Vincent Hampé-Kautz, Ali Salehi, Bernard Senger, Olivier Etienne

A comparative in vivo study of new shade matching procedures

Abstract

Aim: The aim of the present study was to compare six different methods of in vivo color matching: visual shade matching (3D-Master Linearguide shade guide) performed by 1) a novice practitioner, 2) an expert practitioner, 3) the new Rayplicker spectrometer, 4) the Trios III intraoral scanner, and 5) the Omnicam intraoral scanner compared with 6) the Easyshade V spectrophotometer, which was considered as the reference.

Materials and methods: Color matching was performed using the 3D-Master references on the sound maxillary right central incisors of 40 subjects. The study first compared the number of colors found using each of the six methods. The references were then converted to the Commission Internationale de l'Eclairage (CIE) L*a*b* values, from which the difference ΔE between either two methods was derived. Finally, the L* value was used to compare the luminosity measured by each of the six methods.

Results: The Rayplicker showed the smallest ΔE compared with the Easyshade V. The expert found a closer color to the Easyshade V than did the novice, and both were closer to the Easyshade V than the two intraoral scanners. The intraoral scanners showed notable differences compared with the Easyshade V. The intraoral scanners also offered a reduced choice of colors and recorded the highest luminosities compared with the other methods.

Conclusion: Within the limitations of this study, the color matching by the Rayplicker was closest to that of the Easyshade V. The good performance of this new device means that it is a challenging competitor for the Easyshade V. Finally, the new methods based on intraoral scanners were less reliable than the spectrophotometers and the visual shade matching.

Keywords: *spectrophotometers, intraoral scanners, shade matching, Rayplicker, Easyshade V, tooth color, color measurements, Trios III, Omnicam*

Introduction

Tooth color is the major cause of patient dissatisfaction[1] and is therefore a significant concern in esthetic restoration dentistry. With the increase in requests from patients for esthetic improvements[2], the analysis of tooth color and its exact transfer to the laboratory is a critical step in treatment planning.

Currently, there are various methods available for shade matching, from visual methods using basic shade guides to more recent and advanced methods that incorporate spectrophotometers or intraoral scanners.

Visual determination is currently widely used in clinical practice; however, its results are highly subjective and depend on several variables, including the skill and age of the practitioner, the illuminants, and the background[3]. To make shade matching more objective and to better determine the shade of a tooth, practitioners have started to use devices such as spectrophotometers, which show superior results compared with visual shade matching in terms of precision (repeatability and reproducibility) and accuracy (the ability to provide a correct shade match)[4-6]. Recently, intraoral scanner manufacturers have equipped their apparatus with colorimeters, which use filters to control the light that reaches the specimen. The light reflected from the specimen is then measured by a sensor, which measures color tristimulus values according to Commission Internationale de l'Eclairage (CIE) illuminant and observer conditions. A spectrophotometer measures the spectral reflectance for each wavelength in the visible spectrum[7-9], and this minimizes the metameric effect (the fact that the color of an object is seen differently depending on the illuminant). The analysis is carried out during the digital impression, from which the software calculates the optimal shade for the restoration[10-12].

The purpose of the present study was to compare the results of color matching between a conventional visual color assessment performed by either a novice or an expert practitioner using the 3D-Master Linearguide shade guide (Vita Zahnfabrik, Bad Säckingen, Germany), two different spectrophotometers (Easyshade V; Vita Zahnfabrik/Rayplicker; Borea, Limoges, France), and two intraoral scanners (Trios III; 3Shape,

