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ORIGINAL ARTICLE

The repeatability of digital shade measurement—a clinical study

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Abstract

Objectives The intraoral VITA Easyshade spectrophotometer is a shade measurement system that provides for objective determination of the shade of natural teeth and of dental materials. Over a period of 2.5 years, this clinical study assessed the repeatability of VITA Easyshade measurement, using metal ceramic restorations and based on $L^*a^*b^*$ parameters.

Materials and methods Shade tests of 25 metal ceramic crowns were carried out objectively in 19 patients using VITA Easyshade and subjectively by a dentist. The measurements were taken using a separate positioning device at the time of insertion, after 14 days (baseline), after 6 months, after 1.5 years and after 2.5 years.

Results ΔE was calculated from ΔL^*, Δa^*, Δb^* data as a measure of the differences in shade. The average values during the follow-up controls were ΔE_2=2.2 (6 months), ΔE_3=2.3 (1.5 years) and ΔE_4=2.0 (2.5 years). Subjective shade analysis during the follow-up controls did not reveal any changes in the ceramic veneer.

Conclusions The average of ΔE=2.1 represented the difference in color. The examiner could not detect any difference in color over the evaluation period of 2.5 years.

Clinical relevance Good results in terms of the repeatability and accuracy of VITA Easyshade measurements were reported in previous in vitro studies. Objective assessment under clinical conditions is required in order to evaluate the shade stability of tooth-colored restorative materials in the oral cavity. For this purpose, the quality and handling of VITA Easyshade must be verified from a clinical perspective.

Keywords Color · Shade measurement · Repeatability · $L^*a^*b^*$ · Color parameters

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Introduction

Digital shade measurement was developed for dental applications in order to reduce or overcome the inaccuracies and inconsistencies of traditional methods of tooth shade determination. A new generation of portable spectrophotometers, colorimeters, and digital cameras for clinical use is now available. These devices differ in terms of measuring geometry, handling sensitivity, configuration, sturdiness, design, and price. The accuracy and precision they offer with regard to tooth shade determination has been tested in previous studies [1–8].

Spectrophotometers are amongst the most accurate, useful, and flexible instruments for color matching in general and for shade matching for dental applications [9, 10]. They measure the amount of light energy reflected from an object at 1-25 nm intervals along the visible spectrum [6, 11]. A spectrophotometer is equipped with a source of optical radiation, a means of dispersing light, an optical measurement system, a detector, and a means of converting the light obtained to a signal that can be analyzed. The data obtained using spectrophotometers must be processed and translated into a form appropriate for dental professionals. The measurements obtained by such instruments are frequently correlated to dental shade guides and converted to shade tab equivalents [12]. Compared with observations by the human eye, or conventional techniques, it has been found that spectrophotometers offer a 33 % improvement in accuracy and a more objective match in 93.3 % of cases [10].

The digital spectrophotometer VITA Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany) has become the reference standard for manual tooth shade determination in clinical studies [13–15] and has been used to determine differences in the shade of dental materials in numerous studies [1, 8, 13, 16, 17]. Experimental studies on the accuracy and reproducibility [8, 15, 16] offered by VITA Easyshade have reported good results [3, 12, 18, 19]. In a study investigating student opinion on visual and digital tooth shade determination at different European dental schools, the most frequently cited digital system was VITA Easyshade [20].

Precision is tested by evaluating repeatability and reproducibility. Repeatability is a method for evaluating inconsistencies in digital shade measurement using the same method, operator, or instrument. Short-term (several times in succession), medium-term (over a number of hours) and long-term measurements (over a number of weeks or longer) may differ. It is important to demonstrate the repeatability offered by spectrophotometers under clinical conditions in the long term. As a tooth-colored dental material, ceramic has demonstrated good shade stability with an intact surface in both experimental and clinical investigations [21].

