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Data Comparison Between Two Dental Spectrophotometers

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Clinical Relevance

Different color measuring devices (CMDs) are used to determine tooth color and the color of the matching restoration during the manufacturing process. This study questions whether it is possible to communicate color accurately when dentists and dental laboratories use different CMDs at different locations.

Summary

Objectives: The objective of this study was to clinically test whether the data from two different spectrophotometers, based on spot and surface measurements, can be compared.

Methods: Under standardized clinical conditions two devices (Vita Easyshade and SpectroShade-Micro) were used to record the color of three areas (cervical, middle, and incisal) per tooth for three upper maxillary anterior teeth in 102 participants. Each position was measured three times to attain an average for the CIE L*a*b* coordinates and to attain the corresponding Vita Classical shade tab integrated in the software of both devices. Vita tabs were also described as L*a*b* values using earlier published translations so that color differences (ΔE) could be calculated between them.

Results: The regression analysis between the two devices showed that the independent correlation coefficients of the L*a*b* values are low. Yet when the suggested shade codes are compared with Vita colors instead of L*a*b*, 40% of the cases were equal and 51% were clinically acceptable.

Significance: According to this study the two devices do not give a comparable shade selection output, and thus the exchange of L*a*b* values between the two spectrophotometers cannot be recommended.

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INTRODUCTION

The subjective character of visual shade determination makes color assessment one of the most complex aspects of restorative dentistry,[1-4] whereas precise information on color is essential for the creation of an esthetic dental restoration. An escalating number of electronically based devices for tooth color determination have entered the market, compelling dental laboratories and dentists to invest in these devices. Such color measuring devices (CMDs) eliminate the subjectivity related to color determination and increase the level of consistency in the color determination process.[3,5-7] Henceforth, CMDs can be beneficial for the process of shade determination.

Different types of CMDs are based on different technologies, such as colorimetery, focal optics, and spectrophotometry. Dental colorimeters are designed to directly measure color as a function of light reflection perceived by the human eye. They use three filters corresponding to three color stimuli: red, green, and blue (RGB). Measuring tooth color is also possible by analyzing digital images, where a multitude of pixels are measured in RGB units corresponding to RGB stimuli. Spectrophotometers are devices that determine the intensity of reflected or transmitted light as a function of a light-source wavelength.[8]

The optical light settings used in CMDs can have different geometries; illumination at 0 degrees and observation at 45 degrees (0/45), illumination at 45 degrees and observation at 0 degrees (45/0), or a 0/0 degree optical geometry where the light beam and the light detector are in the exact opposite direction.[1]

There are not only different optical geometries between different CMDs but also different methods for measuring optical light[9]: spot-measurement devices and complete-tooth-measurement devices. Spot measurements are made by an optical device with an aperture of about 3–5 mm in diameter. Therefore, several recordings must be taken to obtain a more extensive shade distribution over the entire tooth surface. On the other hand, complete-tooth-measurement devices can measure the entire tooth and produce a color map of the tooth in one image.

There are several systems in which the output of the color measurements can be categorized and identified quantitatively. One of the most commonly used systems is the CIE L*a*b* color system because it approximates uniform distances between color coordinates while entirely covering the visual color space.[10,11] This system has a lightness scale, L*, ranging from 0 (black) to 100 (white), and two opposing color axes: axis a* for redness (+) and greenness (–) and axis b* for yellowness (+) and blueness (–). The output of the absolute color values, expressed as L*, a*, and b* can be translated into shade guide codes, for instance the A, B, C, and D codes of the Vita Classical (Vita, Bad Säckingen, Germany), for clinical use. It is unclear which L*a*b* values different manufacturers apply in their devices to express the different Vita shades. Moreover, the color consistency of the different Vita Shade tabs used by different manufacturers may vary, too. In a study by O'Brien and others,[12] a CIE L*a*b* translation table of the Vita shade guide was presented, as measured by a spectrophotometer. This has been, so far, the only standard where the shade tabs of the Vita shade guide are expressed as L*a*b* values.

