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Clinical Research

In Vitro and *In Vivo* Evaluations of Three Computer-Aided Shade Matching Instruments

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Clinical Relevance

Shadepilot was the only instrument tested in the present study that showed high accuracy and reliability both *in vitro* and *in vivo*. As different L*a*b* values and shade matching results were reported using various instruments for the same tooth, a combination of the evaluated shade matching instruments and visual shade confirmation is recommended for clinical use.

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SUMMARY

This study evaluated the accuracy and reliability of three computer-aided shade matching instruments (Shadepilot, VITA Easyshade, and ShadeEye NCC) using both *in vitro* and *in vivo* models. The *in vitro* model included the measurement of five VITA Classical shade guides. The *in vivo* model utilized three instruments to measure the central region of the labial surface of maxillary right central incisors of 85 people. The accuracy and reliability of the three instruments in these two evaluating models were calculated. Significant differences were observed in the accuracy of instruments both *in vitro* and *in vivo*. No significant differences were found in the reliability of instruments between and within the *in vitro* and the *in vivo* groups. VITA Easyshade was significantly different in accuracy between *in vitro* and *in vivo* models, while no significant difference was found for the other two instruments. Shadepilot was the only

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instrument tested in the present study that showed high accuracy and reliability both *in vitro* and *in vivo*. Significant differences were observed in the L*a*b* values of the 85 natural teeth measured using three instruments in the *in vivo* assessment. The pair-agreement rates of shade matching among the three instruments ranged from 37.7% to 48.2%, and the incidence of identical shade results shared by all three instruments was 25.9%. As different L*a*b* values and shade matching results were reported for the same tooth, a combination of the evaluated shade matching instruments and visual shade confirmation is recommended for clinical use.

INTRODUCTION

The accurate and reliable selection of tooth shade is critical for successful clinical restoration, particularly for esthetics. The traditional method used for visually selecting shades is comparing natural tooth color with commercial standard shade guides.[1,2] However, visual shade selection has been found to be unreliable and inconsistent.[2,3] This selection is a subjective process since visual color perception is the result of psychological and physiological responses that vary between individuals.[4,5] General variables include lighting conditions, the angle of perception, experience levels, age, and eye fatigue as well as physiological variables, such as color perception deficiencies, all of which may lead to discrepancies.[6-8] In addition, the double-layering effect of natural teeth created by enamel translucency in combination with dentin opacity make visual shade selection difficult.[9]

Limitations in visual shade selection have triggered the search for more accurate, consistent, and scientific shade matching methods, ultimately utilizing objective instrumentation. Instrumental color shade selection may have a number of potential advantages over visual shade selection because of its inherent objectivity and the potential for user-independent accuracy and reliability. At the present time, an increasing number of computer-aided shade matching instruments, which include colorimeters, spectrophotometers, digital color analyzers, or a combination of these, are commercially available for clinical use.[7,13] Measurements from these instruments can be rapidly exported to one or more of the dental shade-guide systems, and the results can also be reported as X, Y, Z tristimulus or as Commission International de l'Éclairage (CIE) L*a*b* values. This enables uniform and precise communication of color information between clinicians and technicians and promotes shade analyses, interpretation, and fabrication of restorations.[14] CIE L*a*b* is one of the standard color models used to describe colors in a three-coordinate system. The L* value defines the lightness of the color and can range between 0 (black) and 100 (white). The a* and b* values refer to the chromatic characteristics of the color. The a* value defines green (negative a*) to red (positive a*) colors, while the b* value defines blue (negative b*) to yellow (positive b*) colors.[2,14,15] Delta E (ΔE) describes the color difference between two specimens and is calculated using the following formula[2]: $\Delta E = [(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2]^{1/2}$.

The accuracy and reliability of color measuring and matching functions of shade matching instruments could be affected by the operating principles of the instrument that influence how the instrument handles light reflected from the tooth surface.[14] Spectrophotometers function by measuring spectral curve at the time that light is reflected or transmitted from a specimen.[8,15] In spectrophotometers, the intensity of light reflected from a specimen is measured for all visible spectrum wavelengths.[14,15] Ishikawa-Nagai and others[10-12] have reported computer-aided spectrophotometers as an excellent instrumental method for color matching in porcelain restorations.

