Repeatability, Accuracy and Ergonomics of three devices for tooth color measurement

Short title: Tooth shading evaluation

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Abstract

Objectives: The aim of this study was to compare the performances of three commercial spectrophotometer devices for tooth color measurement: Easyshade, SpectroShade and Rayplicker.
Methods: Three different features were evaluated: repeatability, accuracy and ergonomics. For the repeatability evaluation, the shade of the vestibular aspect of 50 freshly extracted teeth implanted on plaster arch models was detected with each device. Measurements were repeated by three different operators under three different light sources. For the accuracy evaluation an *in-vitro* protocol was followed on 60 metal-ceramic crowns. Lastly, a questionnaire was carried out among the operators in order to evaluate the ergonomic features of the devices.
Results: The repeatability of SpectroShade was similar to that of Rayplicker (71% and 70% respectively) while that of Easyshade was significantly lower (59%). All three devices performed similarly in terms of accuracy. Rayplicker was the most user-friendly while SpectroShade the least one.
Conclusions: While there were not significant differences between SpectroShade and Rayplicker for repeatability and accuracy, the latter displayed a distinguished advantage in terms of ergonomics.
Clinical significance: the choice of the most reliable and user-friendly device for tooth color assessment, as well as a real-time interaction with the dental lab, may have a relevant impact in both clinician and patients' satisfaction when finalizing the restorative procedure.

Key words: color measurement; spectrophotometer; tooth color; tooth shade

Introduction

A beautiful smile directly and positively affects the psychological well-being and self-esteem of an individual. Therefore, a satisfactory treatment in contemporary dentistry, cannot neglect the aesthetic dimension [1]. Among the many parameters that determine an aesthetic treatment outcome in dentistry, tooth color is one of the most important [2]. A color mismatch immediately influences patients' satisfaction leading to disappointment.

At the same time, the selection of shade to match that of natural teeth, represents one of the most challenging problems in today's dentistry. [3] There are currently two available ways for measuring tooth shade, with enhanced differences in their performance: the traditional visual method and the device-assisted method [4]. The visual method is commonly utilised for evaluating tooth color and its outcomes can be constantly improved by training [5]. Though, it has some significant limitations derived from factors concerning the quality of light source, the observer's characteristics (e.g. age, experience, level of fatigue etc.) or environment's characteristics (e.g. brightness of the background) [6]. Consequently, a demand for a device-assisted color measurement was evoked, with different studies proving its superiority when compared to visual measurement [7].

Color measurement devices can be of different types: colorimeters, digital imaging systems and spectrophotometers [8,9]. While the limitations of colorimeters on measuring the color of translucent objects like teeth, has been documented [10,11], digital cameras are gaining increased attention nowadays and when combined with the right calibration protocols, they can produce an overall good result [12]. However, the most reliable tools for color measurement today are represented by spectrophotometers, which can quantitatively measure the reflection or transmission properties of a material for each subsequent wavelength [13]. These data can then be translated into colorimetric information following the protocols of International Commission on illumination (C.I.E.) [14].

The aim of this *ex-vivo* and *in vitro* study was to compare three different spectrophotometry devices for tooth color measurements in terms of repeatability and accuracy. For simplicity, throughout the manuscript the term "tooth shade" will be referred to the vestibular aspect of the crown.

Materials and Methods:

The study was designed and performed by researchers of the Università degli Studi di Milano (MDF, ST, LK), in collaboration with a French colleague (RB) that contributed to the study design, preparation of the models and interpretation of the results. Measurements were all taken in a room of the IRCCS Istituto Ortopedico Galeazzi, Milano, Italy. The three operators performing the measurements were dentists with a fair experience in tooth shading measurement. All of them underwent the same training phase for the study, consisting of 20 measurements of sample teeth, aiming at taking confidence with the devices under investigation and the various procedures (calibration, setting, measurement, output reading).

This study was composed of two different protocols, one for the repeatability and another for the accuracy of the three following devices: Easyshade® V (VITA, Bad Säckinger, Germany), SpectroShade Micro (MHT, Verona, Italy) and Rayplicker (BOREA, Limoges, France). The first two devices are commercially available and well known, and their latest generation was utilised in this study, strictly following the directions for use recommended by their companies. Easyshade® V (VITA) is a spectrophotometer with measurement range of 400 – 700 nm (emitted light) and with an output of tooth shades in the standard VITA classical A1-D4® shade guide [15]. It has a point-by-point technique for tooth shading, meaning that it has a small tip that measures a very small area, and requires multiple measurements in different segments of the tooth in order to establish tooth shade. It also has the necessity of calibration, even though the procedure is relatively fast. SpectroShade (MHT) is a bulky spectrophotometer with a measurement range of 410 - 680 nm [16]. It has a wide reading area and gives information on a wide display for the global tooth shade and shades of different sectors of the tooth in a single measurement. It necessitates a calibration process which takes a considerable time (about 20-25 seconds for a trained operator).

