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Reproducibility and reliability of intraoral spectrophotometers

Introduction:
In the 1990s computerized tooth colour measuring instruments were introduced on to the dental market that facilitated the practical recording of tooth shades in everyday practice. This experimental study evaluated two such devices; comparing the reproducibility, reliability and interreliability of the dental spectrophotometer QuattroShade (QS, Goldquadrat GmbH, Hannover, Germany) and the VITA Easyshade Advance 4.0 (VES, Vita Zahnfabrik, Bad Säckingen, Germany).

Material and Method:
Under simulated clinical conditions the tooth colours and L*a*b* data were measured for 2 extracted human teeth (tooth 12 and tooth 21) in three experimental phases. (I) 3 series of measurements were taken using both devices on both teeth. Initially, calibration took place after every measurement, then in the two following series at intervals after every five and ten measurements respectively (n = 250). (II) 51 recruits each made three measurements (n = 153) for tooth 21 using both devices. Equipment was calibrated before each new user. (III) tooth 21 was measured 153 times (n = 153) with calibration after every third reading. The statistical program SPSS (Inc., U.S.A for windows version 24.0) was used to analyse the data.

Results:
Significant differences (Wilcoxon-test, Friedman-test, p 0.05) were found between the reproducibility measurements of each device. A comparison of measurements between the devices also showed differences. A correlation between frequent and longer calibration intervals was evident. Less deviation occurred with fewer calibrations (after every ten measurements) than with more frequent calibrations (after each measurement). The reproducibility of the L*a*b* values was higher using the VES when compared to the QS. Concerning reliability, slight differences in delta ( ) E values were noted for both devices. The QS showed better values between multiple users than the VES. All deviations are not relevant for clinical purposes (E = 0.8–2.2).

Conclusion:
This study has shown that both devices for tooth colour determination are suitable for daily practice. However, a visual check should still be made with a conventional colour scale.

Keywords: digital tooth colour determination; spectrophotometer; reproducibility; reliability

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Introduction

One of the goals of restorative dentistry is to provide the patient with an esthetic attractive smile [31]. This is challenging because the human eye can detect and discern the subtlest color variations between two adjacent teeth, e.g. two central incisors. Routine prosthetic procedures usually involve selecting the replacement teeth colors by means of a comparison to a standardized shade guide. The selected shade is then communicated to the dental laboratory. However, teeth are not uniform in color and the incisal, middle and cervical regions all reflect incident light differently [25]. Further, color perception varies between individuals and this hampers the correct shade choice when matching the shade guide to the intraoral situation. Thus, choosing an appropriate tooth shade for the patient is far from straightforward and depends on numerous exogenous and endogenous factors [4, 8, 13, 27, 42].

With the introduction in the 90s of tooth shade recording devices these problems were first addressed. Tooth shade could be exactly determined using a meter that detected the color which was then referenced on a color chart in order to record it. But, there remains much skepticism concerning the reliabilty and accuracy of such color measuring devices such as spectrophotometers, colorimeters and digital cameras [2]. In this study both devices presented and evaluated belong within the classification of spectrophotometers.

The VITA Easyshade Advance 4.0 (Vita Zahnfabrik, Bad Säckingen, Germany)(VES) is a portable system used intraorally to determine the shade of individual teeth. The original model was introduced and has been available on the dental market since 2004 [14]. It comprises an electrical base unit upon which rests a detachable electronic unit which incorporates an integral handpiece with a measuring probe at its tip. This handpiece unit has a lamp, a Vacuum Fluorescent Display (VFD), a navigation key, a select key, and contains a Central Processing Unit (CPU). Data can be stored in the unit and later transmitted using Bluetooth to a personal computer. A detachable USB "dongle" is provided for this purpose to be used with the VITA Assist software. The base has a detachable white balance calibration block to ensure consistency in shade determination. The device illuminates a sample using standardized light (illumination angle from 0° to 30° from a D65 light source (6500K)) over the entire measuring area and measures the light intensity remitted back from the sample using a viewing angle of 2°. Every specific reflected wavelength in the range 400–700 nm is recorded to measure the sample's brightness, chroma and hue from which the respective shade can be calculated. Taking readings for most teeth involves covering their middle and cervical thirds with the handpiece tip. When activated, light is scattered through the enamel and propelled towards the dentin where it is partially reflected back to the probe. This spectrophotometer model (VES) only measures reflected light and is optimized for dental materials having optical properties similar to a typical tooth; the most important of which being its translucency. Consequently, when a material sample is too thin (thickness < 0.7mm) or a tooth is very transparent the resulting readings are erroneous i.e. they are too low. The VES comes with a 20 Watt halogen bulb which has a resilient tungsten filament providing an average life of 100 hrs usage. The lamp's color temperature (3350 K) covers the entire visible light spectrum up to the infrared range and is ready to use after a 15 seconds warm up [24,33,43]. A newer model, the VITA Easyshade V came on the market in 2015.