In this prospective clinical study, the repeatability of the $L^*a^*b^*$ values obtained for tooth-colored, metal ceramic restorations using VITA Easyshade was assessed over a period of 2.5 years. Based on the hypothesis that the shade stability of a ceramic veneer in situ remains consistent over a number of years, it is assumed that the values of the shade differences (ΔE) calculated also remain constant and close to zero.

Materials and method

Nineteen patients, ten female (52.6 %) and nine male (47.4 %), participated in the study; the average age was 49 years. Patients with abutment teeth requiring a crown were selected. These patients were fitted with 25 metal ceramic crowns (IPS Inline, d.Sign® Ivoclar Vivadent, Schaan Liechtenstein) placed on eight anterior teeth, nine premolars, and eight molars. The study was approved by the ethics committee of the Medical Faculty of Martin-Luther University, Halle-Wittenberg, Germany.

Visual and digital shade matching were performed by an examiner who is an expert in color science. The shade of the veneer was selected visually using a commercially available shade guide and digitally using VITA Easyshade. The shade of each ceramic veneer was documented before beginning.

Shade evaluation by visual comparison is a subjective method. Prior to shade-taking, the surface of the crown was cleaned using polishing paste [Klint, Voco, Germany] and a rubber cup. The surface was then checked for changes in the ceramic. Shade evaluation was performed using a manual shade guide (Vitapan classical, Vita Zahnfabrik, Bad Säckingen, Germany). For visual comparison, the corresponding tab was chosen. Visual shade determination was carried out chair-side under ceiling lighting (Philips Master TLD 36W) and a dental lamp (KaVo Dental GmbH, Germany).

The dental spectrophotometer VITA Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany) was used for objective shade evaluation.

Vita Easyshade is a portable system for tooth shade determination in the mouth. It has been available on the dental market since 2004 and consists of three main components: a light source, a device that receives the light reflected from the object, and a spectrometer. The spectrometer measures the intensity of the light received in the form of a wavelength in the range of 400–700 nm. The $L^*a^*b^*$ and C^*h^* color space coordinates of the shade are calculated using a D65 illuminant and at an observer angle of 2°.

The CIE $L^*a^*b^*$ color space features a vertical axis that indicates relative lightness or darkness. The two horizontal axes indicate the amount of green/red and blue/yellow. In the $L^*a^*b^*$ color space, "L" is a measure of the lightness of an object, "a" is a measure of greenness or redness and "b" a measure of blueness or yellowness.

To ensure that the measuring head (diameter of measurement area, 5 mm) of VITA Easyshade always records the same spot of the vestibular veneering surface, a customized measurement jig was developed to serve as an adjustment aid. Using thermoforming, the jig was produced using a 2-mm-thick plastic sheet (Erkodent, Pfalzgrafenweiler, Germany) and a prefabricated part with the same diameter as the measuring head (contact tip, Shade Eye NCC® Shofu, Japan). The shade measurements were carried out under identical conditions.

$L^*a^*b^*$ data were measured after applying an infection control shield and calibrating the unit in "Single Tooth" mode. Five single measurements were carried out. Infection control shields were used to prevent patient cross-contamination. After each measurement had been performed on a patient, the infection control shield was replaced and the instrument was recalibrated. The test parameters were gathered at the time of insertion, after 14 days (baseline), and after 6 months, 1.5 years, and 2.5 years.

The equation $\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$ was used to calculate the difference in color ΔE [22]. The ΔL^*, Δa^*, and Δb^* values are the differences in the averaged $L^*a^*b^*$ data for the second measurement (baseline) and subsequent tests.

The SPSS 18.0 statistics program (SPSS Inc., Chicago IL, USA) was used to perform statistical analysis of the data; the average and standard deviation of each measurement series was indicated.

Results

Subjective changes in the shade of the ceramic veneer could not be determined during the given evaluation period of 2.5 years.