Colorimeters have red, green, and blue filters that approximate the spectral function of a human eye. Using colorimeters, the X, Y, Z tristimulus or CIE L*a*b* values of a specimen can be measured after the reflected light has been processed through a series of filters.[8,14] Colorimeters are considered to be more reliable and accurate for color-difference measurement than spectrophotometers.[8] However, their reliability may be poor because of the aging of filters, and their accuracy can be affected by the object metamerism, which occurs when a pair of objects match under one light source but do not match under one or more other light sources.[16]

Although color measuring and matching performance of some types of computer-aided shade matching instruments have been reported,[7,14,15,17-19] these studies were based solely on either *in vitro* or *in vivo* models. Studies considering systematic evaluations using both *in vitro* and *in vivo* methods were not identified by the authors. Results from *in vivo* models may not reflect those obtained *in vitro* because of application-specific issues when the instruments are put into actual use, and thus issues with instrumental accuracy and reliability may remain. Therefore, the present study evaluated color

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measuring and matching performance of three computer-aided shade matching instruments using both *in vitro* and *in vivo* models. The null hypothesis was that there is no difference in color measuring and matching performance of the tested instruments between and within these two models.

MATERIALS AND METHODS

Three commercially available computer-aided shade matching instruments were evaluated (Table 1): Shadepilot (DeguDent GmbH, Hanau, Germany), VITA Easyshade (VITA Zahnfabrik, Bad Säckingen, Germany), and ShadeEye NCC (Shofu Inc, Kyoto, Japan). All the instruments were new and were operated by the same investigator following the manufacturers' instructions. The instruments were first allowed to warm up for 15 minutes. They were then calibrated following the manufacturers' specifications using the included standards before each measurement. Statistical analyses were completed using standard statistical software (SPSS Statistics version 17.0).

In Vitro *Model*

For the *in vitro* model, color measurements were performed with the three shade matching instruments using a common clinically used shade guide (VITA Classical, VITA Zahnfabrik). Five new shade guides (a total of 80 shade tabs) were used. All shade tabs were cleaned with soap followed by pure ethanol (15 minutes) and finally with distilled water (15 minutes) using an ultrasonic cleaning device (VITA Sonic II, VITA Zahnfabrik). The shade tab to be measured was placed in the middle of a medium gingival colored matrix (Shofu Gumy, Shofu Inc), and an identically colored shade tab was placed on either side in an attempt to simulate an oral environment.[7,15] Shade measurements were performed in the central region of the shade tab inside a lightproof box.

To ensure study accuracy, each shade tab from five shade guides was measured once by each of the three instruments. Accurate measurements were defined as identical shade matches to the shade tab. The measuring accuracy of each instrument was calculated as a percentage of correct matches for a total of 80 measurements (corresponding to 80 shade tabs). For the reliability study, each shade tab was measured two nonconsecutive times within an interval of one hour. Reliability measurements were defined as identical repeated measurements, regardless of whether the measurements matched the actual shade tabs. Reliability was calculated as a percentage of the identical repeated measurements of the total shade tabs used.

Table 1: *Shade Matching Instruments Evaluated in the Present Study*

Instrument	Manufacturer	Type
Shadepilot	DeguDent GmbH, Hanau, Germany	Spectrophotometer
VITA Easyshade	VITA Zahnfabrik, Bad Säckingen, Germany	Spectrophotometer
ShadeEye NCC	Shofu Inc, Kyoto, Japan	Colorimeter

In Vivo *Model*

For the *in vivo* model, the maxillary right central incisors of 85 people (45 men and 40 women, average age 33 ± 11 years) were measured. In general, the patients' teeth were normal and varied over a wide range of shades. The selected teeth had to have the least possible variation in surface characteristics and morphology. Thus, teeth with caries, tissue defects, heterogeneous staining, or extremely concave, convex, rough, or irregular surfaces were excluded.[14] All test subjects gave informed consent for the study, and the study protocol was approved by the local Ethics in Research Committee prior to the experiment.