The QuattroShade (Goldquadrat GmbH, Hannover, Germany) (QS) is a portable tooth colorimeter and has been available since 2015. Unlike the VITA Easyshade, it analyzes tooth color across the entire tooth surface. It has two light sources each utilizing a magnetic diaphragm which switch over from the digital camera mode to the spectrophotometer when the color measuring button is pressed. A specially coated diffraction grid divides the measuring light into the colors of the spectrum at 10nm intervals which are sent sequentially through the light guide to the measuring head. The light guide also splits the light so that monochromatic, polarized light is emitted at 45° angles from the measuring head thereby illuminating a test specimen from both sides. Light reflected back at a 0° angle is received by a monochromatic photosensor (Charge Coupled Device, CCD). This is especially setup for a 2x45°/0° measuring geometry and is optimized for light registration between 410–680nm wavelengths. Light captured by the CCD is then processed in 20 nm increments by a "Leutron Frame Grabber Card" in conjunction with the QuattroShade software. This software compares color data by referencing factory scanned color rings. All common color scales are supported [10, 24, 44]. The measured area encompasses approximately 18 x 14 m, measured in 640 x 480 pixels. Besides the monochromatic CCD color measuring sensor the device also has a second polychromatic CCD sensor and an integrated autofocus lens. This enables sharp full color images of teeth to be displayed on the screen which is lit by a 12 volt, 100 watt halogen lamp contained within the unit.

Color system and ΔE-value

The most common color system referenced in dental studies is the CIE-L*a*b*/C*h* system. It is a standardized protocol which includes the essential color dimensions that the human eye requires in order to differentiate colors [3]. With this system, particularly when using electronic shade devices accurate tooth shades can be determined [24]. L* measures the brightness of an object, a* quantifies red/greenness, and b* similarly yellow/blueness. A graphic depiction of the L*a*b* system is shown in Figure 1: Every color is referenced in the three-dimensional color space by specifying its 3 independent coordinates, the L*a*b* values on their corresponding axes.

The assessment of the interplay between the parameters of brightness (L*), color intensity (C*) and hue (h*) has been found by clinicians to be less problematic as characteristics

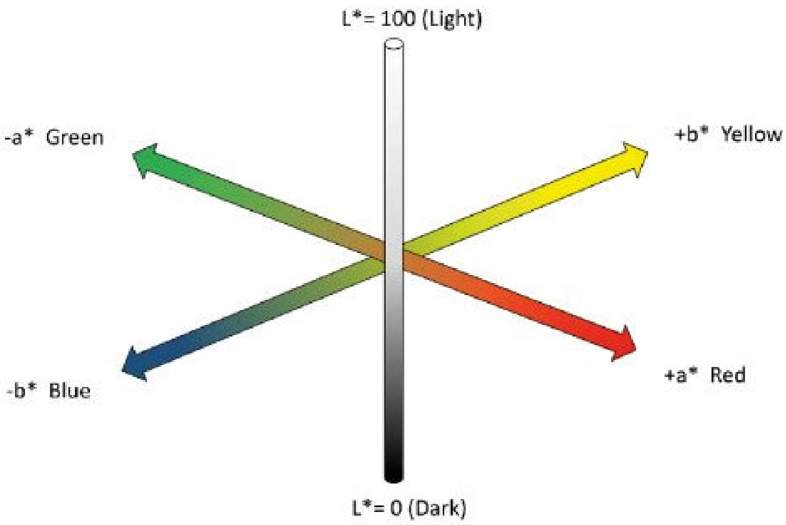

Figure 1 The L*a*b* system

when determining tooth shades. Therefore the a* and b* coordinates have been converted to color intensity (C*) and hue (h*) [3].