Figure 1 shows the mean values of L^*, a^*, and b^* over the evaluation period of 2.5 years. The mean L^* value was between 70.28 and 70.97, with a mean a^* value of between 3.51 and 3.72. The mean b^* value increased from 27.53 to 28.44. The mean values of ΔL^*, Δa^*, and Δb^* are shown in Fig. 2. The mean value of ΔL^* decreased slightly by 0.05 to 0.69. The mean values of Δa^* ranged from −0.09 to −0.2, with the mean values of Δb^* ranging from −0.33 to −0.58. The average ΔE values at the time of assessment in each case were 2.1 ($\Delta E2$=2.2 $\Delta E3$=2.3 $\Delta E3$=2.0). The relevant box plot diagram can be seen in Fig. 3.

The highest ΔE values were achieved after a period of 6 months. In follow-up examinations after 1.5 and 2.5 years, the color distances decreased in relation to the baseline.

Discussion

The objective of this study was to test the measurement accuracy of the VITA Easyshade spectrophotometer under clinical conditions.

The null hypothesis, i.e., that the values of the calculated shade differences would remain constant, was confirmed, as the average ΔE values ranged from 2.0 to 2.3. The expectation that shade differences would be close to zero was not disproved. Visual changes in the ceramic veneer were not observed during the evaluation period of 2.5 years.

Visual shade matching is characterized by several innate difficulties (metamerism, conditions that are less than ideal for shade matching, tools, and methods, as well as the examiner's age/level of fatigue). In this study, the visual assessment was performed under standard conditions by an experienced dentist. It was found that significantly higher visual agreement was recorded for experienced dentists,