Before measurements were performed, test subjects were requested to remove their makeup and to brush their maxillary anterior teeth for about one minute to remove soft deposits. Subjects were then instructed to position their heads against the headrest of the treatment chair and to open their mouth to a slight degree with their tongue remaining in a relaxed position. The tooth to be tested was dried using an air syringe, and tooth color was measured by each of the three instruments. The measurements were taken at the central region of the labial surface of each tooth. In the color matching procedure, the color data were exported into the VITA Classical shade guide system, while in the color measuring procedure, the data were transferred into the CIE L*a*b* value. For CIE L*a*b* value measurements, each tooth was measured three times, and average values were recorded.

The CIE L*a*b* values of shade tabs for the five VITA Classical shade guides used in the *in vitro* model were also measured by each instrument. For

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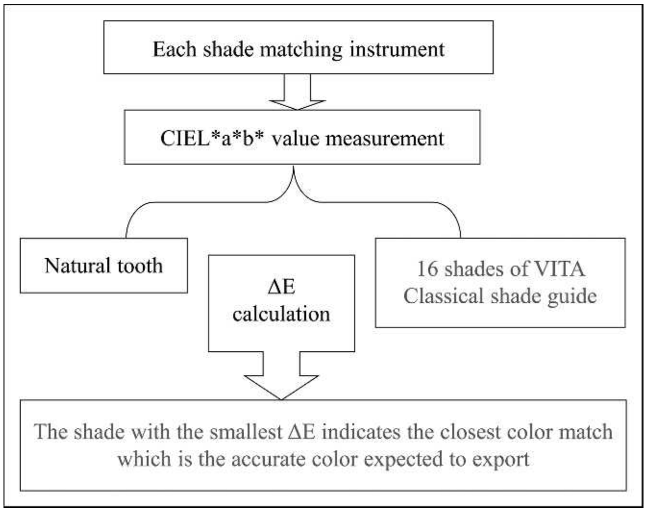

Figure 1. *Method for assessing accurate tooth color using the VITA Classical shade guide system*

each shade tab, three consecutive measurements were performed, and an average value was recorded. The final CIE L*a*b* values of the shade tabs with the same color mark, which represented the CIE L*a*b* values of the 16 different shades of VITA Classical shade guide, were represented as the mean value of these shade tabs.

Tooth color, in terms of the VITA Classical shade guide system, was calculated (Figure 1). The color differences (ΔE) between the tested tooth and the 16 different shades of the VITA Classical shade guide were calculated using the color difference formula from the data obtained.[2] The shade showing the smallest ΔE value indicated the closest color match to the tested tooth, and this shade should be considered the accurate color of the tested tooth, which the measuring instrument was expected to export. For each calculation, the CIE L*a*b* values of the tooth and the shade were provided by the same instrument. It is possible that different instruments would demonstrate different calculation results for the same measured tooth. Correct measurements were defined as identical shade matches to the accurate color. The accuracy of each instrument was calculated as a percentage of correct matches to the total number of measurements (n=85).

For the study of reliability, each tooth was measured twice within an interval of one hour. Reliability measurements were defined as identical repeated measurements, whether or not the measurements matched the accurate shades. The reliability of each instrument was calculated as a percentage of the identical repeated measurements of the total number of individual teeth measured.

RESULTS

Accuracy data for each instrument in both the *in vitro* and the *in vivo* models are shown in Figure 2. The results of multiple comparisons using a chi-square test at the 0.05 level of significance with Bonferroni correction for differences in accuracy are shown in Table 2. For the *in vitro* model measuring shade tabs, the highest accuracy was found when