The visual color space of teeth covers a small volume in the whole L*a*b* color space. As a consequence, the resolution of dental CMDs has to be high to be able to differentiate the whole possible color range of teeth. For the same reason, not only the resolution of the devices is of importance but also the high reproducibility of the measurement itself.[13] For instance, for most CMDs it is extremely important to keep the angle of measurement constant when repeating the measurement.

In an earlier study[8] we evaluated the repeatability and accuracy of five commercially available CMDs and concluded that, of the different CMDs, spectrophotometer measurements were the most reproducible in repeating measurements. The most reliable device *in vitro* and *in vivo* was the Easyshade (ES; Vita, Bad Säckingen, Germany),[8] which is a handheld spot-measurement device that needs to be brought into direct contact with the tooth surface when a measurement is being made. The fiber-optic tip is 5 mm in diameter and uses a pseudocircular 0/0 measuring geometry.[14] Another dental spectrophotometer that was tested in this earlier study was the SpectroShade-Micro (SS, MHT S.p.a., Verona, Italy. This device has the ability to measure the whole tooth surface and is based on illumination at 45 degrees and observation at 0 degrees (45/0).[15]

In principle, CMDs are designed to enhance communication between clinicians and dental laboratories, but the commercialization of the dental market results in the use of different devices among different professionals. However, besides the differences in working mechanisms, the basic signal of most CMDs is an electrical current originating from sensors that are transferred into color data by internal software. This can lead to possible errors when two different systems are used to determine tooth color and the color of the matching restoration during the manufacturing process. A growing number of dental practices work with large dental laboratories abroad; hence, color has to be communicated precisely, especially in such cases where no direct contact is possible between the technician and the patient to determine color. Therefore, the question is whether it would also be possible to communicate color when dentists and dental laboratories use different CMDs at different locations. The objective was to evaluate whether the measurements of two different devices can be exchanged without resulting in a visible color difference. For this study, a color difference of $\Delta E \leq 2.0$ units was regarded as the perceptibility threshold,[12] whereas a color difference of $\Delta E \geq 3.7$ was regarded as the acceptability threshold, and thus considered clinically imperceptible.[1,12]

The hypothesis of this research was that the absolute color data, measured as a spectrum and expressed as CIE L*a*b* values, are comparable between the ES and SS spectrophotometers and therefore can be exchanged.

MATERIALS AND METHODS

The tooth color of 102 participants was measured at the Academic Centre for Dentistry in Amsterdam (ACTA, the Netherlands). A written informed consent was obtained from every subject after a full explanation of the experiment. The group consisted of 42 male and 60 female subjects, and ages ranged from 14 to 58 years (mean=23 years). Tooth color was measured under standardized clinical conditions by one operator using the Vita Easyshade and the SpectroShade-Micro CMDs.

The maxillary central and lateral incisors and the canines from the left or the right side of the maxilla were selected based on the following criteria: 1) absence of dental caries, 2) absence of restorations, 3) no previous endodontic treatment, and 4) no previous bleaching treatment or use of whitening toothpaste. Shade was recorded for all selected teeth at three sites: cervical, middle, and incisal. Thus, nine total locations were measured in 102 participants, resulting in 918 independent color measurements with the ES and SS, respectively. During measurements the participants were asked to keep their tongue in a relaxed position away from the maxillary teeth, lean their head against the headrest of the dental chair, and keep their mouth slightly opened; this was in order to prevent moving or fogging that could possibly affect the measurements. The devices were used and calibrated according to the manufacturer's instructions.