The definition of the perception of the difference between two colors is given by the E value. Delta ( ) stands for the difference, E being the abbreviation for sensation. E thus reflects the difference between two colors as perceived by the human eye [1].

The calculation of the E value takes place by using the coordinates in the L*a*b* color space [1]. It follows the Pythagorean calculation formula for the space diagonal:

$$E = L^2 + a^2 + b^2$$

The calculated result from this formula shows that the E value indicates the absolute "size" of the color distance between the reference color (e.g., the color on a color scale) and the test color (the natural tooth shade to be detected). But, which of the parameters (brightness L*, color intensity C*, color h*) that the deviation in E can be attributed to cannot be inferred from its value.

The calculations of E values for all occurring tooth shades show that brightness (L*) and color intensity (C*) together have about 25 times more influence than the hue (h*) with respect to the perception of the color difference. The reason for this is that there is only a small red-yellow distance between the shades of natural teeth, and consequently the hue plays only a minor role [1]. By comparison, human perception of the agreement or difference between tooth shades is largely based on the criterion of brightness (L*), which should therefore be given the strongest weighting. Errors in the hue or in the color intensity only affect the impression of a color match to a limited extent [3].

Paravina et al. [36] found that colors differing by E < 1.5–2 are so close to each other that the human eye finds it difficult to perceive any difference. Eleven years later, Paravina et al. [38] investigated E values in the range 1.2 to 2.7. They reported that a E = 1 can be defined as the smallest color difference perceptible to the human eye when viewed under optimal conditions [3]. If the E value is greater than 5 between a reference tooth and a test sample, then the human eye perceives the color difference to be disturbingly large [20]. King and deRjik [23] proposed the following classification for color differences:

E ≙0–2: imperceptible
E ≙2–3: barely perceptible
E ≙3–8: to some extent perceptible
E > 8:very perceptible

Objective

The present study researched the reproducibility, reliability and inter-rater reliability of the dental spectrophotometers QuattroShade (QS) and Vita Easyshade Advance 4.0 (VES). The aim was to evaluate the quality of the color determinations of these two dental spectrophotometers. Specifically, the question was addressed as to what would be the differences in color measurements recorded, under standardized conditions, between measurement series repeated at different times, both on the same, or the alternative dental spectrophotometer. Also, the effects of different users as well as different calibration sequences were also considered in the study.

Hypothesis

In order to be able to quantitatively answer these questions the following null hypotheses were formulated:

1. Regardless of the number of users and/or the calibration sequence, each instrument produces consistent (reproducible) and reliable color measurement results from identical inputs.
2. The E values of both devices show no significant difference ($p > 0.05$).
3. The L*a*b*/C*h* values from a triad of measurements with both instruments are not significantly different ($p > 0.05$).

Material and methods

For this in vitro study, two extracted human incisors (teeth 21 and 12) were stored in normalphysiologic salt solution. In order to eliminate error messages or false readings during color measurement, teeth were chosen that were free of any direct or indirect restorations. Both teeth were prepared by ultrasonic cleaning and polishing to remove any exogenous deposits. Their roots were shortened in order to adapt their clinical crowns to the gingival form of an upper jaw model (KaVo, EWL Basic model upper jaw/lower jaw V16). They were secured in this upper jaw model which was next mounted in the appropriate phantom head (KaVo, G50) and then attached to a suitable phantom unit. Both spectrophotometers could now be brought into position, as required in order to access this simulated oral environment, for the purpose of taking color readings. Next the operatory environment was set up to be a typical dental workspace. Even though both manufacturers claim that their devices work independently of ambient light and variable lighting conditions [10, 43] some degree of lighting consistency was preferred. The background lighting was from fluorescent tubes (400–500nm) and indirect daylight. To create as uniform as possible practice-like conditions, the dental unit operating light remained switched off during the taking of measurements. By these means the influence of extraneous light sources was minimized. To begin the study, the "actual" tooth shades of the extracted teeth were recorded by 10 dentists from the department. All of them were experienced with using the VITA 3D Master color scale and the shade readings were taken under optimal conditions (daylight at lunchtime, gray background). The authors of the study did not participate in this process.

The manufacturers' user manual recommendations for the operation of both devices were followed exactly.

