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ORIGINAL ARTICLE

Reliability of shade selection using an intraoral spectrophotometer

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Abstract In this study, we evaluate the accuracy and reproducibility of human tooth shade selection using a digital spectrophotometer. Variability among examiners and illumination conditions were tested for possible influence on measurement reproducibility. Fifteen intact anterior teeth of 15 subjects were evaluated for their shade using a digital spectrophotometer (Crystaleye®, Olympus, Tokyo, Japan) by two examiners under the same light conditions representing a dental laboratory situation. Each examiner performed the measurement ten times on the labial surface of each tooth containing three evaluation sides (cervical, body, incisal). Commission International on Illumination color space values for *L** (lightness), *a** (red/green), and *b** (yellow/blue) were obtained from each evaluated side. Examiner 2 repeated the measurements of the same subjects under different light conditions (i.e., a dental unit with a chairside lamp). To describe measurement precision, the mean color difference from the mean metric was used. The computed confidence interval (CI) value 5.228 (4.6598–5.8615) reflected (represented) the validity of the measurements. Least square mean analysis of the values obtained by examiners 1 and 2 or under different illumination conditions revealed no statistically significant differences (CI=95%). Within the limits of the present study, the accuracy and reproducibility of dental shade selection using the tested spectrophotometer with respect to examiner and illumination conditions reflected the reliability of this device. This study suggests that the tested spectrophotometer can be recommended for the clinical application of shade selection.

Keywords Tooth color selection · Dental shade selection · Shade analysis · Spectrophotometer · Reproducibility

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Introduction

Reproducing the shade (color) of dental restorations (shade matching) according to the remaining natural dentition is a challenging aspect of dentistry. The assessment of the shade (shade selection) of natural remaining teeth is the first aspect of various factors in the process of fabricating a dental restoration. The most frequent technique for shade selection is using a dental shade guide containing tabs of various shades. This procedure depends on the individual visual perception of the observer. Additionally, it has been demonstrated that clinicians cannot duplicate their shade selections on different days [1, 2]. Variables including metamerism, illumination type, light reflection, and individual characterization of natural teeth further contribute to variability in shade selection [3–5].

These inherent characteristics of the shade selection process result in reduced predictability of a successful shade match of the restoration to the natural tooth [6]. Clinically, this leads to increased chair time because of necessary adjustments or even remakes of the restoration until the patient is satisfied, especially in anterior aesthetic areas.

To improve shade selection via shade tabs and to enhance communication between the dentist and the dental laboratory, new designs of shade guides have been introduced and have shown improvements [7, 8], but limitations still persist in terms of color range [9]. Techniques like making a digital photograph together with a matching shade tab and communicating this to the dental laboratory are commonly used. These images show the relative shade match of the two objects to each other. However, the color reproducibility of these images for analysis is influenced by lighting conditions and the color adjustment of the screens. However, the success of the visual process still depends on the level of clinician skill and experience, which, like their matching ability, is highly variable [10].

The application of digital color imaging [11] and digitally supported instrument use [12] has the potential to eliminate the variability of conventional visual shade selection. Using an analysis software to determine the color parameters of conventional digital images produced by a digital camera was described as being equal to using a spectrophotometer system [13] and better than a conventional visual method [10, 14]. A number of digital measuring instruments are available on the market and have been tested [3, 4, 12]. Regarding the measurement and collection of data, the systems are different in terms of the size of area they are capturing. Systems that apply a multispectral camera system, compared to a one-spot device, are able to give a reliable shade gradation across different tooth regions [15]. These digital systems should theoretically improve communication with the laboratory and help obtain an accurate shade match of the restoration to the remaining teeth. They use the Commission Internationale de l'Éclairage (CIE) [16] $L^*a^*b^*$ color coordinates (L lightness, a chromaticity along the red–green axis, and b chromaticity along the yellow–blue axis). Based on such CIE $L^*a^*b^*$ parameters, data on tooth color obtained from computerized colorimetry or spectrophotometry allow for an objective mathematical comparison [17].