Color Measurement with Vita Easyshade

Before measuring tooth color with the ES, the selected tooth was polished using a rubber cup and polishing paste for approximately 10 seconds, after which the mouth was kept closed for at least 1 minute to allow rehydrating. A disposable infection-control polyurethane barrier (Vita Infection Control Sleeves; Vita Zahnfabrik) was used on the tip of the probe, and the device was calibrated for each participant by placing the probe with a diameter of 5 mm against a calibrated block inside the machine. Measurement proceeded by placing the probe on the previously determined area of the tooth and pressing the probe switch, taking care that the probe was not moved during a measurement and/or set at a different angle. The specific area of the tooth (Figure 1) was determined using a caliper to establish the midposition of each point and the equal distance between the three measuring areas: cervical, middle, and incisal. Tooth colors expressed in CIE L*a*b* values and the corresponding suggested Vita Classical shade codes were directly obtained for each position along the labial surface of each tooth.

Color Measurement with SpectroShade

An infection-control mouthpiece and adhesive pad were placed on the optic handpiece, and then the SS was calibrated. During measurement the mouthpiece was carefully positioned over the tooth required. The screen display permitted the operator to view the whole tooth surface under the right angle, as verified by a horizontal green line (representing accurate geometry); after this the color could be recorded. After color registration of three teeth, the results were imported into the software, which automatically outlined the CIE L*a*b* values and the derived Vita Classical shade codes for each position on each tooth. The three positions were determined by locating the software tool circle with the radius of 5 mm in the cervical, middle, and incisal area and by this way approximating the same area of color measurement as used with the ES.

DATA EVALUATION

Three different methods were used to evaluate the two sets of data from the two devices:

1. Direct comparison of the measured L*a*b* values obtained with the two instruments expressed in ΔE. The following equation was used:

