center of the buccal surface of the teeth with the camera hand held.

All images were taken in a darkroom, using a color corrected light source (Demetron Shade Light, Kerr) as background illumination.

Fig. 2. Camera settings.

The obtained images were analyzed using experimental software: DetColorDent 1.1. The software is a complex one, for our study we used an application which allows to compare the color parameters of two different images - in our case two equivalents round areas of 6 mm diameter on the middle of the buccal surface of the teeth, before and after immersion in coloring solution, respectively.

DetColorDent 1.1 software indicates the two groups of color parameters, corresponding to the selected images (L_1*, a_1*, b_1 *and L_2 *, a_2*, b_2*, respectively) and, in the same time, it generates the ΔE* value (fig.3)

Fig. 3. Buccal surface of the teeth analyzed with DetColorDent 1.1 software. The round equivalent surfaces, which were selected, in this case, for color parameters evaluation may be observed in both images.

In order to maintain a reproducible position of the extracted teeth during the measurements, the anatomic roots were embedded in a silicon impression material.

3.2 Experimental staining

In order to simulate an accelerated staining procedure, the extracted teeth were immersed in a coffee infusion 14 days; the solution (7 grams coffee, 300 ml boiled water) was daily renewed.

3.3 Color measurements after staining

The spectrophotometric and digital analyzing measurements were repeated for each tooth. A new pair of colour parameters were obtained (L_2*, a_2*, b_2*).

When the spectrophotometer was used, the colour difference ΔE* was calculated for each tooth by the following equation:

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \quad [2]$$

In each case, $\Delta L^* = L_2^* - L_1^*$, $\Delta a^* = a_2^* - a_1^*$, $\Delta b^* = b_2^* - b_1^*$.

Softwere DetColorDent 1.1. indicate the value of ΔE* automatically (see fig 3).

3.4 Statistics

The agreement of measurements between the two instrumental methods of colour selection (spectrophotometry - SP and digital image analysis - DIA) has been evaluated using Bland-Altman plots. A Bland-Altman plot or difference plot is a method of data plotting used in analysing the agreement between two different assays [13].

Bland-Altman difference plots have been represented for each colour parameter (L^*, a^*, b^*), regarding the results of both colour readings: one before experimental staining of the investigated teeth (defined as baseline and coded L_1^*, a_1^*, b_1^*) and one after experimental staining (defined as subsequent readings and coded L_2^*, a_2^*, b_2^*). Agreement between methods (SP vs. DIA) has been investigated regarding ΔE^* values computed between the two readings.

Colour parameters L^*, a^*, b^*, as well as ΔE^* values computed between colour readings before and after experimental staining were investigated for the presence of significant differences among methods, using paired Student's t-test.

Since minor deviations from normality were exhibited in some cases after tracing Q-Q plots of data against a normal distribution, the same comparisons were also performed using a non-parametrical test for paired samples: Wilcoxon's signed ranks test.

For both tests, the threshold level for statistical significance has been considered α=0.05.

Statistical analysis has been performed using SPSS 16.0 for Windows.

4. Results

The color parameters (L*, a*, b*) and the colour variation (ΔE*) obtained by using the dental spectrophotometry and the digital images analyse (DetColorDent) , before and after accelerated staining is included in Tables 1 and 2 and 3.

Table 1. Values of L_1^* a_1^*, b_1^*, L_2^*, a_2^*, b_2^* and ΔE obtained by using spectrophotometer Vita Easyshade.*

Tooth	Before staining			After staining			
	L_1^*	a_1^*	b_1^*	L_2^*	a_2^*	b_2^*	ΔE^*
1	79.7	-0.5	27.6	77.2	0.3	24.9	3.76
2	77.5	5.2	32	75	4.3	26.1	6.47
3	75.8	-0.7	28.2	71.7	0.4	25.1	5.16
4	83.3	2.2	37.3	74.7	4.1	35.1	9.07
5	78.8	4.6	40.2	71.6	6.1	39.4	7.39
6	75.5	3.9	41	67.9	3.5	37.3	8.46
7	74.1	4.7	43.8	67.9	7.3	43	6.77
8	80.9	0.6	34	76.6	1.8	33.3	4.51
9	74.3	5.4	44.3	74.8	4.2	37.7	6.72
10	74.6	2.6	39.9	67.5	6.4	42.3	8.4
11	88	0.7	34	67.4	5	33.1	21.06
12	69.5	6.1	42.8	70.3	6.1	39.2	3.68
13	79.2	2.4	37.2	71.7	5.4	36.7	8.09
14	78.5	0.6	37.3	76.1	6.2	44.2	9.2
15	89.5	-1.8	31	70.3	4.4	31.8	20.19