The third device, Rayplicker (BOREA) is an innovative spectrophotometer, provided with a CMOS color sensor at its measuring tip, with the ability to evaluating tooth shade in a single measurement and to take a polarized picture of the tooth and its translucency as well. The calibration of this device is done automatically. Finally, the data are first acquired through a dedicated software, that allows data transfer via Cloud to the laboratory [17].

Repeatability *ex-vivo* protocol. Fifty natural freshly extracted teeth were utilised (12 incisors, 9 canines, 11 premolars, 18 molars). They were extracted for any reason (mostly for periodontal reason), and the only selection criteria was that the crown had to be intact, without signs of caries or filling. Each tooth underwent a standard cleaning session (by scaling procedure) before being used in this study, in order to remove any deposits of dental plaque and calculus, that could interfere with the actual tooth color measurement. They were numbered to ensure that different users evaluated them in the same order, and then implanted on plaster arch-models (Fig. 1). The cervical, middle and incisal third of each tooth crown was measured with three different devices utilised in parallel by three different users. Measurements were repeated under three different types of illumination source: Light 1 (cool white, Luminous Flux 2900Lm, Color Temperature 4000K), Light 2 (daylight, 2850Lm, 5400K) and Light 3 (warm light, 2700Lm, 3000K) (Fig. 2). Therefore, a total of 4050 data was obtained (3 measurements for each tooth x 3 lights x 3 devices x 3 users x 50 teeth). The output of the measurements was expressed as a value of the standard VITA classical A1-D4® shade guide. For assessing the repeatability of each device, the matching shades were counted for measurements taken by different operators using the same device, under the three different light conditions separately. The effect of the operator was also evaluated by grouping the results obtained with different devices and counting the matching outputs.

Accuracy *in vitro* protocol. Sixty crowns fabricated by the same dental laboratory and made by the same ceramic material were utilized. All crowns were ceramic-metal with a ceramic thickness of 1 mm and without translucency. Each crown was numbered and implanted on a plaster arch-model (Fig. 3). The sample was divided into three groups of 20 crowns each (Fig. 4a-c). The first group included 20 mono-color crowns with the following selected shades (according to the standard VITA classical A1-D4® shade guide): B1, A3, C2, C4 (five crowns per each shade). The second group included 20 crowns with two shades each, distributed as follows: five crowns with A4 shade in the incisal third and A1 in cervical two-third, five crowns with B4 shade in incisal two-third and B1 in cervical third, five crowns with C4 shade in incisal third and C1 in cervical two-third, five crowns with D4 shade in incisal two-third and D2 in cervical third. The third group included 20 crowns with three shades distributed as follows on an incisal-cervical direction: five crowns D3-B2-A1, five crowns C3-D2-A2, five crowns A2-A3.5-C3, five crowns B3-A4-A3. A clear demarcation between different shade-zones was requested to the laboratory. All measurements were done by one single user (RB) under the same source of illumination (warm light), utilising the three different devices. For the first group a total of 4 measurements were performed for each crown (one general color measurement, and three different measurements for the cervical/middle/incisal part). For the second and third group three measurements were performed for each crown. A total of 600 data was obtained.

Ergonomics. After all the measurements were performed, a questionnaire was provided to each operator, in order to evaluate different aspects that could be related to the ergonomics of the devices and lead to individual preferences towards one of them. The questionnaire was composed of 10 questions, that were the same for each device (except for the easiness of calibration, done automatically in the Rayplicker device), and the answers were based on a 4-point Likert-type scale, where 4=absolutely, 3=much 2=not much, 1= not at all. The questions were: Is it easy to get confident with the device? Is the device comfortable to handle? Are the calibration procedures easy to perform? Is it easy to take a measurement? Is it easy to repeat a measurement in the same tooth region? Is it easy to take measurements in any tooth of the arch? Do you like the output aspect? Is the output on the display easy to understand? Do you feel the measurement is accurate? Do you get tired frequently when using the device? (for the latter question the scoring is inverted).