Studies comparing the visual (human) versus digital shade selection reveal poor agreement between these techniques and favor the instrumental and digital determination [6, 10, 15, 18–26]. However, one study demonstrated that human examiners showed a significantly higher agreement (40.2%) when compared with five digital devices [27]. The interexaminer reliability with these techniques was found to be acceptable to excellent in clinical measurements on natural teeth [23, 28, 29], dental restorations, or both [25].

Studies have been conducted to assess the final results of the entire process when using digital shade selection. Da Silva et al. [24] evaluated clinical effectiveness and showed that crowns matched with the spectrophotometer used in their study had significantly better shade matches than those using a conventional technique. These results are still influenced by the variation in the ceramic process in the laboratory, which cannot be neutralized by the initial data of the digital shade selection. Similar studies have reported on various digital measurement systems with similar positive results for the outcome of restorations [6, 10, 20–22]. The influence of a standardized or clinical environment on accuracy was evaluated with five different measuring devices by using shade tabs and natural teeth. Two of the five systems performed more reliably in the in vitro setting [30]. For visual shade selection, the light used in the environment is an important factor [5]. Because available spectrophotometers operate with an internal light source, the measurement surface is illuminated with this standardized light during capture. However, the possible influence on the degree of accuracy depends on the instrument used [25, 31, 32], type of material, opacity, texture, and translucency of the measured side [6, 33].

In order to apply digital shade selection for human teeth, the accuracy and reproducibility, as well as interexaminer reliability, must be considered. The purpose of the present study was to evaluate the reproducibility of measurements using the Crystaleye digital spectrophotometer (Olympus, Tokyo, Japan). The variables of different examiners and different illumination conditions were tested for their influence on the reproducibility of measurements.

Materials and methods

Fifteen subjects (8 men and 7 women) in need of one intact and untreated maxillary central incisor tooth were recruited for this investigation. The subjects ranged in age from 22 to 47 years, with a mean age of 26.1 years. Two examiners made ten repeated measurements of the labial surface of the tooth for each subject. One examiner was a dental technician and one was a postgraduate dental student. Every measurement involved three evaluation sides on the tooth (cervical, middle, and incisal) with the output of the values of L^*, a^*, and b^* (n=300) for each side. The measurements by the two examiners were made under the same light conditions, which represented a dental laboratory situation (environment A) with mixed natural and artificial light (Lumilux cool white, Osram, München, Germany). Examiner 2 repeated the measurements of the same subjects under different light conditions (environment B) (Fig. 1). Environment B represented the conditions of a dental unit situation with a chairside lamp (Kavolux, KaVo, Biberach,

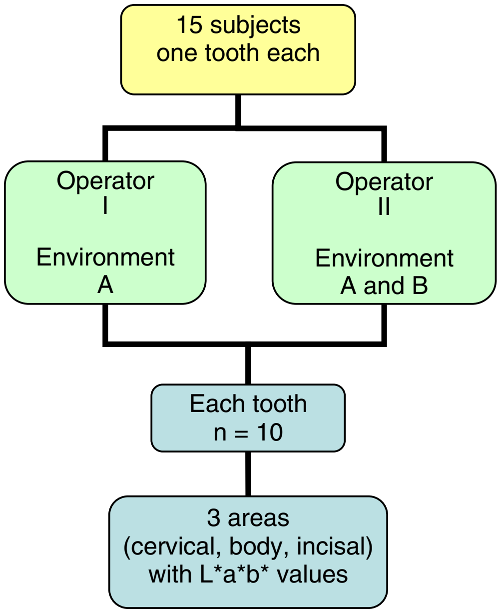

Fig. 1 Outline of the study. Fifteen subjects were measured by two operators (I and II). The measurements were repeated ten times for each tooth and in three different areas with $L^*a^*b^*$ values. Operator II performed the measurements in two different environments (A and B)

Germany) directed on the measurement side of the subject's mouth. For each measurement, all teeth were clean, no saliva was on the surface and the teeth were not dry.