Table 2. Values of L_1^* a_1^*, b_1^*, L_2^*, a_2^*, b_2^* and ΔE obtained by using digital colour analyse (DetColorDent).*

Tooth	Before staining			After staining			
	L_1^*	a_1^*	b_1^*	L_2^*	a_2^*	b_2^*	ΔE^*
1	61.57	-6.45	20.09	57.21	-5.08	18.51	4.83
2	52.21	-4.44	14.88	62.13	-2.96	12.53	10.3
3	53.35	-7.19	21.59	53.46	-4.8	22.95	2.75
4	65.87	-5.78	20.61	53.16	-2.41	22.61	13.3
5	70.49	-3.72	25.49	66.02	-1.66	23.3	5.45
6	64.79	-4.18	26.3	58.81	-3.2	21.36	7.81
7	61.58	-4.85	24.05	54.8	-0.31	23.21	8.2
8	66.2	-5.67	17.2	62.19	-4.85	15.96	4.27
9	60.74	-3.76	29	51.94	-2.76	24.33	10.01
10	60.78	-5.11	25.16	54.46	-3.43	19.24	8.82
11	73.68	-6.73	12.51	65.08	-5.18	12.81	8.74
12	62.19	-4.09	28.21	55.72	0.01	27.85	7.66
13	57.03	-6.04	18.79	58.97	-3.97	17.6	3.07
14	60.57	-4.6	28.73	52	-0.71	25.6	9.91
15	59.66	-7.84	14.53	50.9	-5.17	15.91	9.26

Table 3. Mean values of the colour coordinates (before and after experimental staining).

Coordinate	Before (BS)/After (AS) Staining	Spectrophotometry (mean value)	Std deviation	Std error mean	Digital colour analyse (mean value)	Std deviation	Std error mean
L* (mean)	BS	78.613	5.2940	1.3669	62.0473	5.70233	1.47233
	AS	72.047	3.4873	0.9004	57.1233	4.89091	1.26283
a* (mean)	BS	2.400	2.5074	0.6474	-5.3633	1.29009	0.33310
	AS	4.367	2.1263	0.5490	-3.0987	1.79708	0.46401
b* (mean)	BS	36.707	5.4218	1.3999	21.8093	5.43019	1.40207
	AS	35.280	6.2633	1.6172	20.2513	4.61710	1.19213

When spectrophotometer Vita Easyshade was used, the color parameters, varied between:

L_1^*= 69.5 - 89.5, a_1^*= –1.8 - 6.1,
b_1^*= 27.6 - 44.3
L_2^*= 67.4 - 77.2, a_2^* = 0.3 - 7.3,
b_2^* = 24.9 - 44.2

The colour differences ΔE* ranged between 3.68 and 21.06. Two values of ΔE* (tooth 11 and 15) were found to be extreme outliers.

When DetColorDent (1) was the method of choice, the colour parameters ranged between:

L_1*= 52.21 - 73.68, a_1*= –7.84 - –3.72, b_1* = 12.51 - 28.73

L_2*= 50.9 - 66.02, a_2*= –5.18 - 0.01
b_2* = 12.53 - 27.85

The colour differences vary between and 2.75 and 13.3.

The Bland-Altman plots representing the differences between methods (SP minus DIA) traced against the corresponding average measurement of the two methods have been represented in figures 4-6, for each colour parameter, before and after experimental staining of the investigated teeth (L_1^*, a_1^*, b_1^*, respectively L_2^*, a_2^*, b_2^*).