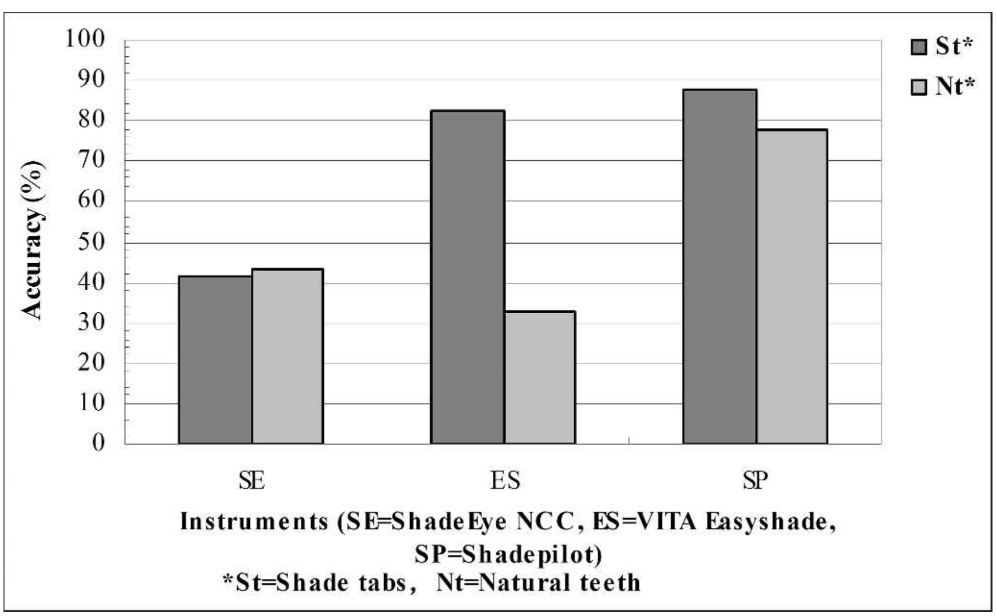

Figure 2. *Accuracy data for* in vitro *shade tab and* in vivo *natural tooth measurements using the three shade matching instruments*

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Table 2: *Differences in Accuracy for Shade Tab and Natural Tooth Measurements*

	Shade Tabs		Natural Teeth	
	χ^2 Value	p	χ^2 Value	p
ShadeEye NCC vs VITA Easyshade	28.85	<0.001*	2.02	0.115
ShadeEye NCC vs Shadepilot	37.31	<0.001*	20.72	<0.001*
VITA Easyshade vs Shadepilot	0.78	0.376	34.36	<0.001*

** Statistically significant difference set at p≤0.0167 following Bonferroni correction applied to the overall significance level of 0.05.*

using Shadepilot (87.5%), followed by VITA Easyshade (82.5%). The accuracy of ShadeEye NCC (41.3%) was significantly lower than the other two instruments ($p<0.001$). For the *in vivo* measurements using natural teeth, Shadepilot also demonstrated the highest accuracy (77.7%), while both ShadeEye NCC and VITA Easyshade showed significantly lower values (43.5% and 32.9%, respectively; $p<0.001$).

Differences in accuracy in comparing *in vitro* vs *in vivo* measurements of each instrument with a chi-square test are shown in Table 4. Only VITA Easyshade showed a significant difference in accuracy in comparing *in vitro* and *in vivo* measurements ($p<0.001$).

Reliability data for each instrument *in vitro* and *in vivo* are shown in Figure 3. The results of multiple

Table 3: *Differences in Reliability for Shade Tab and Natural Tooth Measurements*

	Shade Tabs		Natural Teeth	
	χ^2 Value	p	χ^2 Value	p
ShadeEye NCC vs VITA Easyshade	3.01	0.083	1.10	0.293
ShadeEye NCC vs Shadepilot	1.84	0.175	0.06	0.808
VITA Easyshade vs Shadepilot	0.13	0.468	0.66	0.417

** Statistically significant difference set at p≤0.0167 following Bonferroni correction applied to the overall significance level of 0.05.*

Table 4: *Differences in Accuracy and Reliability for Shade Tabs vs Natural Teeth Measurements According to Each Instrument*

Shade Tabs vs Natural Teeth	Accuracy		Reliability	
	χ^2 Value	p	χ^2 Value	p
ShadeEye NCC	0.09	0.767	0.02	0.885
VITA Easyshade	41.29	<0.001*	0.35	0.554
Shadepilot	2.76	0.097	1.00	0.318

** Statistically significant difference at the 0.05 level.*

comparisons assessed using the chi-square test at the significance level of 0.05 with Bonferroni correction for differences in reliability appear in Table 3. VITA Easyshade showed the highest reliability between the *in vitro* and *in vivo* methods, with 96.3% for shade tabs measurements and 92.9% for natural teeth measurements. Shadepilot demonstrated lower reliabilities (93.8% and 89.4%). The lowest reliability was found with ShadeEye NCC (87.5% and 88.2%). However, no statistically significant differences in reliability were found among all of the instruments between and within *in vitro* and *in vivo* models (Tables 3 and 4).