To facilitate accurate and reproducible measurements, a thermoformed positioning guide was custom made for use with the Easyshade system [5, 15, 33]. This enabled the measuring probe of the VES to be identically repositioned on the teeth whilst taking color readings. A positioning guide was not required for the QS, but instead the tooth being measured was correctly centered and aligned using the device's screen.

An overview of all 3 experimental setups is shown on the flow chart in Figure 2.

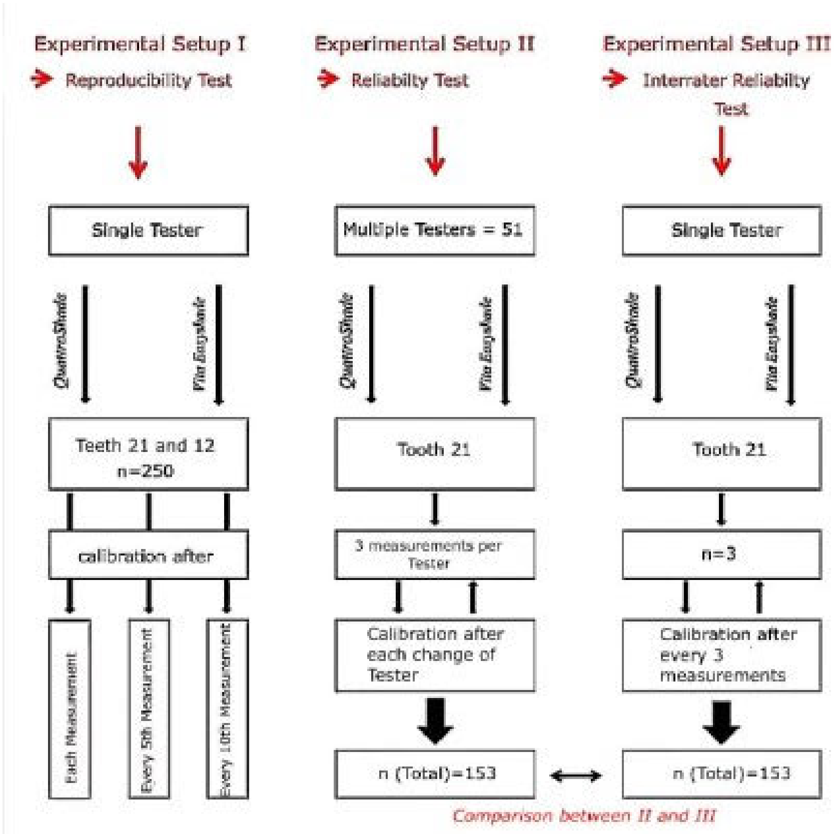

Figure 2 Overview of the three examinations

In the first experimental setup (I) the reproducibility of measurements made with both the QS and VES and the effect of different calibration intervals were analyzed. A single user carried out the test measurements for both devices. Under clinically simulated conditions both teeth (teeth 21 and 12) were assessed consecutively using both devices. In the first phase the devices were calibrated after each reading (n = 250), in the second phase calibration was done after every 5 readings (n = 250), and in the third phase calibration was done after every 10 readings (n = 250). The investigatorfor the 3 phases was a 25 year old, female dental student in her 9th semester. She had no prior experience with tooth colorimeters, but she was given detailed instruction and training in the handling of both devices.

The second experimental setup (II) scientifically investigated the reliability of both devices. A total of 51 preclinical dental students, consecutively recorded three measurements each, with both devices on tooth 21 (n = 153). Calibrations immediately took place after every change of user. The tooth was stored before and between measurement series in physiologic salt solution, it was cleaned before every test series, fixed in the identical maxillary model (KaVo, EWL Basic model upper jaw/lower jaw V16) and installed in the phantom unit. By these means, the same standardized conditions as experimental setup I were reproduced. Every student received detailed instructions for handling both devices.

The recruitment of these preclinical students took place on the Phantom Course II, during their 5th semester at the University Hospital of Leipzig. Every student investigator also received a detailed curriculum about clinical tooth shade differentiation [35], covering both theoretical and practical aspects. However, they had had no practical, "hands on" familiarization with intraoral digital measuring.

To investigate the interrater reliability of both devices, a third setup (III) was arranged. In this final part of the series, a single user measured tooth 21 for a total of n = 153 times, calibrating after every 3rd reading. The results could then be directly compared with the results from setup II (51 subjects, calibration after every 3rd reading before the next user).