The two examiners were educated and experienced with the applied digital spectrophotometer Crystaleye (Fig. 2). Prior to data acquisition of each subject, the instrument was automatically calibrated using an integrated calibration plate on the base station of the device. It uses seven light-emitting diodes as an illumination source, with a 45°/0° geometry. The capture time is always 0.2 s. A single-use rubber contact cap was placed on the measurement tip of the device and then positioned to capture the tooth image. The device was set to have the captured tooth in focus (Fig. 3). For each of the measurements ($n=10$), the position of the device was newly selected and repositioned to generate ten different measurements of each tooth. The position of the tip was located for each measurement in such a way to assure that the three relevant areas (cervical, middle, and incisal) for the analysis were not reflecting light (Fig. 4). The tip was moved and relocated for each measurement. The three areas were selected automatically by the system and not changed (Fig. 5). The base station of the spectrophotometer was connected to a personal computer (XPS M1210, Dell, Austin, TX, USA) with the Crystaleye software (version 1.4) installed. Data transfer from the device to the computer was performed via the connected base station. The software was used to export the L^*, a^*, and b^* values of each of the three sides into an Excel® data table (Microsoft Office 2003®, Redmond, WA, USA) for the statistical analysis.

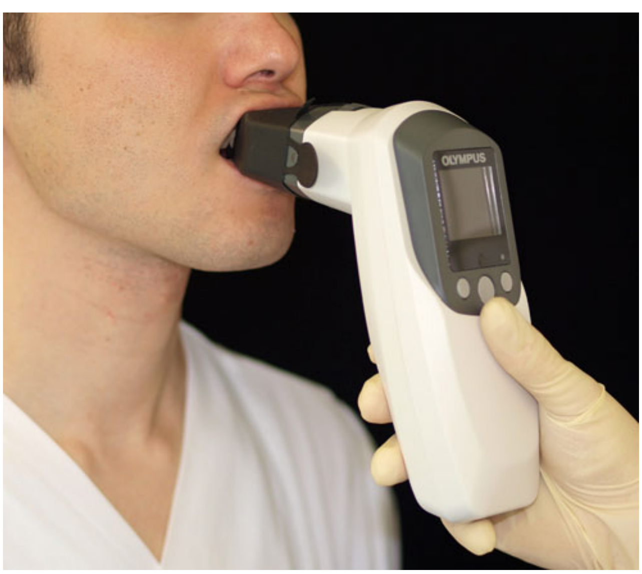

Fig. 2 Data acquisition with the digital spectrophotometer used in the study. The measurement was performed with a single-use cap for each patient

Statistical analysis

The validity of the mean color difference from the mean (MCDM) as a measure of precision was calculated as shown where each measurement is compared with the average, L^*, a^*, b^*, followed by the summation of N color differences, $\Sigma_{i=1N}$, then divided by the number of measurements, N [34].

$$\mathrm{MCDM} = \frac{\sum_{i=1N}\left[\left(L_i^* - \bar{L}^*\right)^2 + \left(a_i^* - \bar{a}^*\right)^2 + \left(b_i^* - \bar{b}^*\right)^2\right]^{\frac{1}{2}}}{N}$$

Fig. 3 Level of the depth of focus can be switched between tooth (*T*), lips (*A*), and facial (*F*) position. For the purposes of this investigation, the level of focus was selected on position *T*

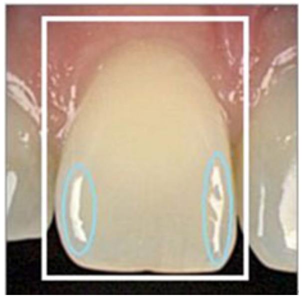

Fig. 4 The examined tooth should be positioned inside the displayed square and with symmetrical light reflection on both sides of the measurement surface

Two general linear models using generalized estimating equation techniques for correlated outcomes were fitted to the data. Each subject was considered as a single cluster. The independent correlation matrix type structure was used and only measurements from different subjects were considered to be statistically independent (PROC GENMOD, REPEATED statement; SAS 9.1, Cary, NC, USA). In the first model, the continuous response variable was modeled as a function of light, target, color space, and the corresponding interactions as explanatory variables. In the second model, the continuous response variable was modeled as a function of observer, target, color space, and the corresponding interactions as explanatory variables. Model assumptions were graphically checked by residuals and other regression diagnostics, thus the normality of error terms can be assumed.