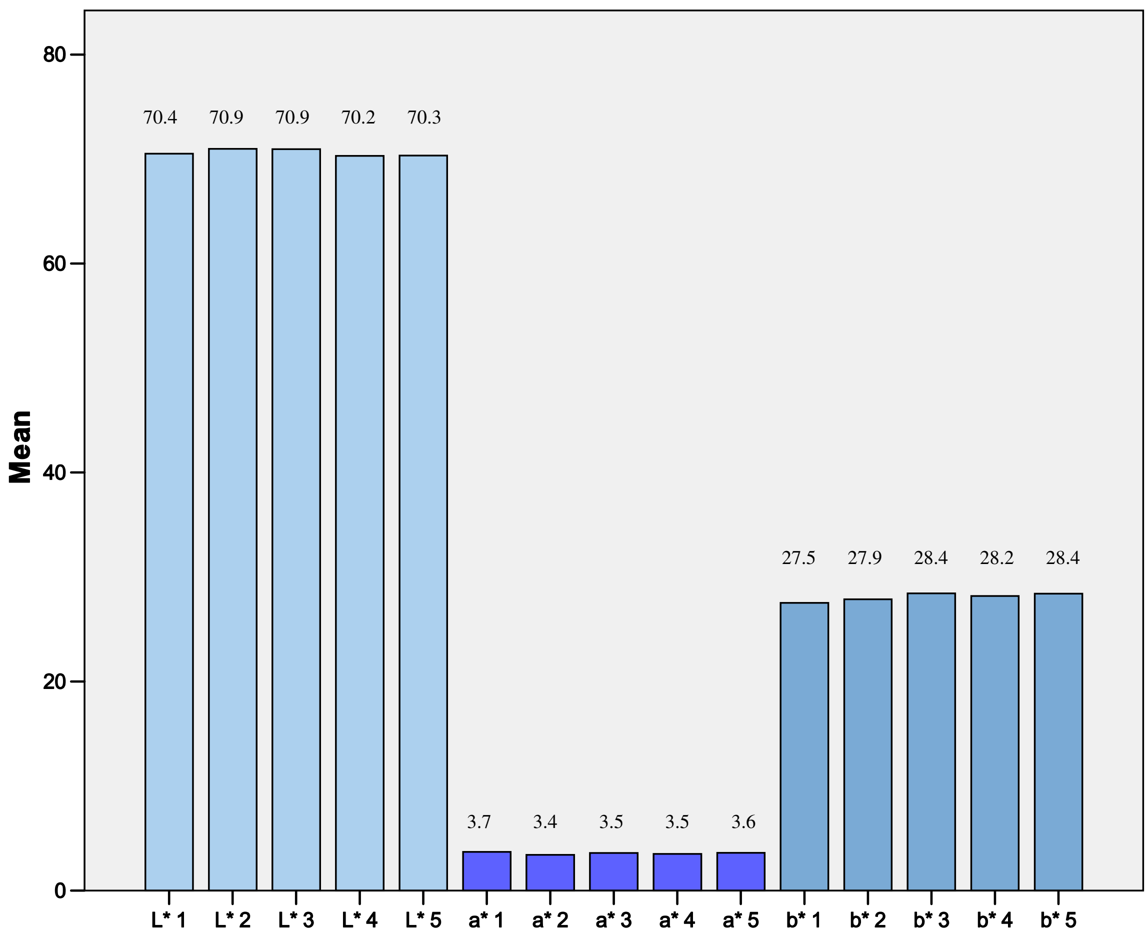
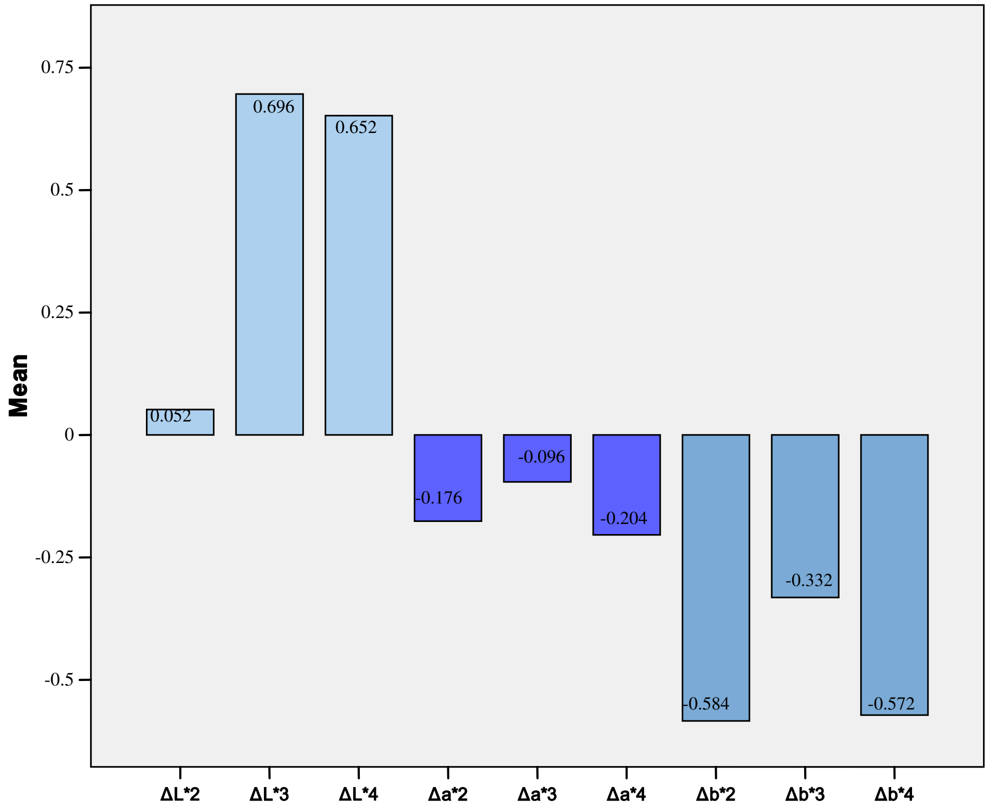