For a valid comparison of the data, in each case the total tooth color value was recorded for the analysis. For this, the VES has an operating mode "Basic color determination on the natural tooth". In rare cases, the VES emitted mixed shades (e.g., 1M2–2M2), and in these instances the first mentioned color was then included in the analysis. With respect to the QS, there is a menu function that enables it to calculate average tooth

	25th Percentile	Median	75th Percentile	Minimum	Maximum	Count
L (QS/VES) - calibration after every x1 measurement	77.1/82.6	78.4/83.0	79.2/83.6	73.7/81.8	79.8/92.6	250/250
L (QS/VES) - calibration after every x5 measurements	78.9/81.8	79.1/82.3	79.2/82.7	78.2/79.0	79.9/86.2	250/250
L (QS/VES) - calibration after every x10 measurements	76.4/81.3	76.8/81.8	77.2/82.2	75.2/78.4	78.1/84.4	250/250
a (QS/VES) - calibration after every x1 measurement	2.9/2.5	3.0/2.6	3.1/2.8	4.4/0.8	3.8/3.2	250/250
a (QS/VES) - calibration after every x5 measurements	3.2/2.3	3.4/2.4	3.5/2.6	18.8/1.9	3.9/3.0	250/250
a (QS/VES) - calibration after every x10 measurements	3.1/2.1	3.2/2.2	3.3/2.3	0.6/1.8	3.6/3.0	250/250
b (QS/VES) - calibration after every x1 measurement	18.5/27.1	18.7/27.6	18.8/28.1	18.0/17.8	28.8/29.0	250/250
b (QS/VES) - calibration after every x5 measurements	18.7/26.4	18.9/27.0	19.2/27.4	18.4/25.4	43.9/28.8	250/250
b (QS/VES) - calibration after every x10 measurements	20.6/25.7	21.1/26.2	21.5/26.6	19.1/24.7	24.6/28.4	250/250

Table 1 Reproducibility test data QS/VES. L*/a*/b* values

color, from the 3 regional (cervical, middle and incisal) area specific values that it measures. However, for this study it was deemed more suitable, to select and use the QS's option "Determination of the total color" for the measurements. The tooth color values that were ascertained from both devices were then documented using the VITA 3D Master Color System. The data were further classified in preparation for the appropriate nonparametric statistical tests. All of the L*a*b*/C*h* values produced by the devices together with the average color were noted after each measurement. The calculated L, a, b, C, h and E values were entered into an Excel spreadsheet and statistical analysis was undertaken using SPSS software (Statistical Program SPSS Inc., U.S.A for Windows Version 24.0). The median and quartiles for each series of measurements were calculated, followed by significance testing ($p < 0.05$), carried out with either the Wilcoxon or the Friedman test. The appropriate test was chosen according to the characteristics of the measurement series under consideration.

Results

There were statistically significant differences (Wilcoxon test; Friedman test, p 0.01) between the measurements for reproducibility both within and between the devices, both by single and multiple users. Deviations within the L*a*b* measurement data were found to correlate with the calibration frequency. Scattering of the data occurred more often with frequent calibration (after each measurement) than with calibration after every 10th measurement (Table 1). The reproducibility of the L*a*b* values was higher for the VES as compared to the QS.

E values for each individual device (Friedman test) as well as between the devices (Wilcoxon test), returned significant differences ($p < 0.05$). Figure 3 shows the deviations of all E values for both devices, together with a comparison of the calibration values after every 1st, 5th and 10th measurements. For the QS, a noticeably high extreme value was detected during the calibration after every 5th measurement. The VES presented significantly higher median, upper, and lower percentile values (8.1–11.5) for each calibration sequence than the QS (2.14–2.67). All 3 categories did not differ significantly. Compared to the QS (0.1–0.6), there was a greater variation found in the values of the VES (1.2–1.4).

With regard to reliability, all values (L*, a*, b*, C*, h*) showed different results between the different users. However, for individual experimenters, the data of the L*a*b*/C*h* values were very consistent across each of their 3 measurements. This was applicable to both the QS and the VES, there being only a few outliers observed. Considered seperately, for the VES all the values (L*, a*, b*, C*, h*), and for the QS the a*, b* and h* values, no significant differences were found (Friedman test, $p > 0.01$). As an example, Figure 4 shows the boxplots of the L* values for both devices relating to the 1st, 2nd and 3rd measurements.