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

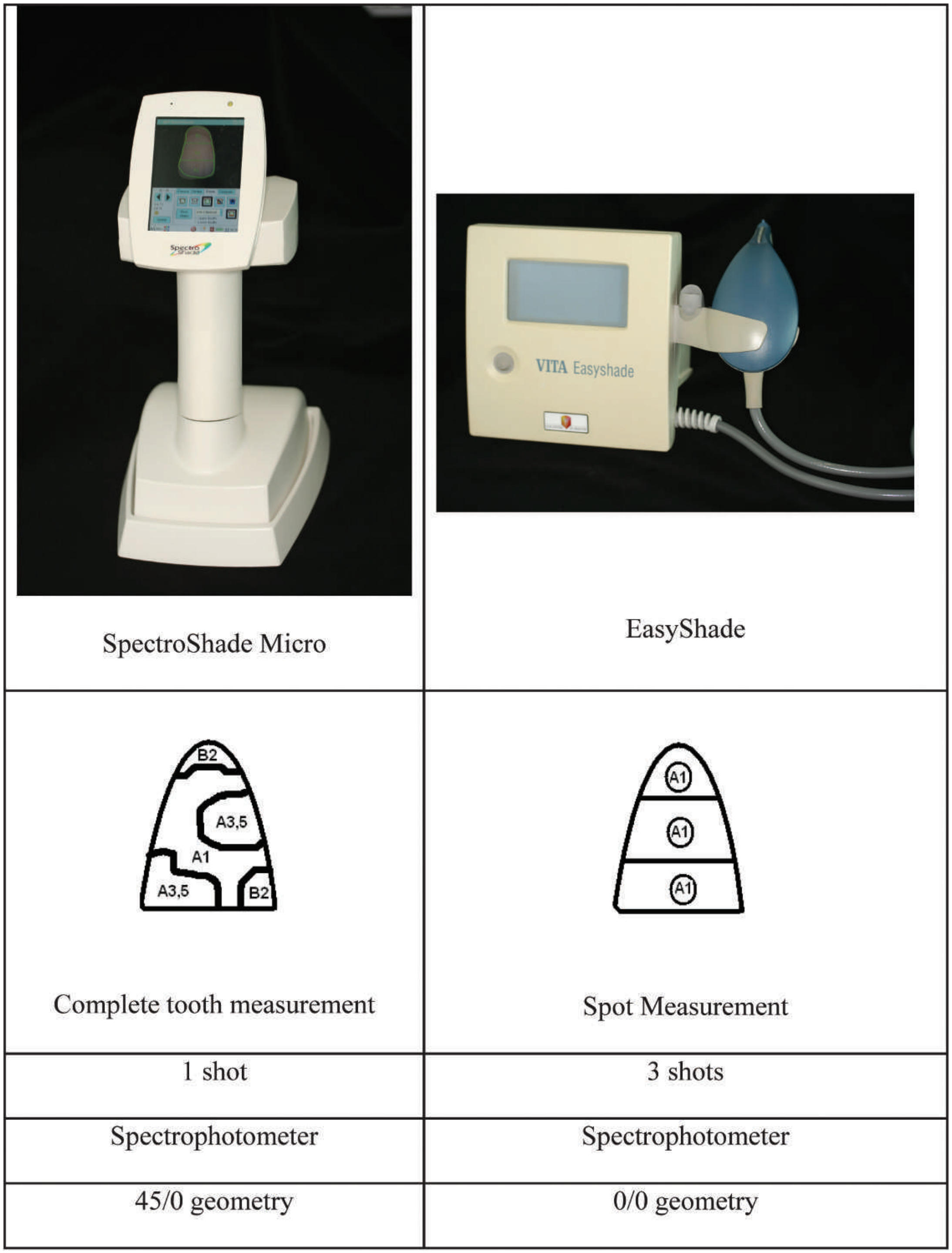

Figure 1. *Comparison between the two CMDs.*

In this equation the ΔL*, Δa*, and Δb* are the mathematical differences between the ES and the SS L*a*b* values. In previous studies it was shown that color differences between 2.0 and 3.7 were visually detectable under clinical conditions, but they resulted in an acceptable color difference[1,12] Therefore, in this study clinically relevant data were obtained by counting the number of cases of $\Delta E > 2.0$ and $\Delta E > 3.7$, respectively.

2. To ensure that the measurements of both devices were comparable, the relation between their individual measurements at the L*, a* and b*

Table 1: *CIE L*a*b* Translation Table of the Vita Shade Guide*

	L*	a*	b*
A1	79.6	–1.6	13.1
A2	76.0	–0.1	16.7
A3	75.4	1.4	19.6
A3.5	72.3	1.5	21.8
A4	68.6	1.6	21.0
B1	78.9	–1.8	12.3
B2	76.7	–1.6	16.6
B3	74.1	0.5	22.3
B4	71.8	0.5	22.2
C1	74.2	–1.3	12.6
C2	71.0	–0.2	16.7
C3	68.8	0.0	16.7
C4	64.8	1.6	18.7
D2	75.3	–0.5	13.5
D3	72.6	0.6	16.1
D4	71.9	–1.0	17.8

levels was evaluated by comparing the obtained L*, a*, and b* values of both instruments in a linear regression analysis.

3. As differences in the outcome of the L*a*b* measurements per spectrophotometer might be taken into account in the internal software to suggest an appropriate color in Vita shades, the coinciding suggested color codes were also compared. In order to quantify this data, the coinciding suggested Vita codes given by the devices were changed into the L*a*b* values, by using the referential values to shade guide codes as published by O'Brien and others[12] (Table 1). The color differences (ΔE*) between the derived values of the Vita Classical shade guide for the two devices were also calculated according to Equation 1.

Statistical Analysis

Initially, the mean color differences between direct comparison of CIE L*a*b* values and the derived CIE L*a*b* values of the Vita Classical shade codes were analyzed with one-way analysis of variance (ANOVA). Analysis showed that the mean color difference was not normally distributed, and analysis based on Gauss distributions was not justified. Therefore, a nonparametric Mann-Whitney U test and Kruskal-Wallis one-way ANOVA on ranks with post hoc Tukey (p=0.05) were used to evaluate different data. The data sets of L*, a*, and b* values of equal specimens measured by the two different devices were subjected to a linear regression model to analyze the correlation between the obtained values of the ES and the SS. The software used for this purpose was SigmaStat 3.1 (Systat Software, Inc, Richmond, CA, USA).