The mean CIE L*a*b* values of the 85 natural teeth measured by the three instruments are shown in Figure 4. ShadeEye NCC showed the lowest values of tooth color parameters. Compared with Shadepilot, VITA Easyshade showed higher L* and b* values but lower a* values. Significant differences in the L*a*b* values among the three instruments were found (Table 5; Tukey HSD test, $p<0.001$).

The pair-agreement rates for VITA Classical shades exported by all instruments when color measurements were performed on natural teeth are shown in Figure 5. The pair-agreement rates of Shadepilot-ShadeEye NCC and Shadepilot-VITA Easyshade were 48.2% and 44.7% respectively, higher than ShadeEye NCC-VITA Easyshade (37.7%). No significant difference was found among the pair-agreement rates of the three instruments (chi-square test, $\chi^2=2.01$, $p=0.366$). The agreement rate for all three instruments was 25.9%.

DISCUSSION

Accuracy and reliability are two important considerations when selecting shade matching instruments in both the laboratory and the clinic. The accuracy of

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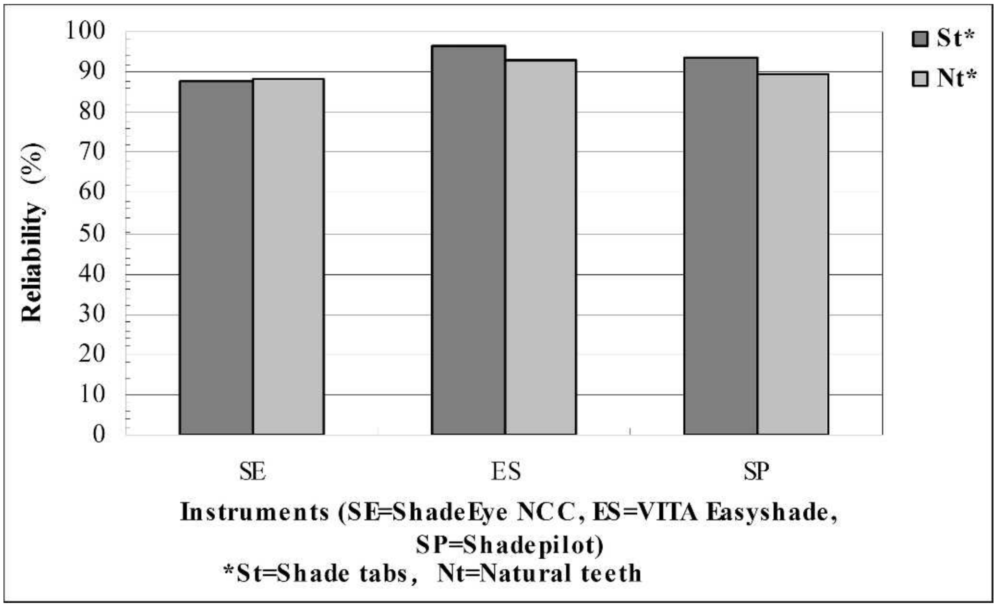

Figure 3. *Reliability data for* in vitro *shade tab and* in vivo *natural tooth measurements with the three shade matching instruments*

an instrument represents its ability to make a correct color match to a tested substrate, while reliability represents the consistency of the shade matching results when measuring the same substrate.[7] The results of the present study mandate rejection of the null hypothesis, which anticipated no differences in color measuring and matching performance of the three instruments. Shadepilot exhibited a significantly higher accuracy than ShadeEye NCC, both *in vitro* and *in vivo*, while VITA Easyshade demonstrated a significantly higher accuracy *in vitro* than *in vivo*. All instruments showed high reliability (over 87%). No differences in reliability were observed among the three tested instruments between and within the *in vitro* and *in vivo* models.