Fig. 1 Averages of $L^*a^*b^*$ data. *L*1*—averaged data/time of insertion. *L*2*—averaged data/after 14 days (baseline). *L*3*—averaged data/after 6 months. *L*4*—averaged data/after 1.5 years. *L*5*—averaged data/after 2.5 years. *a*1*—averaged data/time of insertion. *a*2*—averaged data/after 14 days (baseline). *a*3*—averaged data/after 6 months. *a*4*—averaged data/after 1.5 years. *a*5*—averaged data/after 2.5 years. *b*1*—averaged data/time of insertion. *b*2*—averaged data/after 14 days (baseline). *b*3*—averaged data/after 6 months. *b*4*—averaged data/after 1.5 years. *b*5*—averaged data/after 2.5 years

Fig. 2 ΔL^* Δa^* Δb^* data. ΔL^*2—difference of the averaged data/baseline and after 6 months. ΔL^*3—difference of the averaged data/baseline and after 1.5 years. ΔL^*4—difference of the averaged data/baseline and after 2.5 years. Δa^*2—difference of the averaged data/baseline and after 6 months. Δa^*3—difference of the averaged data/baseline and after 1.5 years. Δa^*4—difference of the averaged data/baseline and after 2.5 years. Δb^*2—difference of the averaged data/baseline and after 6 months. Δb^*3—difference of the averaged data/baseline and after 1.5 years. Δb^*4—difference of the averaged data/baseline and after 2.5 years

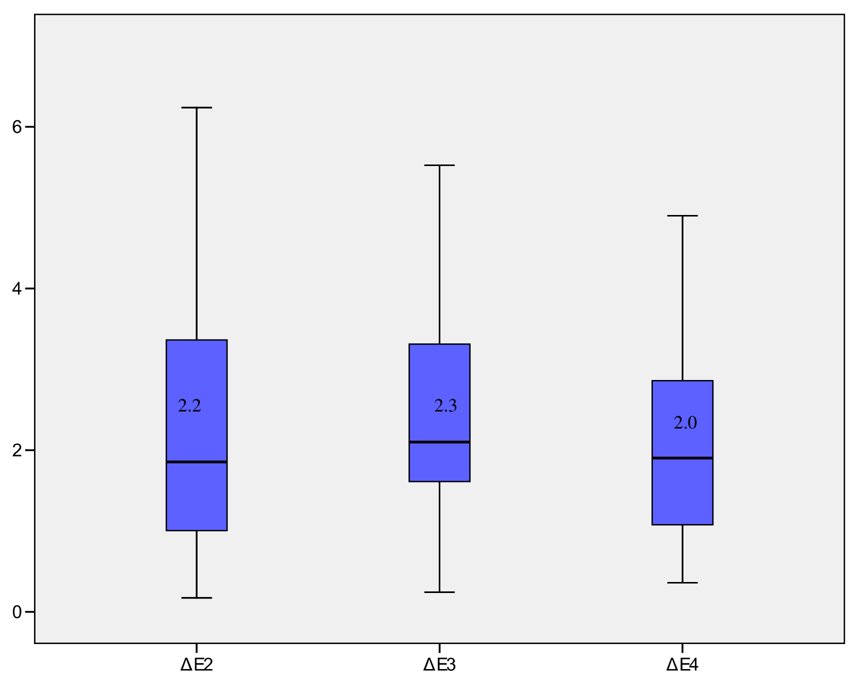


regardless of the shade guides and ambient lighting used [23]. The human eye can discern very small differences in shade.

The examiner was not able to detect any changes in the shade of the veneered crowns. The human eye is able to perceive differences in shade only to a limited degree. Starting from a color distance of ΔE=4, a clearly perceivable difference in shade can be assumed. On average, a ΔE value of less than 3.3 was considered to be clinically acceptable [24].