Results

The mean of the MCDM was 5.228 (the confidence interval range, 4.6598–5.8615) of the measurements. The mean least squares means for examiner 1 was 5.2607, for examiner 2 5.1962, for the measures body 4.7166, cervical 5.4693, and incisal 5.4995. The confidence limits were 4.6598 and 5.8615 for examiner 1, 4.6727 and 5.7197 for examiner 2, 3.9332 and 5.500 for body, 4.5128 and 6.4257 for cervical, and 4.6317 and 6.3673 for incisal. The differences of least square means between examiners 1 and 2 were graphically explored with 95% confidence intervals, separately for each CIE and evaluation side. There were no statistically significant differences between values obtained by the two examiners or between different illumination environments.

Fig. 5 *Three squares* in the cervical, body, and incisal areas used for color measurement. These positions were selected automatically by the system and not changed

Discussion

Digital measurement devices for dental shades, such as spectrophotometers, have proven to be a reliable improvement over conventional visual shade selection using shade tabs [3, 4, 12]. However, possible misreadings can occur due to variation in surface texture and luster, the influence of the light in the operating room, and incorrect positioning of the device. A general limitation of most digital devices is the size of the measurement probe. A large probe, such as the device used in this study, cannot be used in the posterior area. This current study was designed to test the reliability of a newly introduced spectrophotometer under different light conditions and with different operators. Therefore, no conclusion can be drawn regarding the result or quality of the shade of a dental restoration. The collected data for the statistics are based on the values of each of L^*, a^*, and b^* and not of the calculated ΔE^*_{ab} values, which provide the quantity of difference in this color system.

The type of testing environment has an influence on the evaluation and can be performed in a standardized (shade tabs) or clinical (natural teeth) environment. Dozic et al. [30] showed different results comparing these two environments. Three out of five digital devices were more reliable in an in vitro setting. Therefore, the present study was performed in a patient treatment setting as similar to everyday use as possible. One operator performed the measurements repeatedly in a laboratory with mixed light and at a different appointment with a dental unit chairside lamp shining on the measurement side. No significant difference between the two sides was found.

Interexaminer reliability is an important issue in using a measurement device that is supposed to deliver reliable results for different users. In the present study, the results of the two examiners were compared to each other. The deviation between the users was not statistically significant. Similarly, Schmitter et al. [23] reported acceptable to excellent agreement of three examiners using a spectrophotometer. However, Derdilopoulou et al. [29] showed 49.7% agreement between two examiners. Similar results were reported by Gehrke et al. [25], showing significant disagreement (45%, 18 of 40 cases) among three examiners. This indicates variability in the reliability and sensitivity for different operators and their specific handling of some of the systems.

Reproducibility is important to the precision of a spectrophotometer. Clinically, it is important to know how reliable the first measurement is. In the present study, the same tooth of one subject was repeatedly measured ten times at the same appointment. The measurements showed no significant variation. Tung et al. [28] showed that a tested colorimeter agreed with itself 82% of the time, whereas visual selection showed 64% agreement. The agreement of the three measurements at different times was 89.6% when using a digital device.

Conclusion

Within the limits of the present study, the accuracy and reproducibility of dental shade selection using the tested spectrophotometer with respect to the examiner and illumination conditions reflected the reliability of this device. Therefore, it can be recommended for clinical application.

Conflicts of interest The authors have no conflicts of interest to declare.

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