Kim-Pusateri and others[7,15] determined the accuracies and reliabilities of several instruments in an *in vitro* model using shade tabs as measuring standards. A similar *in vitro* model was used in the present study to evaluate color matching performance of the three instruments. In the present study, the accuracy and reliability of VITA Easyshade were 82.5% and 96.3%, respectively, while in the Kim-Pusateri study, comparatively higher values were reported (92.6% and 96.4%). A potential reason for the differences may result from the potential variability of the shade guides used in the two different experiments. Variation between shade guides has been reported, even in guides made by the same manufacturer.[15] The present study also verifies the fact that CIE L*a*b* values from the same kind of shade tab, including the five VITA classical shade guides utilized, were different. In addition, the irregular surface of shade tabs may affect the obtained results.

Significant differences in shade matching accuracy were determined among the three instruments studied. The reason for these differences may be due to a combination of factors, including the mechanisms by which the instruments use to illuminate the tooth, the instrument's ability to measure complex translucent objects, the internal design of the instrument, the software managing data collection and analysis, and also the inherent variability of shade guides.[2,14] Additionally, instrument type and the mechanism that each instrument uses to perform the measurements may be potential causes for discrepancies in the accuracy of color measurement. For example, Shadepilot and VITA Easyshade are spectrophotometers, which work with the full spectrum of light reflected from a tooth, while ShadeEye NCC is a colorimeter, which filters the incoming spectrum of reflected light. In addition, Shadepilot measures reflected light from a whole region of the tooth (complete-tooth measurement), while VITA Easyshade and ShadeEye NCC measure a specific spot on the tooth (spot measurement). Other differences in instrumental measurements involve the shape of the detecting head. Since shade tabs and natural teeth have surface anomalies and curve variations, their surfaces are typically not flat. Both VITA Easyshade and ShadeEye NCC have a flat terminal detecting head designed to measure flat surfaces. Therefore, they are prone to significant edge-loss effects, which

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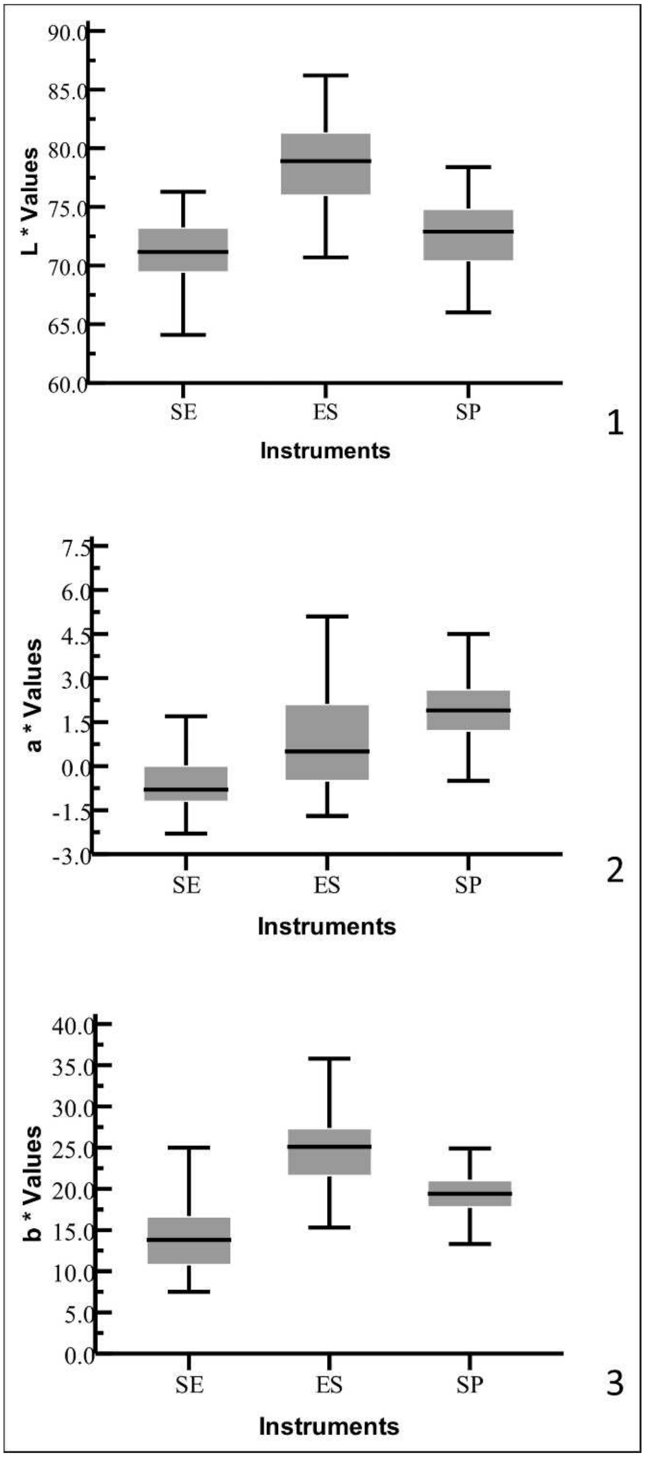