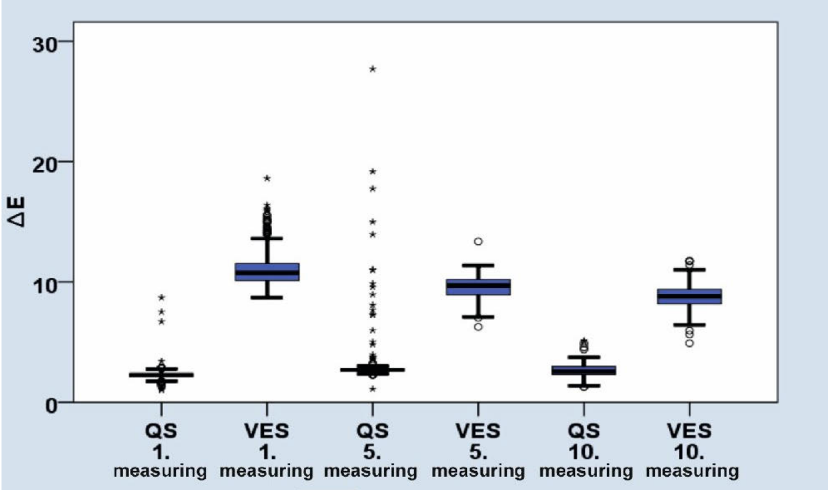

Figure 3 ΔE, tooth 12, calibration after 1, 5, 10 measurings, QS and VES

Discussion

The aim of this study was to analyze and compare the reproducibility, reliability and interrater reliability of the spectrophotometers QuattroShade (QS) and VITA Easyshade (VES). To accomplish this, three different experimental setups were used. In each case, the shade of two extracted human teeth was measured with both colorimeters. The frequency of calibration as well as the effect of different users as variables has been taken into account.

The first null hypothesis reads: Regardless of the number of users and/or the calibration sequence, each instrument produces consistent (reproducible) and reliable color measurement results from identical inputs. The color measurements collected in the study showed statistically significant differences ($p < 0.05$) and therefore this hypothesis was rejected. As far as the two devices are concerned, the data points obtained using the VES demonstrated less statistical spread, and therefore, has a better reproducibilty than the QS.

Similarly, the second null hypothesis was rejected, because here, significant differences in E values ($p<0.05$) were established. These deviations highlight an inherent inaccuracy in the functioning of these devices.

The third null hypothesis reads: The L*a*b*/C*h* values from a triad of measurements with both instruments are not significantly different ($p > 0.05$). All values (L*, a*, b*, C*, h*) showed varying results between the different users and therefore, the third null hypothesis was also rejected. However, considering the devices individually the null hypothesis is supported for the VES in all the values (L*, a*, b*, C*, h*) and as concerns the QS by the a*, b* and h* values ($p > 0.05$).

In comparison, both devices showed significant differences in color measurements, and this was independent of whether it was in operation with a single or multiple users. The VES showed a lower variability in the values for several of the parameters, and therefore, has better reproducibility than the QS. The best reproducibility was obtained, for both devices, when they were calibrated after every ten measurements, although the results from the differing calibration frequencies varied only very slightly. For this reason, calibration protocols did not play a significant role, as Olms et al. [33] have previously reported for the VES. Changing users on both devices demonstrated very good reliability results, but, the QS had a smaller data spread and thus gave a slightly superior performance than the VES.

The most important factor in dental spectrophotometry is to have a device that returns the most precise and error-free recording of tooth shades [6]. The VES 4.0 is considered to be the most frequently evaluated spectrophotometer, and has become the reference standard for digital tooth shade determination in clinical trials [32, 37, 45]. The 5th generation digital colorimeter, VES V, was introduced in 2015 [43], but was not yet available at the time that this study was begun. So far, there are no published studies about the VES V. Likewise, for the QS, there are as yet no published scientific studies regarding its reproducibility and reliability for shade determinations. Even a comparison between the two spectrophotometers, VES 4.0 and QS, is not available in the current literature. The present study was not performed in vivo, because of the difficulty in controlling for diverse factors, for example, the differences between tooth shades, surface morphologies, tooth convexities and degrees of opacity occurring in teeth. Furthermore, the high number of measurements (1056 per device), as well as wanting a controllable system for recording repeat measurements were more suitable for an in vitro study. Nevertheless, consideration was given to simulating a normal dental surgery environment for all the test procedures. It is recognized that the time consuming construction of a positioning guide, would not be a viable option under everyday clinical conditions, but was utilized in this study for the VES. Incorporating this guide provided audit quality, because the measuring head of the VES could be replaced in an identical position on the tooth being scrutinized. Previous studies by Olms et al. [33] and Leibrock et al. [30], have confirmed improved measurement reproducibility when a positioning guide was being utilized. Another study by Blum et al. [5] found that for pure color measurement (VITA 3 D-Master) a positioning guide does not significantly influence the color result. However, for making