Statistical analysis

The data were synthesized by means of absolute counts and percentages of matched measurements for repeatability and accuracy. The Pearson's chi-squared statistical test ($\chi 2$) was applied for all comparisons for repeatability and accuracy. The Kruskal-Wallis test was used to evaluate differences between groups for ergonomics aspects. A significance threshold of P=.05 was set.

Results:

Repeatability

Table 1 shows the absolute counts and percentage of repeatability of the three devices under separate lights and the total repeatability when measurements with all three lights are aggregated. SpectroShade and Rayplicker exhibit a similar repeatability (71% and 70% respectively), while Easyshade follows with a gap of 11-12%.

According to Pearson's p value, within Light 1 Rayplicker shows a significantly better repeatability, whereas under light 2 and 3, Rayplicker and SpectroShade performed significantly better when compared to Easyshade. Rayplicker was the only device completely independent from the type of light while the latest might have some influence in the results of the two other devices.

Accuracy

Accuracy results are indicated in Table 2. All three devices produced a good accuracy in detecting tooth color. Rayplicker showed the best outcomes, with an overall accuracy of 66%, which was significantly superior when compared to Easyshade (55.5%, p=0.03) but not to SpectroShade. (58%, p=0.10). The most significant differences were found in the first test (One-shade crown), where the superiority of Rayplicker respect to the other two devices was clear.

Ergonomics

Regarding the ergonomics aspect, from the questionnaire emerged that the three devices differed in some aspects: according to the operators SpectroShade was the less comfortable to handle ($P=0.03$), the least user-friendly for taking measurements ($P=0.046$), and produced tiredness more frequently ($P=0.02$). Rayplicker was the preferred for taking measurements in any tooth of the arch, while Spectroshade resulted the least comfortable also in this aspect ($P=0.02$).

Discussion

Today's demand for aesthetic dentistry fully justifies the emergence of new technologies and devices for tooth color detection. The objective evaluation of the tooth color represents an important advantage of devices for tooth shading measurement when compared to the traditional visual method [7, 18]. Simultaneously, a necessity to evaluate and compare the different available devices is evidenced. This *in vitro* and *ex-vivo* study, with the advantage of a standardised protocol, represents an effort to address such a necessity. It compared three spectrophotometry devices: Easyshade, SpectroShade and Rayplicker based on three parameters: repeatability, accuracy and ergonomics.

Following the *ex-vivo* repeatability protocol, all the 4050 measurement data were reported in a predetermined excel file organised in order to evaluate and compare the repeatability of the three devices in tooth color determination, as well as the influence of illumination and operator.

Table 1 quantifies the repeatability of the three devices and shows the influence of different lights. All three devices demonstrated good values of repeatability in different lights. Spectroshade and Rayplicker showed a similar overall repeatability (71% and 70% respectively) whereas Easyshade showed a significantly lower repeatability (59%) when compared to SpectroShade and Rayplicker ($p=.00015$ and $p=.0005$ respectively). Within cool white illumination, Rayplicker has a significantly better repeatability when compared to Easyshade and Spectroshade ($p=.002$ and $p=.016$ respectively). Within daylight and warm light illumination Easyshade had a significantly lower repeatability when compared to Spectroshade. All three devices performed slightly better under warm light illumination making it the light of choice for tooth shade determination in the present study. This was the reason for using warm light in the assessment of accuracy of the devices that followed the repeatability protocol. However, this doesn't mean that a systematic use of warm light is recommended in the daily practice.

Aiming at better understanding the influence of different lights on the repeatability potentials of the devices, between-lights p-values were calculated (Tab. 1). Based on this data, Easyshade performed similarly under three lights with the only significant difference between cool white and warm light (p=0.02). For SpectroShade cool white illumination produced significantly worse results when compared to daylight and warm light (p=0.0005 and p=0.00003, respectively). Rayplicker performed similarly under the three different lights, with no significant difference among them, representing the only device truly independent from the type of illumination.