Figure 4. *Box plots of CIE L*a*b* values of 85 natural teeth measured using ShadeEye NCC (SE), VITA EasyShade (ES), and Shadepilot (SP). (1): L* values. (2): a* values. (3): b* values*

may lead to incorrect color measurements.[1,8,20] Alternatively, complete-tooth measurement does not cause edge loss; however, with this alternative method, it is difficult to control the measuring angle.

Of all three shade matching instruments included in the present investigation, VITA Easyshade showed significantly lower accuracy for *in vivo* natural tooth color measurements in comparison to VITA Easyshade's accuracy performance *in vitro*. This highlights the influence of the complex characteristics and variations of natural teeth in comparison to shade tabs and demonstrates that *in vitro* evaluations may be insufficient to evaluate the actual clinical performance of a computer-aided shade matching instrument. VITA Easyshade has a large terminal detecting head with a diameter of 6.0 mm, while ShadeEye NCC has a much smaller terminal detecting head with a diameter of only 2.5 mm. The larger the flat detecting head, the more difficult it becomes to contact the curved surface of a natural tooth and, consequently, the more space that remains between the edge of the detecting head and the tooth surface. This may result in loss of reflected light and incorrect color measurements. Furthermore, accurate *in vivo* color measurements are more difficult to achieve than *in vitro* color measurement.

For *in vivo* measurements, VITA Easyshade showed greater CIE L*a*b* values than the other two instruments, with the exception of the b* values obtained from Shadepilot. The cause of these differences may also be a combination of factors. The results of the present study reconfirm the results of a previous *in vitro* study,[14] in which 31 extracted anterior human teeth were measured using VITA Easyshade and ShadeEye NCC, and the results showed that VITA Easyshade provided greater CIE L*a*b* values than ShadeEye NCC. In clinical practice, different L*a*b* values would not affect the final color of the restoration if the extrapolation algorithm of the instrument were properly established to correctly transfer these color parameters to the standard color of a shade tab in a clinical guide.[14] As Shadepilot demonstrated high accuracies in both the *in vitro* and the *in vivo* models, it seems to have a more precise interpolation algorithm.

All the pair-agreement rates of VITA Classical Shades reported by the three instruments when color measurements were performed on natural teeth were lower than 50%. Low agreements for computer-aided shade matching instruments were also found by Hugo and others.[13] Although the measurements exported by each instrument were different, the unpaired results of the measurement of the same tooth were typically close to each another. For example, when measuring the same tooth, one instrument exported the result as A3,

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Table 5: *Significant Differences Among CIE L*a*b* Values of Natural Teeth Measured Using Each Instrument Assessed with Tukey HSD Test*

	L*		a*		b*	
	*p***	95% CI	*p***	95% CI	*p***	95% CI
ShadeEye NCC vs VITA Easyshade	<0.001	(−8.20, −6.99)	<0.001	(−1.72, −1.14)	<0.001	(−12.24, −10.40)
ShadeEye NCC vs Shadepilot	<0.001	(−2.16, −0.96)	<0.001	(−2.79, −2.21)	<0.001	(−6.17, −4.33)
VITA Easyshade vs Shadepilot	<0.001	(5.44, 6.64)	<0.001	(−1.36, −0.78)	<0.001	(5.15, 6.70)

*** The mean difference is statistically significant when* $p < 0.05$.

while the other instrument may have exported the result as A3.5. These minor differences may due to the different L*a*b* values and interpolation algorithms of the instruments.