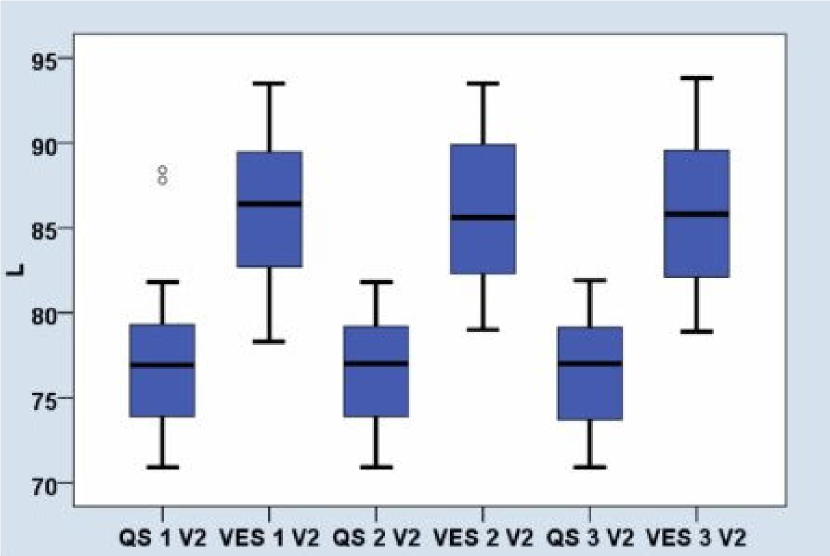

Figure 4 Reliability, L-value, QS and VES, 1.–3. measuring

(Fig. 1–4, Tab. 1: C. Olms)

a comparison of the L*a*b* values a positioning guide is preferred. In use, the QS illuminated the entire surface of a tooth and therefore a positioning guide was unnecessary.

According to the manufacturer' instructions, a calibration of the VES should be carried out after switching on the device and also after changing the cross-infection protection sheath. In use, the measuring tip must lie flush against the tooth surface [43]. The QS must be calibrated after starting as well as after each color determination. It has on its screen an angle control for correct positioning on the tooth [10].

Most existing studies which used the VES [9, 14, 22, 26, 46] are lacking information regarding calibration frequencies. Only Olms et al. [33] reported different calibration sequences after 5 and 20 measurements using the the VES. With this in mind, the influence of the calibration sequence on the reproducibility of measurements was deemed important enough to be included as a factor investigated by this study.

The VES can be categorized as a spot meter because it uses only a small area of about 3 mm² from the entire tooth surface to evaluate tooth color. A published study [20] showed that data collected with a spot meter can be error prone due to irregularities of the tooth surface, an increased likelihood of tooth dehydration and errors when capturing images. However, other published studies [9, 12, 22], explicitly showed that spot meters are accurate and can be relied upon. QS partitions and identifies tooth color across the entire tooth surface ("complete tooth measurement") and is able to create a topographic color map of the tooth. Furthermore, devices such as the QS are able to allocate average values from the three tooth areas (cervical, middle and incisal) by means of only one data capture. In other published studies concerning the reproducibility and reliability of spectrophotometers, the teeth were divided into their thirds during measurement taking [7, 18, 44]. But, since individual thirds have no influence on the results [44], such a dividing protocol was not considered in this present study. The QS is also capable of capturing the reflected spectrum from the entire tooth surface. The supporting software converts these spectral data into color information which can then be analyzed in the familiar L*a*b*/C*h* format [17]. Like the spot meters, the data from these complete tooth-measurment devices are also reliable and able to improve the final result [24, 39].