As a general consideration, the range of shades output was rather limited for Easyshade and SpectroShade. The former mostly provided outcomes as three evenly represented values (from 27.6% to 32.8%) of the standard shade guide, that includes 16 different shades, while seven shades (B1, B4, C1, C2, C3, D2, D4) were never detected. SpectroShade in 52.1% of the cases detected the tooth shade as A1, and in 13.4% and 15.9% of cases as A2 and B2, respectively, with the remaining shades very rarely displayed. Conversely, Rayplicker showed a wider range of outputs, with 5 different shades represented for more than 10%, and other 10 shades detected with lower frequency (from 0.3% to 5.3%), covering almost all the range of shades. Indeed, we don't know the actual shade of the 50 extracted teeth evaluated, though we believe it is unlikely that their shade was limited to only two or three values of the whole range. It is not our intention to speculate about the devices' capability of detecting the true shade in this case, since the ex-vivo study was only designed to evaluate the repeatability feature.

For the accuracy protocol, a total of 600 data was obtained and analysed. All three devices showed an overall good accuracy with Rayplicker having a significantly better accuracy only when compared with Easyshade (p=0.03). Within the one-shade group of crowns, Rayplicker was significantly more accurate when compared to Easyshade and SpectroShade (p<0.001 and p=0.01 respectively). For the two-shade and three-shade groups, no significant difference was observed among different devices. Nevertheless, though all measurements were taken carefully, we cannot exclude the possibility of a certain degree of mismatch between the produced color from the laboratory and the requested shade based on the shade guide. In order to minimize such inconvenience in the daily practice, it is mandatory that the same spectrophotometer devices and reference shade guides are used by both the dentist and the laboratory throughout the whole process, from intra-oral shade taking to crown manufacturing in the laboratory, and finally to the application of the crown.

The third aspect we intended to analyse was ergonomics. Modern dentistry has fully embraced the importance of an ergonomic practice, that is, the establishment of a proper relationship between people, equipments and working place in order to increase efficiency and decrease the risk of professionally-related shortcomings [19]. Therefore, when choosing the device for tooth color determination, ergonomics should be taken into consideration. In this respect, the parameters that we evaluated include: head size, weight, number of measurements required and calibration, infection control procedures, time of data processing and data transfer options (Table 3). SpectroShade has the bulkiest head size, inhibiting the accessibility to the posterior regions of the mouth, whereas Rayplicker and Easyshade with their reduced head size can easily measure tooth color on posterior regions. Weight is an important feature that can directly affect the comfortability of the operator and consequently the final result. SpectroShade has the highest weight (915g), nearly double when compared to the other devices, with Easyshade having the lowest weight (215g) and Rayplicker a slightly higher one (380g). As for the overall process of tooth shade registration, the number of measurements required and calibration are different among the three devices. Easyshade has a single-point technique, requiring several measurements for detecting the shade of a single tooth, whereas SpectroShade and Rayplicker have a multi-point technique, meaning that they only require a single measurement for a specific tooth. For a color detecting device, calibration is an important process, representing the configuration of the device so that the results fall within an acceptable range [20]. Both SpectroShade and Easyshade need a manual calibration process even though that of SpectroShade is much more complex and time consuming. Rayplicker is the only device with an automatic calibration, meaning that no time is needed to be dedicated to this process.

Another major optical feature that is important to fabricate an aesthetically appropriate dental prosthesis is tooth translucency. Teeth have by nature a certain degree of translucency (or semitransparency) that allows a given quantity of light to diffuse through the tooth from the surrounding environment. Though this characteristic was not specifically assessed in the present study, among the devices investigated both Rayplicker and Spectroshade are able to evaluate tooth translucency, while EasyShade does not provide information regarding such component.

Furthermore, sterilisation properties for infection control have a crucial importance in a medical environment. Both SpectroShade and Rayplicker possess a sterilisable tip but Rayplicker comes with an additional protection sheath that further insures infection control. Easyshade only provides a disposable protection sheath.

Lastly, data processing differs from one device to another, with Rayplicker having the most time-consuming process when confronted to SpectroShade and Easyshade which can process data quickly after measurement. All three devices offer the possibility to digitally transmit the data through email but Rayplicker is the only device that can use Cloud to transmit data and contextual pictures taken with a dedicated mobile application, to better evaluate the tooth prosthesis context, and to facilitate the communication between the doctor and the technician. In an overall point of view, considering the many parameters we evaluated, Rayplicker represented the most ergonomic and user-friendly device.

Conclusion

As a bottom line to our study, among the three devices we evaluated, SpectroShade and Rayplicker performed similarly to each-other and superiorly to Easyshade in terms of repeatability and accuracy. Rayplicker had a distinguished advantage in terms of ergonomics and user-friendly features. It has a small head size, and an acceptably low weight. It needs no calibration, shade taking is relatively fast and only one measurement is required. It also offers an important advantage in terms of infection-control as it has a sterilisable tip and a protection sheath at the same time. Finally, Rayplicker may facilitate the interaction with the laboratory as it may share the acquired data not just through emails as others devices do, but directly via Cloud as well.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Table 1. Comparisons of repeatability between different devices in different light conditions. P-values of the comparisons are also reported.