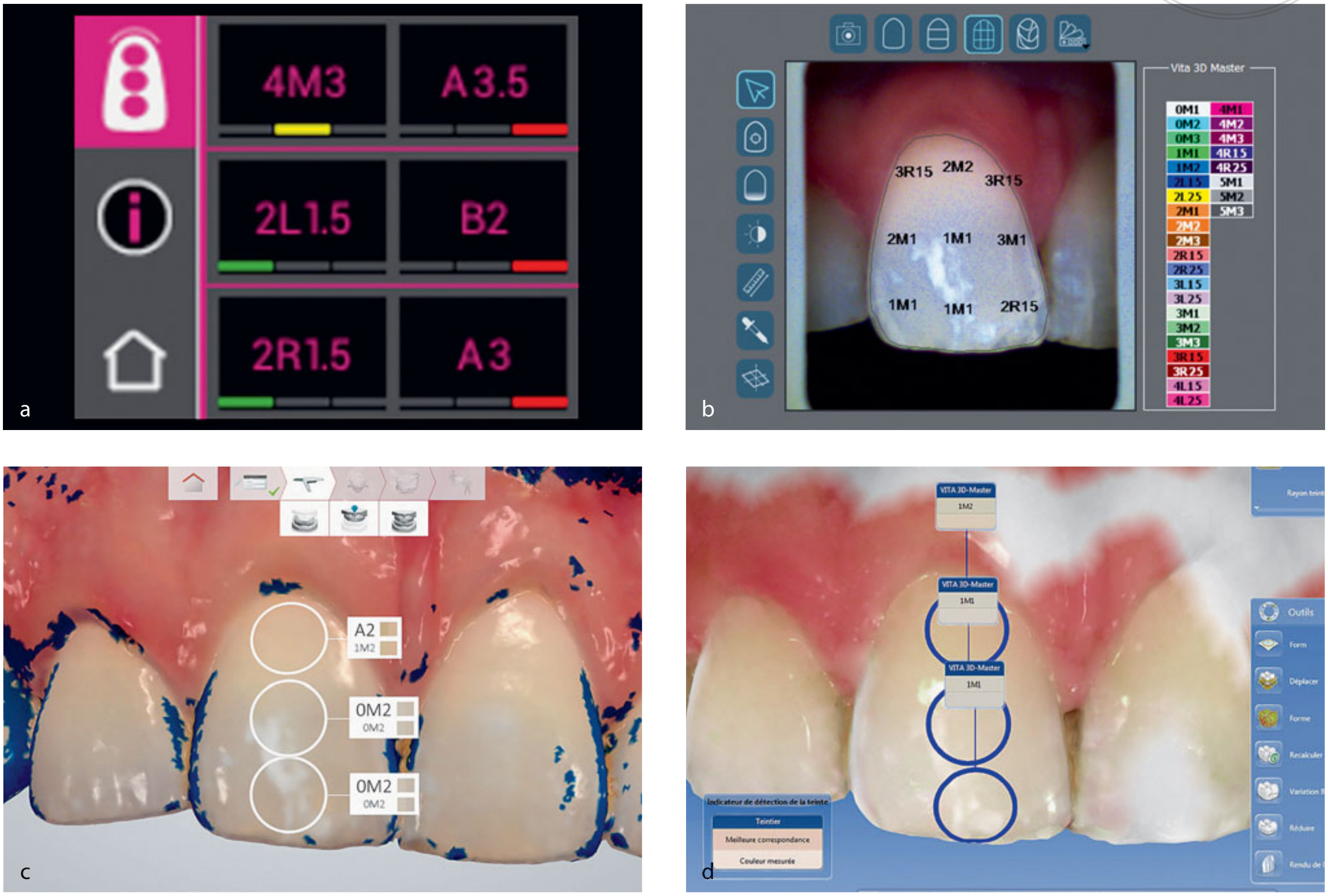

Fig 1 Screenshots of the interfaces of the four electronic shade matching measurements: Easyshade V (Vita Zahnfabrik; a); Rayplicker software (Borea; b); Cerec Omnicam CAD/CAM software (Dentsply Sirona; c); Trios III CAD/CAM software (3Shape; d).

Copenhagen, Denmark/Omnicam; Dentsply Sirona, Bensheim, Germany). As Easyshade V is one of the most frequently referenced systems and shows the best color agreements, it was chosen as the standard for this study.

Materials and methods

This in vivo comparative study measured the color on the middle third of the maxillary right central incisor of 40 subjects (n = 40) between the ages of 18 and 25 years. Inclusion criteria were: 1) the presence of at least the four maxillary and mandibular incisors and both canines; and 2) good oral hygiene. Exclusion criteria were: 1) the presence of restorative, orthodontic or endodontic treatments; 2) periodontal disease or decay; and 3) a previous bleaching treatment.