RESULTS

The mean CIE L*a*b* values (n=918) obtained after measuring the three locations per tooth of three teeth in each of 102 subjects with the ES and SS, respectively, are summarized in Table 2. The mean color difference (ΔE) for all L*a*b* measurements between the two devices was 12.1 (3.0), and the medians and quartiles are summarized in Table 3.

The Vita Classical shade guide codes were converted to CIE L*a*b* parameters, and the color differences between them were calculated for both devices according to Equation 1 (see Table 1). The mean color difference (ΔE*) was 3.1 (3.3), and the medians and quartiles are summarized in Table 3. Mann-Whitney U test showed that the mean differences between CIE L*a*b* values and the converted CIE L*a*b* values of the Vita Classical shades were significantly different (T=1262876;

Table 2: *Mean CIE L*a*b* Values (Standard Deviations) Obtained for Nine Locations in 102 Subjects Measured with the Easyshade and the SpectroShade-Micro*

	L*	a*	b*
Easyshade	71.6 (2.8)	6.7 (1.6)	20.8 (3.0)
SpectroShade-Micro	80.9 (4.2)	0.1 (0.1)	26.6 (5.8)

Table 3: *Means (Standard Deviations), Medians, and Quartiles of the Calculated E Values by 3 Different Evaluation Methods Obtained for 918 Measured Locations and Number of Clinical Cases with E Cut-off Values of 2.0 and 3.7*

	ΔE (L*a*b*)	ΔE (Vita)	ΔE (Vita) Cervical	ΔE (Vita) Middle	ΔE (Vita) Incisal
Mean	13.7 (2.9)	3.1 (2.1)	3.1 (2.2)	3.1 (2.1)	3.0 (2.0)
Median	13.9	3.3	3.2	3.5	3.2
25%	12.0	1.5	1.5	1.5	1.5
75%	15.5	4.6	4.6	4.6	4.6
ΔE < 2.0	0%	40.0%	41.0%	40.0%	39.7%
ΔE < 3.7	0%	55.1%	55.4%	53.4%	57.0%

$p<0.001$). Furthermore, the converted CIE L*a*b* values of the Vita Classical shades per region (cervical, middle, and incisal) are summarized in Table 3. Statistical analysis showed that there were no significant differences between the three measured regions (H=0.096; $p=0.953$).

The linear regression plots are depicted in Figure 2, and the obtained formulas and their correlation coefficients summarized in Table 4.

DISCUSSION

The purpose of this study was to reveal whether it is possible to compare color data between two different spectrophotometers. The results show that when L*a*b* values for the same tooth area are considered, both instruments differ to such an extent that in no case was comparable color data obtained. However, the best results were achieved when the Vita code suggestions were compared. When the suggested Vita shades were compared, in 40% of the cases both devices gave an equal suggestion, and a total of 51% resulted in clinically acceptable suggestions. The fact that 49% of the cases led to an unacceptable color measurement between the two devices can be interpreted as a poor result. However, in comparison to *visual* shade determination, where shade selections matches in only 26.6% of cases[3] this might be interpreted as a valuable contribution in dental color selection.

In the present study, the data were collected by the ES, which can be categorized as a spot-measurement device, and by the SS, which is a complete-tooth-measurement device. It has been stated that the data collected by spot-measurement devices may not be entirely accurate because of the non-homogenous shade structure of the tooth, the increased potential for tooth dehydration, and errors in image capture.[16] The color measurement of the exact same spot on a curved tooth surface can also prove to be challenging, which may affect the consistency of the measurements (Figure 1).[17] However, one study explains that the spot measurements in particular are more accurate because measurements are made with the tip of the probe.[18] In contrast, in devices such as SS, software calculations of an average value for the three tooth areas may decrease accuracy of measured color. On the other hand, in contrast to the ES, the complete tooth measurement with SS presents a topographical color map of the entire tooth in only one image, making the color readings from different areas much more consistent (Figure 1). The color of human teeth has a specific distribution pattern according to the different regions of the tooth surface[19] (segment relation in color from cervical to middle and incisal). These relations in color have been established by use of a digital camera, which recorded images of the whole tooth.[20] Looking at Table 3, it is evident that the three different tooth regions do not influence the measurements taken by the two devices.