	L 1	L 2	L 3	Total	L1 vs L2	L1 vs L3	L2 vs L3
EASYSHADE	81/150 (54%)	87/150 (58%)	100/150 (67%)	268/450 (59%)	0.48	0.02*	0.12
SPECTROSHADE	87/150 (58%)	115/150 (77%)	120/150 (80%)	322/450 (71%)	<0.001*	<0.001*	0.48
RAYPLICKER	107/150 (71%)	103/150 (69%)	108/150 (72%)	318/450 (70%)	0.61	0.99	0.52
Total	275/450 (61%)	305/450 (68%)	328/450 (73%)		0.03*	<0.001*	0.09
E vs S	0.48	0.006*	0.009*	<0.001*			
E vs R	0.002*	0.32	0.32	<0.001*			
S vs R	0.016*	0.1	0.1	0.77			

L1= cool white, L2= daylight, L3= warm light, E= Easyshade, S=SpectroShade, R=Rayplicker. The asterisk indicates significance.

Table 2. Comparisons of accuracy between different devices in warm light conditions. P-values of the comparisons are also reported.

	One-shade	Two-shade	Three-shade	Total
EASYSHADE	34/80 (42.5%)	34/60 (56.7%)	43/60 (71.7%)	111/200 (55.5%)
SPECTROSHADE	46/80 (57.5%)	34/60 (56.7%)	36/60 (60.0%)	116/200 (58%)
RAYPLICKER	62/80 (77.5%)	35/60 (58.3%)	35/60 (58.3%)	132/200 (66%)
E vs S	0.06	1.00	0.17	0.61
E vs R	<0.001*	0.80	0.12	0.03*
S vs R	0.01*	0.80	0.85	0.10

E= Easyshade, S=SpectroShade, R=Rayplicker. The asterisk indicates significance.

Table 3. Comparative features of the three devices used in the study.

Feature	Easyshade (VITA)	SpectroShade (MHT)	Rayplicker (BOREA)
Head size	small	big	small
Weight	215g	915g	380g
Nr.Measurements.	multiple	single	single
Calibration	fast	time consuming	automatic
Sterilisable tip	no	no	yes
Protection Sheath	yes	no	yes
Data processing	fast	fast	slow
Translucency	no	yes	yes

Figures

Fig. 1. Plaster arches with natural teeth implanted for the repeatability study.

Fig. 2. The three illumination sources used in the study. From the left: cool white, warm light, daylight

Fig. 3. Ceramic-metal crowns implanted in plaster arch-model, used for the accuracy study.

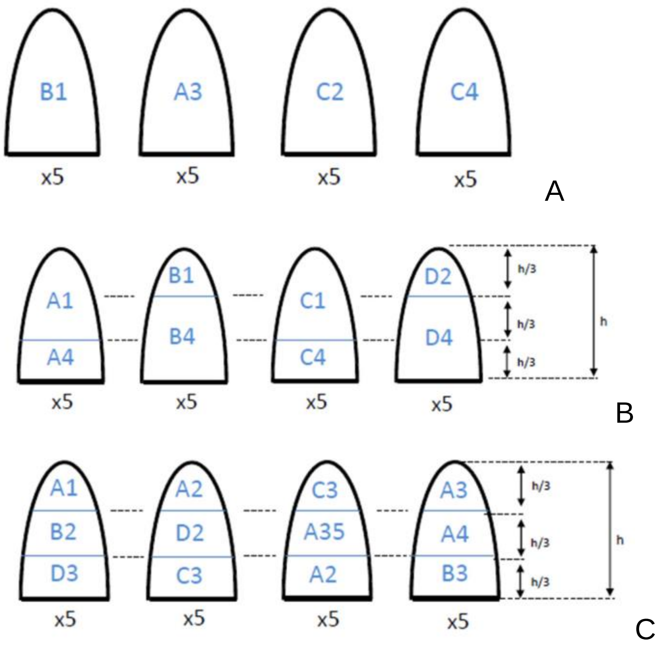

Fig. 4. Scheme of the tooth shades of the crowns used for the accuracy study. A: one-shade; B: two-shade; C: three-shade.