Design of the study

The colorimetric analysis was realized on the same day, under the same environmental conditions, and using the same illuminants on the middle third of the tooth. The measurements were performed without moistening. The study was designed as a shade-matching experiment on the 40 subjects using six different methods (Fig 1):

1. A visual shade matching using the 3D-Master Linearguide shade guide by a novice practitioner (5 years of dental clinical practice).
2. A visual shade matching using the 3D-Master Linearguide shade guide by an expert practitioner (25 years of specialist esthetic dental clinical practice).
3. An electronic shade matching using the Rayplicker spectrophotometer.

4. An electronic shade matching using the Trios III intraoral scanner.
5. An electronic shade matching using the Omnicam intraoral scanner.
6. An electronic shade matching using the Easyshade V spectrophotometer (reference).

The two practitioners performed the shade matching independently of each other. The novice was introduced to the visual shade matching technique and to the four electronic instruments. The instruments were calibrated according to the respective manufacturers' instructions:

- **Easyshade V:** calibration on the standard tile provided by the manufacturer.
- **Rayplicker:** calibration by the manufacturer's tip used as a gray scale for the apparatus during the measuring.
- **Trios III and Omnicam:** calibration according the manufacturers' instructions using their respective calibration color tools.

Each approach was focused on the middle third of each subject's tooth. The axes of the spectrophotometers' tips were oriented perpendicularly to the tangent of the surface the tooth. The electronic devices were set up to specifically analyze and record the color of the middle third and not the average color of the total surface of the tooth.

Color differences ΔE

Shade guides are based on the three parameters: brightness, hue, and chroma. In this study, each tooth color was recorded using the 3D-Master shade reference, which was then converted to the CIE colorimetric value. The CIE L*a*b* system defines a specific color by three coordinates: L*, a*, and b*. The coordinate L* is related to brightness, while the coordinates a* and b* are related to the chromatic characteristics (hue and chroma) on the red-green axis and the yellow-blue axis, respectively. A ΔE value is the Euclidian color difference between two specimens, as calculated by the CIEDE2000 formula[13], which is the most accurate tool for the evaluation of color differences in dentistry, according to Pecho et al[14].

The visual shade matching and the Omnicam and Trios III intraoral scanners do not give the values of L*, a*, and b* required for the computation of ΔE. Therefore, for consistency, the same 3D-Master reference was output by the two spectrophotometers. The 3D-Master reference given by each of the six methods was converted into L*, a*, and b* values using the table provided by Bayindir et al[15].

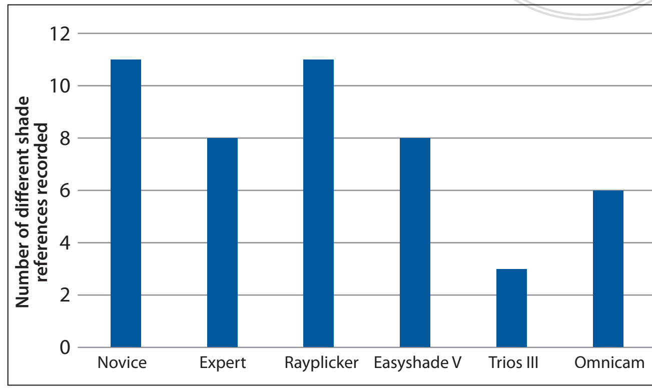

Fig 2 Number of 3D-Master color references recorded by each process over the sample of 40 subjects.

The ΔE value quantifies the difference between two colors as seen by the human eye: A high ΔE denotes a relevant visual difference, whereas a low ΔE denotes a negligible difference. Khashayar et al investigated 48 studies on the threshold value of ΔE, which separates an acceptable from a non-acceptable color difference in dentistry[16]. Most of the studies define acceptability thresholds ranging from ΔE = 2.0 up to ΔE = 4.0.

In the present study, the calculations of ΔE were realized with Excel 2016 software (Microsoft; Redmond, WA, USA). The statistical analyses were performed with SigmaPlot 11.2 (Systat Software; San Jose, CA, USA) and Maple 18 (Waterloo Maple; Waterloo, Canada) software.