When evaluating the regression analysis between the two devices, the correlation coefficients of the L*a*b* values are independently so low that further analysis was not considered. On average, the SS assessed higher b* values than the ES (Figure 2), meaning that the SS determines the color of a tooth as being more yellow than the ES indicates. On the other hand, the ES constantly measured a much higher a* value for the same spot than the SS (Table

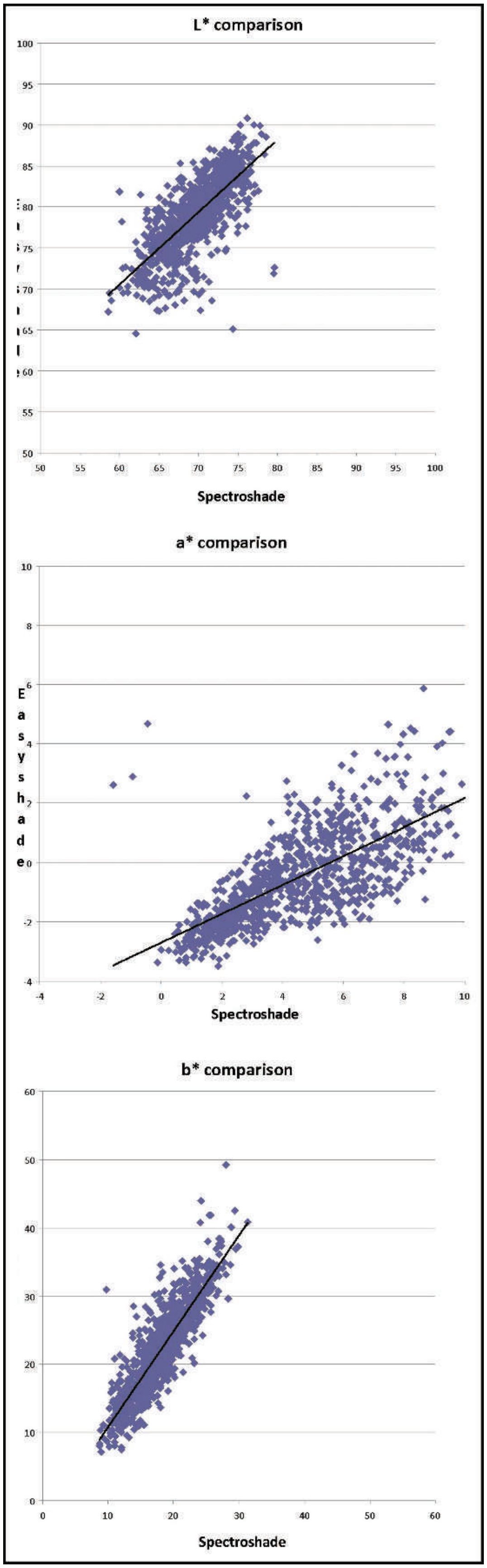

Figure 2. *The linear regression plots of the L*, a*, and b* values of the Easyshade and the SpectroShade obtained at 918 different points.*

Table 4: *Regression Formulas and Correlation Coefficients for L*a*b* Data Exchange Between the Easyshade and the SpectroShade-Micro*

Color Coordinate	Regression Formula	Correlation Coefficient
L*	$L^*_{Easyshade} = L^*_{SpectroShade} * 0.88 + 17.6$	$R^2 = 0.51$
a*	$a^*_{Easyshade} = a^*_{SpectroShade} * 0.49 - 2.7$	$R^2 = 0.50$
b*	$b^*_{Easyshade} = b^*_{SpectroShade} * 1.41 - 3.3$	$R^2 = 0.76$