The differences between the two methods (SP minus DIA) regarding L^*, a^*, b^* (values highlighted in textboxes in Figs. 4-6) proved to be highly significant ($p<<0.001$) after both parametric and non-parametric testing.

Differences between methods (SP minus DIA) regarding ΔE^* values computed between the two readings, traced against the corresponding average ΔE^* values resulting from the two methods have been represented in Fig. 7.

No statistically significant difference (+0.97 in Fig. 8) was found between mean ΔE^* resulting from spectrophotometry (8.59± 5.18) and ΔE^* resulting from digital image analysis using the DentColorDent software (7.62 ± 2.98), after neither parametric ($p=0,47$ - paired Student's test) nor non-parametric testing ($p=0,98$ - Wilcoxon's signed ranks test).

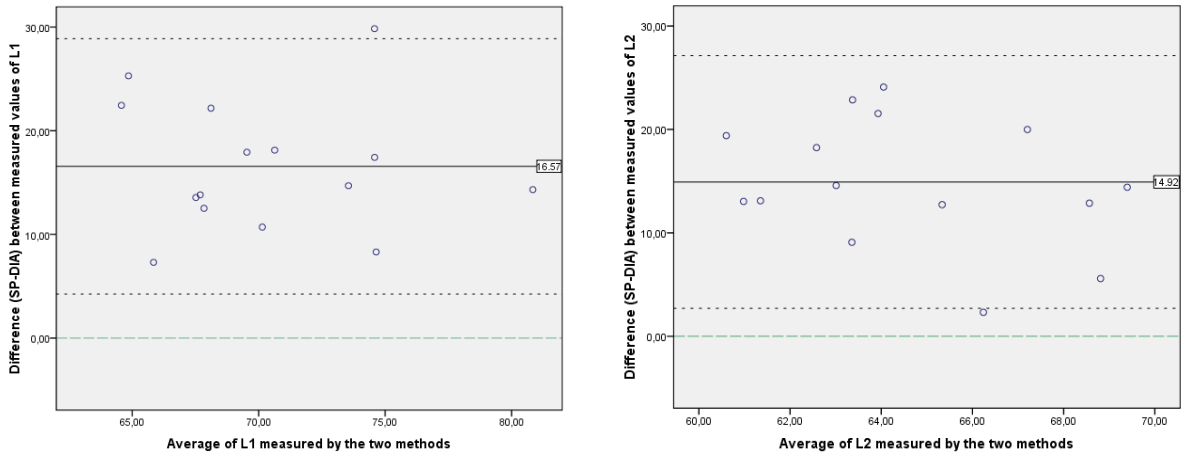

Fig. 4. Bland-Altman difference plots of L_1^* (before staining) and L_2^* (after staining) between spectrophotometry (SP) and digital image analysis (DIA).