Results

The intraoral scanners presented a more restricted choice of colors

The first part of the study consisted of counting the number of different 3D-Master color references recorded by each method on the sample of 40 teeth (Fig 2). The method that recorded the highest number of different shades was the visual evaluation performed by the novice and the Easyshade V(11 references), followed by the expert and the Rayplicker (8 references). The Omnicam (6 references) and Trios III (3 references) intraoral scanners were the methods with the lowest diversity of shades in the sample of 40 subjects.

This result shows a lack of color discrimination by the two intraoral scanners. Nevertheless, it is important to know whether the recorded differences between the different colors are clinically significant or whether they are due to negligible discrepancies between the results of each method.

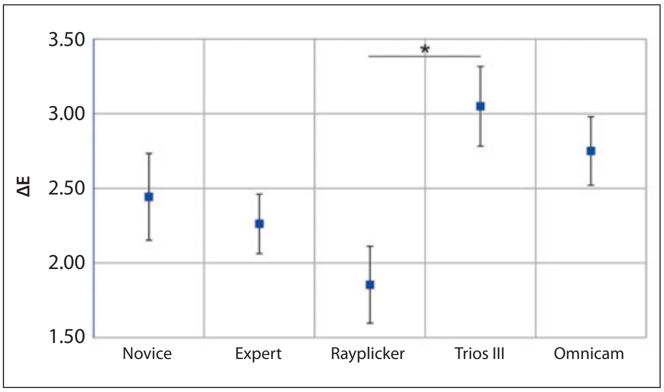

Fig 3 Mean and standard error of the mean of ΔE between the color assessed by Easyshade V and (from left to right) the visual shade matching by 1) the novice dentist, 2) the expert practitioner; and the instrumental shade matching by 3) the Rayplicker spectrophotometer, 4) the Trios III intraoral scanner, and 5) the Omnicam intraoral scanner. A significant difference ($P < 0.05$) was obtained between the Rayplicker and the Trios III (*).

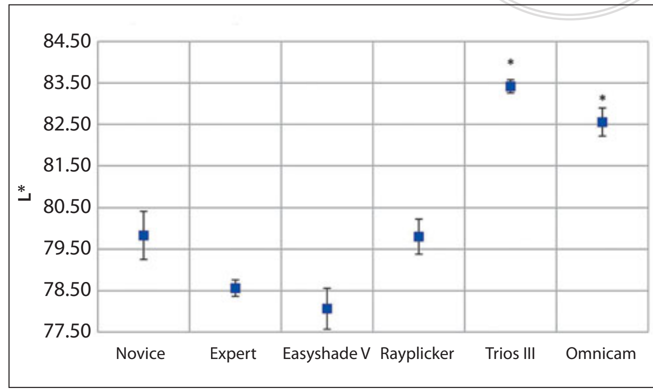

Fig 4 Mean and standard error of the mean of the L* values recorded by each shade-matching process. L* values obtained by the Trios III and Omnicam were significantly higher ($P < 0.05$) than those obtained using any of the four other methods (*).

The Rayplicker demonstrated the best agreement with the Easyshade V

The color difference between the Easyshade V and the Rayplicker showed the smallest ΔE mean (1.85 ± 0.26). The expert (2.26 ± 0.20) showed a better agreement with the Easyshade V compared with the novice (2.44 ± 0.29). The largest differences were found for the Omnicam (2.75 ± 0.23) and the Trios III (3.05 ± 0.27) intraoral scanners (Fig 3). According to the Kruskal-Wallis test, the only significant difference ($P < 0.05$) was obtained between the Rayplicker and the Trios III.

For the 200 values of ΔE obtained using the Easyshade V as the reference, the median was 2.45, whereas the individual medians were 2.84, 2.37, 2.01, 3.39, and 2.91 for novice, expert, Rayplicker, Trios III, and Omnicam, respectively. The value of 2.45 was chosen to define the threshold between an acceptable and a non-acceptable color difference. The number of ΔE values inferior to this chosen threshold for each of the methods were 18, 23, 26, 19, and 18 for the novice, expert, Rayplicker, Trios III, and Omnicam, respectively. A probability test based on the ‘heads or tails’ model revealed that only the Rayplicker led to a frequency of small ΔE values (ie, smaller than the above-defined threshold), which was significantly higher than would be expected by chance ($P < 0.05$).