2), which means that the same tooth is determined as being more red with the ES. Such results could be attributable to the fact that the ES and SS have different optical geometries and that they irradiate tooth surface in different ways. The SS irradiates the tooth at an angle of 45 degrees, and the detector receives the reflected light from the tooth at the location of 0 degree. The ES irradiates the tooth surface and receives the reflected light at 0 degree. Therefore, the area of irradiation is smaller with the ES than with the SS. In previous studies it was shown that the CIE L*a*b* values, which use a smaller irradiated area, are shifted toward green and blue and to lower brightness relative to the actual color coordinates.[17,21,22] This means that the ES should have lower L*, a* and b* values than the SS. The results of this study are in agreement with these findings for L* and b* but not for a*. This might be attributable to fact that the optical geometries are different, but this has not been studied previously. The origin of the fact that CIE L*a*b* values depend on the irradiated area, could be the wavelength-dependent edge loss that occurs by small area colorimeters and spectrophotometers. It has been shown that the edge loss for green light is approximately 85% of the edge loss for red light, and this effect could have been decreased by using larger measuring areas.[17]

The corresponding CIE L*a*b* values of the Vita shade tabs originate from the study of O'Brien.[12] Although other reports have described absolute values of the Vita Classical shade tabs,[18,23-25] only O'Brien actually described the results as CIE L*a*b* values. The fact remains that even different shade guides from the same manufacturer are not identical,[26,27] which means that the CIE L*a*b* values used in this present study are specific for this study only.

One can assume that one of the reasons for the findings in this study could be the fact that the evaluation of a CMD in the oral environment is very complex. Many handling errors with the different instruments could play a role in the results. In a clinical setting, the instruments can be sensitive to the patient's movement, fogging, the angle and position of the probe, different inclinations, and different shapes of the teeth. Moreover, the accuracy of the incorporated light source can change over time, influencing the measured values.[8]

Although the L*a*b* values are absolute and standardized, they were not interchangeable between the two investigated devices. This means the dentist and the dental laboratory that work together are obliged to use the same device to communicate color between them. Manufacturers of these devices should consider putting more effort into standardization to improve the reproducibility of the data in clinical circumstances.

CONCLUSIONS

The color values (L*a*b*) of teeth, measured with two different spectrophotometers, were not comparable in this study. Therefore, the exchange of the L*a*b* values between two spectrophotometers cannot be recommended.

The two devices match each other better when the output of the tooth color is given as the closest corresponding shade tab according to the device's database. This is because the devices automatically select the closest color match from an internal database of Vita shade codes.