Baltzer and Kaufmann-Jinoian [1] found in their study that teeth with brightness levels 1 and 5 are extremely rare and about 50 % of all natural teeth present in the middle, with a brightness level 3. This study used predetermined teeth assessed with the VITA 3D Master Color Scale. With tooth 21 registering 2M3, and tooth 12 being 1M2, these test specimens corresponded to brightness levels of 1 and 2 respectively.

Both the VES and the QS presented different color distributions. Dozic et al. [9], measured five predefined teeth as templates using five different colorimeters, and obtained different color distributions between the devices. A possible explanation, is that these device specific hues and distributions, were caused by fluctuations in the individual colors of the teeth that were serving as templates. The various color calculation algorithms of the individual devices could also be responsible. The algorithms may define color boundary decisions differently and may also allocate differing weightings to the color parameters hue, brightness and saturation. Another possibility, is that an extracted tooth being assessed was of an unsuitable color. For example, if it was of such a color that fell midway between two of the templates defining the color space in the reference model, then an unambiguous assignment of its hue would be more difficult [44].

Although, the L*a*b* values are absolute and standardized, it is important to realize, that they are not interchangeable between two different measurement devices [19, 28, 29, 40]. This study's results also support this opinion. A possible reason for deviating results may be due to variability between the measuring devices being used. Already, Kim-Pusateri et al. [22] have reported deviations between colorimeters and devices from the same manufacturer. The VES showed better reproducibility in several parameters than the QS. Several publications [9, 26, 46] have confirmed excellent reproducibility of the VES. This study found that both devices showed their best reproducibility when calibrated after every 10 measurements. This contradicts the results of Olms et al. [33], whereby a lower standard deviation was found, with more rather than less frequent calibration. However, Olms et al. [33] confirmed that for the VES, the calibration protocol only plays a minor part, in affecting the color measurements.

The influence of different users on color measurements was also determined. Both devices were rated as very good but their reliability results differed. All values (L*, a*, b*, C*, h*) gave different results when measuring the same tooth. This was applicable when using one of the devices for repeated measurements, but also, when comparing measurements recorded from the alternate device. This is in agreement with the clinical observations of Kim-Pusateri et al. [22], who measured and compared the reliability of four different colorimeters, which included the VES. Nevertheless, the QS recorded a lower variance for the L*, a*, b*, C*, h* data, which is a result that is confirmed by the work of Schmitter et al. [41]. These authors also graded the reliability of the QS's precursor model, ShadePilot as "acceptable to excellent".

The E value is often used to express the difference between two measured colors. The range of detectable E values for an excellently trained eye starts at 0.4 [11] under laboratory conditions and extends to a mean of 3.7 [16]. Paravina et al. [38], however, found a E range from 1.2 to 2.7 in their study. All of the E values in this study varied between 0.1 and 2.2. Therefore, according to the research just mentioned above, this study's E values would have been reported as barely perceptible and considered to be clinically irrelevant.

A fundamental point is that, an objective reference or control group, could have been used as the standard for the "true values" of the teeth that were being color measured. However, there was no distinction made in this study, as to whether the devices were correctly identifying the "true colors" of the teeth, and therefore no control group was used. The measured results only relate to the consistency of the color devices. A device that produces more reliable measurements is also likely to be more predictable than an inconsistent one. However, that is just an assumption and further clinical research is needed to support it and to explain the meaning of any differences.

This in vitro study did not adequately simulate a patient in a clinical situation, but the results suggest that both spectrophotometers provide very good to excellent results in both reproducibility and reliability. Nevertheless, the manufacturers have not yet succeeded in eliminating all imprecision from their devices. Therefore, a visual check of the color selection should always be done when operating either of the devices.

Conclusion

The present study evaluated the quality of color determination measured using the dental spectrophotometers VITA Easyshade and QuattroShade.

The results on reproducibility and reliability demonstrate, that both devices can be considered to be dependable and precise. However, significant differences in color measurement values were noted both internally and when comparing devices, irrespective of whether they were used by single or multiple users.

But, for use in a clinical setting these differences were not practically relevant. Therefore, these electronic devices can serve as a convenient alternative for taking dental shades. However, it is recommended that in clinical practice shade choices should be safeguarded by checking them against a standard shade guide.

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Conflicts of interest:

The authors declare that there is no conflict of interest under the guidelines of the International Committee of Medical Journal Editors.

Literature

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