Vita Easyshade can measure $L^*a^*b^*/C^*h^*$ values for translucent materials with a minimum thickness of 0.7 mm. These materials include natural teeth and ceramic materials. The method described here includes some items for discussion, which are referred to in the following. Dental ceramic

Fig. 3 Boxplot diagram



material was used as a material in the study (in the form of veneered metal crowns). Compared to natural teeth, a ceramic veneer is distinguished by considerable resistance to endogenous and exogenous discoloration, and a homogeneous surface [21]. Tooth shade is determined by the combined effects of intrinsic and extrinsic coloration [25]. Extrinsic color is associated with the absorption of materials (e.g., tobacco, tea, red wine, chlorhexidine) on the surface of enamel [26]. Tooth whitening and mechanical abrasion by toothbrushes and paste influence shade stability. These factors are associated with changes in tooth shade.

In vitro studies on the shade stability of ceramics have found that surface quality does influence shade stability. Accordingly, it is possible that the consumption of coloring agents via food/beverages may have resulted in differences in the measurement data [27]. An investigation by Seghi showed that even minor surface variations due to the presence of abrasions and impurities can influence colorimetric measurements [28]. Despite the use of the measuring jig, minor positioning errors of the measuring head under clinical conditions cannot be excluded. Due to individual layering, the veneered crowns that were examined did not demonstrate a uniform structure in terms of shade and shape; this may be a reason for the shade differences identified between examination periods.

A customized measuring jig was manufactured to ensure precise positioning of the measuring head on the specimen. Shimada et al. confirm enhanced reproducibility of measurement data when using an adjustment aid [29]. According to the manufacturer's instructions, the instrument must be calibrated when it is switched on and when the infection control shield is replaced. When different materials are used, recalibration is not required. During the calibration process, the instrument compares the default data of the calibration block with the new data received. This procedure excludes shade measurement inaccuracies in the system during calibration, including the effects of the thickness and deviation in color of the infection control shield. Studies often do not include any information about the calibration frequency [18, 27, 30]. Ozturk et al. and Celik et al. [16, 17] indicate a calibration interval of ten measurements for Vita Easyshade. The study by Olms et al. [31] showed that a short calibration interval (five measurements) had a positive impact on the repeatability of the measurement data. To eliminate the influence of ambient light, visual shade measurement was carried out under identical ambient light sources. The ambient light did not have a noticeable influence on the $L^*a^*b^*$ values during digital shade measurement with VITA Easyshade [31].

A limitation of this study was that Vita Easyshade measurement was tested in vivo without a control group. It should be noted that Vita Easyshade is the most frequently cited digital system.

In previously published studies, changes in the shade of ceramic, resin, or composite materials were captured with the VITA Easyshade system [14, 16–18, 27, 30, 31]. The study by Pohjola et al. [30] demonstrated the influence of disinfection of shade guides on changes in color. Wriedt et al. [27] investigated the influence of food coloring on the shade stability of esthetic brackets.

Vita Easyshade was developed to determine the shade of natural teeth and ceramic restorations. Consequently, the measuring head of VITA Easyshade differs from the standard sizes of industrial systems for shade determination. Standardized measuring heads require larger sample surfaces than those of natural teeth and tooth restorations. The $L^*a^*b^*$ data measured with Vita Easyshade are not necessarily identical to the measurement data of a standardized spectrophotometer [19]. However, measurement data acquired with VITA Easyshade can be compared. The manufacturer does not provide any information on the color space that can be measured with VITA Easyshade. Wriedt et al. state that—in cases of significantly different ΔE values—the shade of the sample to be measured also has an influence on the $L^*C^*h^*$ values [27]. In this publication, it is not possible to comment on the color space that can be measured as in the case of the veneers that were examined, the shades were consistent with the color space of the natural tooth shades in the study.

Conclusion

This was the first study to date to examine the repeatability of in vivo VITA Easyshade measurement of metal ceramic restorations under controlled standardized conditions over a period of 2.5 years. Within the limitations of this study, an average of ΔE=2.1 represented the difference in color. The examiner could not detect any difference in color during this time. Additional studies on the surface quality of the veneered crowns and a longer period of examination are required for final assessment.

Conflict of interest The authors declare that they have no conflict of interest.

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