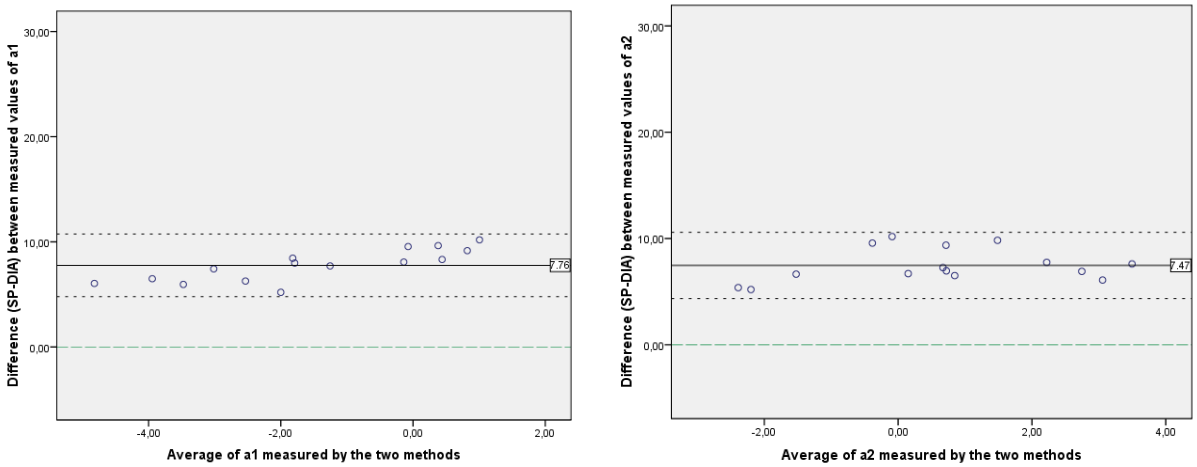

Fig. 5. Bland-Altman difference plots of a_1^* (before staining) and a_2^* (after staining) between spectrophotometry (SP) and digital image analysis (DIA).

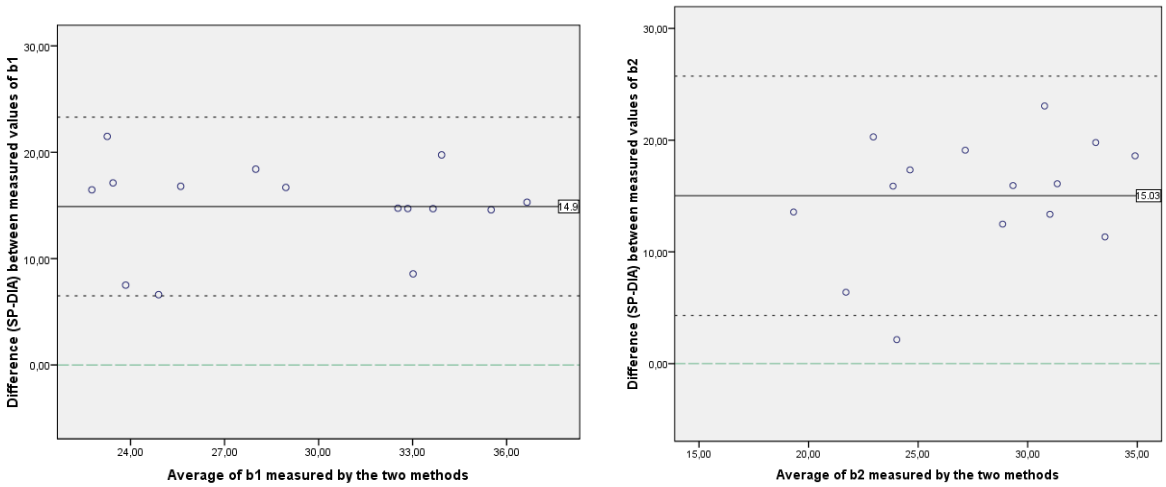

Fig. 6. Bland-Altman difference plots of b_1^* (before staining) and b_2^* (after staining) between spectrophotometry (SP) and digital image analysis (DIA).

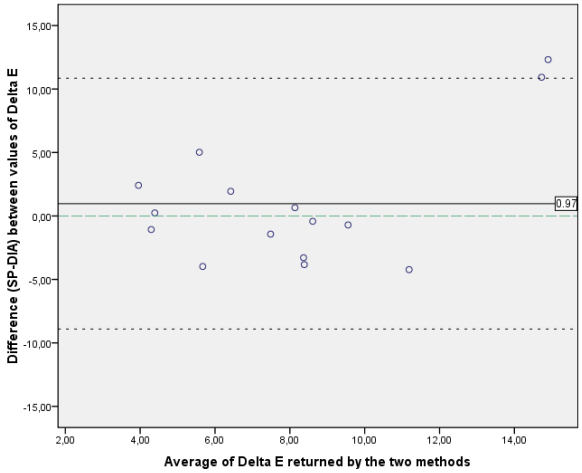

Fig. 7. Bland-Altman difference plots of ΔE between spectrophotometry (SP) and digital image analysis (DIA).*

L^* values and b^* values were higher when the spectrophotometer was used. a^* values, were positive in most cases when the spectrophotometer was used and negative, when a^* values were recorded using the experimental software.