The analysis described above might appear arbitrary to some extent because of the choice of a threshold. To overcome this possible weakness of the analysis, another criterion was defined: for each tooth, the best method (ie, the one that yields the result closest to that obtained with the Easyshade V, which means the smallest ΔE value) was given the score 1. In the case of m equally best-measuring methods, the score 1/m was ascribed to each. The total scores obtained, rounded to the nearest integer, were 8, 9, 14, 4, and 5 for the novice, expert, Rayplicker, Trios III, and Omnicam, respectively. The ‘heads or tails’ model was used once more to detect which counts were significant, and again the Rayplicker was the one most frequently nearest to the Easyshade V as far as the ΔE values were concerned ($P < 0.05$).

The intraoral scanners recorded colors with the most important luminosity

The L* coordinate represents the brightness of a color, which is one of the most important factors for determining a tooth shade[17]. The analysis of L* can determine whether the color differences between the devices are due to a difference of the chroma or hue, or whether they are due to the luminosity. The luminosities recorded by the six different methods (Fig 4) were statistically compared using the ANOVA on ranks test ($P < 0.05$). The L* values recorded by the Trios III (83.42 ± 0.16) and Omnicam (82.56 ± 0.34) intraoral scanners were significantly higher than the L* value obtained by the novice (79.84 ± 0.58) and the expert (78.56 ± 0.20), the Easyshade V (78.06 ± 0.50), and the Rayplicker (79.81 ± 0.42). The L* values between the two practitioners and the two spectrophotometers showed no significant differences among each other.

Discussion

The exact color of a tooth is unknown. In this in vivo study, the tooth shade given by the Easyshade V spectrophotometer was considered as the reference because it is one of the most reliable devices on the market today[6,7,18-20]. The present study compared the colors recorded by different methods, not to the true color of a tooth but to the color output by the most accurate device on the market. For the conversion of the 3D-Master shade to the (L*, a*, b*) coordinates of the CIE model, the table proposed by Bayindir et al[15] was used. These values are defined in an empirical way that can vary according to different authors[21,22], and the 3D-Master has a lack of color and a large gap between each tab. This conversion with the table is an approximation, but it is the only way at present to convert the human eye and colorimeter perceptions to mathematical L*a*b* values. The 3D-Master reference has to be input in the color guide parameters of the spectrophotometers and intraoral scanners. The apparatus record L*a*b* values and choose the shade reference with the closet L*a*b* coordinate that leads to a difference.

In the present study, the shade matching was focused on the middle third of the tooth because the incisal third often shows some degree of mixed color and many characteristics such as white spots or translucent areas that are difficult to analyze both for spectrophotometers[23] and in the case of visual assessments. Also, the color of the cervical third of the tooth often changes due to the contrast with the gingiva. Visual shade matching is often focused on the middle third of the tooth, but the color can vary on the total tooth surface. This problem is solved by the Rayplicker, which records the color of the complete tooth before mapping the shade on the total tooth surface, which is then analyzed in the software. Ideally, such a study evaluating shade matching should be extended to the whole tooth and to all the teeth in different situations, and the result and the ergonomics of the different devices must be compared, as has already been done by Klotz et al for the Easyshade V[20]. The color difference value ΔE helps to estimate whether the difference between two colors is clinically relevant or negligible. According to Khashayar et al[16], the clinical expression of the ΔE values can vary depending on the practitioner and the formula used for the calculation[14,24]. For the present study, the global median was chosen as the ΔE threshold (ie, $\Delta E = 2.45$), but it is not a universally accepted threshold.

The precision of intraoral scanners for digital impression taking is steadily increasing[25], but their colorimetric analysis remains unreliable because they have a narrow choice of colors and yield results that are significantly different from those of spectrophotometers. As a result, they should not be used for deciding the shade for a final restoration.

The present study results corroborate the results of previous studies that have shown that the visual method is practitioner-dependent[3,26]. Despite being the most accurate shade guide available today, the 3D-Master has weaknesses[5], and the color obtained by using it differs from that obtained using spectrophotometers.