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REFERENCES

1. Johnston WM, & Kao EC (1989) Assessment of appearance match by visual observation and clinical colorimetry *Journal of Dental Research* **68(5)** 819-822.
2. Okubo SR, Kanawati A, Richards MW, & Childress S (1998) Evaluation of visual and instrument shade matching *Journal of Prosthetic Dentistry* **80(6)** 642-648.
3. Paul S, Peter A, Pietrobon N, & Hammerle CH (2002) Visual and spectrophotometric shade analysis of human teeth *Journal of Dental Research* **81(8)** 578-582.
4. Seghi RR, Hewlett ER, & Kim J (1989) Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain *Journal of Dental Research* **68(12)** 1760-1764.
5. Cal E, Sonugelen M, Guneri P, Kesercioglu A, & Kose T (2004) Application of a digital technique in evaluating the reliability of shade guides *Journal of Oral Rehabilitation* **31(5)** 483-491.
6. Karamouzos A, Papadopoulos MA, Kolokithas G, & Athanasiou AE (2007) Precision of in vivo spectrophotometric colour evaluation of natural teeth *Journal of Oral Rehabilitation* **34(8)** 613-621.
7. Li Q, & Wang YN (2007) Comparison of shade matching by visual observation and an intraoral dental colorimeter *Journal of Oral Rehabilitation* **34(11)** 848-854.
8. Dozic A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, & Khashayar G (2007) Performance of five commercially available tooth color-measuring devices *Journal of Prosthodontics* **16(2)** 93-100.
9. Chu S, Devigus, A., & Mieleszko A. (2004) *Fundamentals of Color: Shade Matching and Communication in Esthetic Dentistry* Quintessence Publishing Co, Inc, Carol Stream, Ill.
10. Commission Internationale de l'Eclairage: *Colorimetry*, ed 2, CIE Publication No. 15.2, Paris, 1986, Central Bureau of the CIE.
11. Seghi RR (1990) Effects of instrument-measuring geometry on colorimetric assessments of dental porcelains *Journal of Dental Research* **69(5)** 1180-1183.
12. O'Brien WJ, Groh CL, & Boenke KM (1990) A new, small-color-difference equation for dental shades *Journal of Dental Research* **69(11)** 1762-1764.
13. Corciolani G, & Vichi A (2006) Repeatability of colour reading with a clinical and a laboratory spectrophotometer. *International Dentistry South Africa* **8(5)** 62-70.
14. Paravina R, & Powers, J. (2004) *Esthetic Color Training in Dentistry* Elsevier Mosby, Inc, St. Louis, Mo.
15. Da Silva JD, Park SE, Weber HP, & Ishikawa-Nagai S (2008) Clinical performance of a newly developed spectrophotometric system on tooth color reproduction *Journal of Prosthetic Dentistry* **99(5)** 361-368.
16. Khurana R, Tredwin CJ, Weisbloom M, & Moles DR (2007) A clinical evaluation of the individual repeatability of three commercially available colour measuring devices *British Dental Journal* **203(12)** 675-680.
17. Bolt RA, Bosch JJ, & Coops JC (1994) Influence of window size in small-window colour measurement, particularly of teeth *Physics in Medicine and Biology* **39(7)** 1133-1142.
18. Kim-Pusateri S, Brewer JD, Davis EL, & Wee AG (2009) Reliability and accuracy of four dental shade-matching devices *Journal of Prosthetic Dentistry* **101(3)** 193-199.
19. Dozic A, Kleverlaan CJ, Aartman IH, & Feilzer AJ (2004) Relation in color of three regions of vital human incisors *Dental Materials* **20(9)** 832-838.
20. Dozic A, Kleverlaan CJ, Aartman IH, & Feilzer AJ (2005) Relations in color among maxillary incisors and canines *Dental Materials* **21(3)** 187-191.
21. Lee YK, Lim BS, & Kim CW (2003) Difference in polymerization color changes of dental resin composites

by the measuring aperture size *Journal of Biomedical Materials Research Part B Applied Biomaterials* **66(1)** 373-378.

22. Lee YK, Lim BS, & Kim CW (2004) Influence of illuminating and viewing aperture size on the color of dental resin composites *Dental Materials* **20(2)** 116-123.

23. Analoui M, Papkosta E, Cochran M, & Matis B (2004) Designing visually optimal shade guides *Journal of Prosthetic Dentistry* **92(4)** 371-376.

24. Lee KY, Setchell D, Stokes A, & Moles DR (2005) Brightness (value) sequence for the Vita Lumin Classic shade guide reassessed *European Journal of Prosthodontics and Restorative Dentistry* **13(3)** 115-118.

25. Park JH, Lee YK, & Lim BS (2006) Influence of illuminants on the color distribution of shade guides *Journal of Prosthetic Dentistry* **96(6)** 402-411.

26. Cal E, Guneri P, & Kose T (2006) Comparison of digital and spectrophotometric measurements of colour shade guides *Journal of Oral Rehabilitation* **33(3)** 221-228.

27. Klemetti E, Matela AM, Haag P, & Kononen M (2006) Shade selection performed by novice dental professionals and colorimeter *Journal of Oral Rehabilitation* **33(1)** 31-35.