However, considering the variations of the colour parameters during the experimentally accelerated staining, using both methods, we obtained the same tendency in the variation of the colour's parameters: increasing in redness (a* increased in values in most cases), decreasing in yellowness (b* decreased in value for most of the cases) and decreasing of L* (lightness).

5. Discussion

Colour is not an intrinsic characteristic of an object, but rather it has to be perceived as the reflection of the light that enters the eye, being reflected by that object [14].

Colour matching in dentistry is a complex process, which can generate errors, no matter the method involved in shade selection (visual or instrumental).

During the visual evaluation, shade guides or colour standards are used; the tab which match most closely the optical properties of the dental surface is recorded [15]. Several factors can affect the quality of the visual selection of the dental shade, such as: shade matching conditions (incidental light, the colour of the adjacent objects and environmental shades, shade matching methods and shade guides optical properties) [15]. Metamerism is the phenomenon, which alter the perception of the colour, due to the incidental light; moreover, when colour objects that do not have the same spectral components (such as teeth and the shade guide's samples material) do not match under different lighting condition [14,16]. However, the currently used shade guides lack to cover the entire colour spectrum of natural tooth colour; more than that the materials used for the shade guide tabs may be different from the ones used for the actual restorations [5].

According to the Munsell system of colour ordering, colour dimensions are: Hue (h- colour name, colour family), Value (L, lightness, achromatic scale) and Chroma (C, pale to strong) [15]. Apart of this system, investigators have attempted to use colour science and colour theory to allow expression of colour parameters numerically, in much the same way length and weight are expressed, for easier and more precise transfer and communication of colour in restorative dentistry [17]. In 1931, the Commission International de l'Eclairage (CIE 1931) developed a system, which enabled colour perception to be quantified, based on standard observer curves and standard illuminants [18].

The colour coordinates currently used in dental research in order to define the optical properties of the tooth structure or restorative materials are mainly derived from CIEL*a*b* system: CIE L* value is a measure of the lightness of an object such that a perfect black has a CIE L* value of zero and a perfect reflecting diffuser (White) has a CIE L* value of 100. CIE a* green/red coordinate value is a measure of redness (positive value) or greenness (negative value). CIE b* blue /yellow coordinate value is a measure of yellowness (positive value) or blueness (negative value) [19,20]. Using these parameters, chroma (C*) and hue (h^o) can also be calculated [3].

Subsequently, the revised CIEL`a`b` uniform colour space was recommended by the CIE for use in calculating a newly recommended colour difference called CIEDE2000 [21,22].

In our study, we used the values derivated from the CIEL*a*b* system, recorded by two instrumental methods.

In order to define the space colour of the natural teeth, several types of measurements have been used (spectrophotometric, colorimetric, computerized analyse of the digital images), either in vitro, on extracted teeth, or in vivo. According to the limits generated by every study, several data regarding the colour parameters of the natural dentition have been reported. Our study used extracted teeth in order to establish the colour range and distribution of human dentition.

The values of L*, a*, b* recorded in our study, using both instrumental methods, before and after the experimental staining are included into the intervals reported by other authors: Paravina et al [3]: L* = 55.5 - 89.6, a* = – 4.2 - 7.3, b* = 3.6 - 38.9, O`Brien et al [23 cit ref 3]: L = * 55.9 - 83, a* = – 0.7 - 4.6, b* = 4.4 - 27.0 and Russel: mean values: L* = 48.31, a* = – 1.35, b* = 2.73 [18]

Colour difference (ΔE*) represents the difference in colour's parameters (hue, value and chroma) between the compared objects [15, 24]. The Euclidean distance ΔE* is a measure of colour difference between 2 points in 3-dimensional colour space [24, 25].

In dental colour science, several values of ΔE* show clinical relevance: ΔE* =1 is considered to be undetectable by 50% of the observers and ΔE* = 2.7 or 3.3 is the acceptability limit in the colour difference for 50% observers [3].