Spectrophotometers are the best-adapted tools for shade matching since they record the L*, a*, and b* values of one color. However, they must convert these numerical values to the closest 3D-Master shade reference, which can increase the imprecision of the color measurement. Laboratory technicians interpret the information provided to them in order to create a tooth restoration with different ceramic powders. The result depends on many factors such as the thickness or the type of ceramics used and the technician's skill[27-29]. These two steps (the conversion to the 3D-Master reference and the technician's workflow) can induce color differences between the shade recorded and the final restoration. Some new approaches such as the eLab process[30] try to avoid the limited choice of color references and define the exact ratio of ceramic powders on the basis of the (L*, a*, b*) coordinates of the tooth.

The Rayplicker showed output results that are comparable to those of the Easyshade V. It therefore appears to be a good alternative to the Easyshade V, with color software that is very comprehensive and user-friendly, according to the two practitioners who participated in this study.

Conclusion

Within the limitations of this study, the following conclusions can be drawn:

- For shade matching, the Rayplicker showed the best color agreement with the Easyshade V.
- The expert performed shade matching that was closer to the output of the spectrophotometers than the shade matching performed by the novice.
- The intraoral scanners recorded a statistically different color than that recorded using the spectrophotometers or the visual methods.
- Intraoral scanners record brighter colors than spectrophotometers and the human eye.
- Intraoral scanners record a smaller variety of colors than spectrophotometers and practitioners.

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Eine komparative In-vivo-Studie neuer Farbbestimmungstechniken

Schlüsselwörter: *Spektralfotometer, Intraoralscanner, Farbbestimmung, Rayplicker, Easyshade V, Zahnfarbe, Farbmessung, Trios III, Omnicam*

Zusammenfassung

Ziel: Ziel der vorliegenden Studie war ein Vergleich von sechs verschiedenen Methoden der In-vivo-Farbbestimmung: visuelle Farbbestimmung (Farbskala Linearguide 3D-Master) durchgeführt von *1.)* einem noch unerfahrenen Zahnarzt bzw. *2.)* einem erfahrenen Zahnarzt sowie mit *3.)* dem neuen Spektrometer Rayplicker, *4.)* dem Intraoralscanner Trios III und *5.)* dem Intraoralscanner Omnicam verglichen mit *6.)* dem Spektralphotometer Easyshade V, das als Referenz diente.
Material und Methoden: Die visuelle Farbbestimmung erfolgte durch Abgleich der 3D-Master-Farbproben mit dem gesunden Zahn 11 von 40 Probanden. Zunächst wurde die Anzahl der mit jeder der sechs Methoden bestimmten Farben verglichen. Anschließend wurden die Referenzen in die L*-, a*- und b*-Koordinaten des Farbsystems der *Commission Internationale der l'Eclairage* (CIE) konvertiert, aus denen die Farbdifferenz ΔE zwischen jeweils zwei der getesteten Methoden berechnet wurde. Schließlich erfolgte ein Vergleich der mit jeder der sechs Methoden ermittelten Helligkeit anhand der L*-Werte.
Ergebnisse: Das Rayplicker-System zeigte gegenüber dem Referenzsystem Easyshade V das kleinste ΔE. Die erfahrenen Zahnärzte ermittelten näher am Easyshade V liegende Farben als die noch unerfahrenen, und beide Gruppen lagen näher am Easyshade V als die beiden Intraoralscanner. Die Intraoralscanner zeigten im Vergleich mit dem Easyshade V deutliche Unterschiede. Zudem lieferten die Intraoralscanner eine kleinere Palette an Farben und ermittelten im Vergleich der Methoden die höchsten Helligkeiten.
Schlussfolgerung: Im Rahmen dieser Studie kam die Farbbestimmung mit dem Rayplicker-System derjenigen mit Easyshade V am nächsten. Die gute Leistung des neuen Gerätes macht es zur Alternative und Herausforderung für den Easyshade V. Ferner waren die neuen Methoden der Farbbestimmung mit Intraoralscannern weniger zuverlässig als die Spektralfotometer und die visuelle Farbnahme.

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