There are a few limitations with the present study. One limitation is that the measuring units of shade tabs and natural teeth were not repositioned by positioning guides; however, this may have only a slight influence on the results since all the color measuring reliabilities of the shade tabs and natural teeth were high and showed no significant differences. This study did not involve a comparison between instrumental and visual shade selection methodologies. Although instrumental color shade selection has a potential advantage over visual shade selection and is considered to be objective, as determined in the present study, shade measuring and matching results varied among the three instruments. Therefore, visual shade confirmation is still recommended when using the three tested shade matching instruments included in the present study.

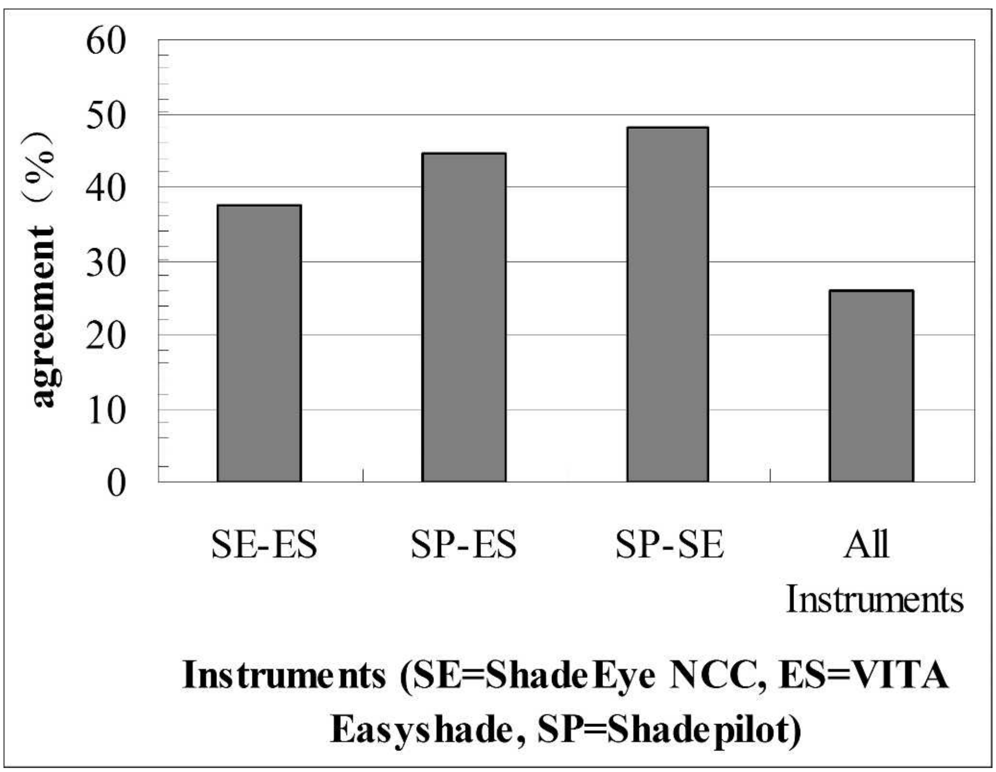

Figure 5. *Pair-agreement rates of* in vivo *natural tooth measurements*

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CONCLUSION

ShadeEye NCC, VITA Easyshade, and Shadepilot showed highly varied accuracy in a range from 32.9% to 87.5% for *in vitro* and *in vivo* models. All instruments had similarly high reliability (>87%). Shadepilot was the only instrument to show both high accuracy and reliability in the *in vitro* and *in vivo* models. VITA Easyshade showed a significantly lower accuracy *in vivo* than *in vitro*. In addition, the L*a*b* values of the same tooth measured by the three instruments were different, and the pair-agreement rates of shade matching results were less than 50%. Therefore, this study highlights the importance of *in vivo* assessment of shade matching instruments as well as the recommendation that color matching instrumentation measurements be combined with visual confirmation in the clinic.

Conflict of Interest Declaration

The authors of this manuscript certify that they have no proprietary, financial or other personal interest of any nature or kind in any product, service and/or company that is presented in this article.

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