In our study, the ΔE* values recorded by using both instrumental methods were higher than the undetectable value and, in most cases, higher than the acceptable limit, after the immersion of the extracted teeth in a coffee solution. The accelerated staining method used in this study generated the expected results; moreover, the same tendency of variation (decreasing in lightness (L*), increasing in redness (a*) was reporteted by other studies as a result of other common oral habits correlated with dental staining, such as smoking [3]

There are several types of instrumental methods which can be used for dental shade assessment, including: spectrophotometers, recognised for there extreme accuracy, colorimeters or advanced computerized instruments which can precisely quantify colour and are, therefore, extensively used in dental research [26]. Significant advantages to spectrophotometric measurements include the ability to analyse the principal component of a series of spectra and the ability to convert spectrophotometric measures to various colour measures [21].

As far as the limits of the spectrophotometers - sometimes, the accuracy of the measurements could be confusing for the clinician; there is an important variation of the recorded values with the position of the instrument related to the dental surface- different values could be recorded within the same 1-to 2 mm distance in an individual tooth [26]. Moreover, it is concluded that these types of instruments are originally designed for flat surfaces, not for curved ones, such as labial dental surfaces, which are recorded for colour parameters. In order to improve the precision of the instrument, it was suggested to record the dental shade several time, and to take into account the values, which occur more often; however, into every day dental practice this is not always possible. More predictable results are also correlated with an increased experience in using these types of instruments.

Another factor which may influence the accuracy of the recorded data using spectrophotometers originates from the optical properties of the tooth itself, which is made of layers (enamel and dentine) exhibiting differences in colour parameters, translucency, fluorescence.

In the present study, the values obtained for the colour parameters were different from the ones obtained when the DetColorDent software was used; on the other hand, the variation between the similar parameters followed the same algorithm, which was supported by the fact that we didn't record a statistic significant difference between ΔE* values.

When dental spectrophotometer was used the L^* values and b^* values were higher than in the case of the experimental software and the a^* values were positive, in most of the cases).

In our study, we favoured the use of Bland-Altman plots over the interpretation of Pearson's correlation coefficients, since a high correlation does not automatically imply that there is good agreement between the two investigated methods [13].

The interpretation of Bland-Altman plots in our study, indicated consistently lower readings of all colour parameters (L^*, a^*, b^*) when using digital image analysis (DIA), compared to spectrophotometry (SP).

The mean values of these differences ranged between +7.47 and +16.57 in favour of (SP) and were all found to be highly significant ($p<<0.001$) for all colour parameters.

As may be observed for each pair of Bland-Altman plots, the differences observed between methods at baseline (before experimental staining) maintained roughly the same level between subsequent readings (after experimental staining), confirming the consistently lower readings of DIA compared to SP.

This was also confirmed by the very good reproducibility of ΔE^* between the two methods. Since it quantified itself the colour difference produced by experimental staining, ΔE^* exhibited a high level of reproducibility between methods, with a mean difference close to zero (+0.97), difference that proved to be statistically insignificant after both parametric (p=0.47 - paired Student's test) and non-parametric testing (p=0.98 - Wilcoxon's signed ranks test).

On the basis of the present study, it might be concluded that the experimental software can be used in order to monitor the variation in the dental shade, but in order to use it as a reliable instrument for dental shade parameters, it needs further improvements.

6. Conclusions

1. The values of L*, a*, b* recorded in our study, using both instrumental methods (spectrophotometry- Vita Easyshade and dental image analyse –DetColorDent) , before and after the experimental staining are included into the intervals reported by other authors.

2. The colour difference ΔE^* recorded by using both instrumental methods was higher than the undetectable value (ΔE^*) and, in most cases, higher than the acceptable limit ($\Delta E^* = 3.3$), after the immersion of the extracted teeth in a coffee solution. The tendency of variation indicated the decreasing in lightness L* and increasing in redness (a*), as a result of accelerated staining.

3.Consistently lower readings of all colour parameters (L^*, a^*, b^*) when using digital image analysis (DIA), compared to spectrophotometry (SP) were obtained.

4.The variation between the similar parameters followed the same algorithm, which was supported by the fact that we didn't record a statistic significant difference between ΔE^* values.

5.The experimental software can be used in order to monitor the variation in the dental shade, but in order to use it as a reliable instrument for dental shade parameters, it needs further improvements.

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