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Accuracy and Reliability of Shade Detection from an Intraoral Scanner

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Abstract

Limited research has been published evaluating the shade detection feature on the new intraoral scanner, CEREC Primescan (Dentsply/Sirona). **Objective:** The purpose of this study was to compare the accuracy and reliability of shade detection of a new intraoral scanner (CEREC Primescan) to a spectrophotometer (VITA Easyshade Advance 4.0) . **Methods:** The CEREC Primescan and VITA Easyshade were calibrated according to the manufacturer's instructions. Ten sets of two commercial shade guides were used: Vitapan Classical (VITA) with 16 shade tabs and Vitapan 3D Master (VITA) with 26 shade tabs. Three shade tabs of the same color were placed in a medium gingiva-colored matrix. The matrix was then placed in a black box to simulate an oral cavity. The middle third of the middle shade tab was then measured using the VITA Easyshade and then the CEREC Primescan and recorded. The measurements were repeated for every shade tab, resulting in 840 total. The data were then analyzed for percent accuracy to the actual shade tab color and for percent reliability, or how often the same shade tab color was recorded. A median and Interquartile Range (IQR) were determined for each group. The data were analyzed with Mann-Whitney U tests (alpha=0.05). **Results:** No significant difference in accuracy was found between the two devices for both the Vitapan Classical and Vitapan 3D Master shade tabs. However, both devices were relatively inaccurate in detecting the shade of the tabs. For reliability, no significant difference was found between the two devices with the Vitapan 3D Master, but a significant difference was found between the two devices with the Vitapan Classical shade tabs. **Conclusions:** Both shade matching devices had relatively low but similar accuracy. Conversely, both shade matching devices had relatively good reliability. However, the VITA Easyshade had better reliability when using the Vitapan Classical shade tabs.

Introduction

Shade matching has been around in dentistry since the inception of tooth-colored restorations. Historically, shade matching has been performed by dentists using the visual shade matching method. However, like most things that are performed by humans, it is prone to errors. Studies have shown that this method is difficult to apply with accuracy and often yields unreliable and inconsistent results.[1-3]

There are multiple external factors that affect the accuracy of shade selection, such as the type of light, the quantity of light, the color of the surrounding environment, and color adaptation. Color adaptation occurs when a person stares at an object, and it appears less saturated until it appears almost gray.[4] Internal factors include the tooth itself, such as surface texture and translucency. There is also a phenomenon called metamerism where two colors appear identical under one type of light such as fluorescent but appear completely differently under a different type of light, such as sunlight. In addition to these factors, there are usually at least two people involved in this process, the dentist and the dental lab technician, further compounding the possibility of error being introduced into shade matching. As one can see, there are numerous potential problems with the visual shade matching method. A study compared humans and a spectrophotometer and showed that the accuracy of human observers was 26.6%, while the accuracy of spectrophotometers was 83.3%.[3] As a result, electronic color measuring instruments have been developed to bypass these potential problems.

With advancements in technology, shade matching is being done more and more with the aid of machines due to their high accuracy and reliability. The gold standard electronic color measuring instrument is the spectrophotometer. Spectrophotometers measure the light reflectance at wavelength intervals over the visible spectrum.[4] Spectrophotometers have a prism that disperses white light from a tungsten-filament bulb into a spectrum of wavelength bands between 5 and 20 nm.[5] The VITA Easyshade spectrophotometer is a contact-type spectrophotometer with standardized illumination, meaning it has its own independent light source, which eliminates the effects of surrounding light.[6] An in-vitro study compared the reliability and accuracy of four dental shade-matching devices: Easyshade (VITA North America, Yorba Linda, CA),

SpectroShade (MHT Optic Research AG, Niederhasli, Switzerland), ShadeVision (X-Rite America, Inc, Grand Rapids, MI), and ShadeScan (Cynovad, Montreal, Canada). The study found that the devices all had similar reliability (87.4-99.0%), but accuracy was markedly more varied (66.8-92.6%). The instrument with the greatest accuracy was the VITA Easyshade spectrophotometer (92.76%).[7] Contrasting to the spectrophotometer, VITA Easyshade, the CEREC Primescan (Dentsply Sirona, Charlotte, NC) is an intraoral scanner that projects light radiation onto an area and acquires the reflection to calculate the position of the target object.[8,9] It then detects color through its software.

Accuracy and reliability (also referred to as precision and repeatability) are key metrics that are examined to determine color detection effectiveness. Accuracy is defined as the ability to correctly identify the color, while reliability is the ability to consistently obtain the same results throughout multiple readings, even if those readings are incorrect. There have been numerous studies on the accuracy[10-14] and reliability[10-13,15-18] of instrumental shade detectors. However, there are not many studies on shade detection accuracy and reliability on intraoral scanners. A recent study compared the accuracy and repeatability of different intraoral scanners on shade determination and concluded that caution should be exercised when using instrumental shade determination due to less than expected accuracy and repeatability.[19]

The purpose of this study was to compare the accuracy and reliability of the shade analysis feature of a new intraoral scanner system, CEREC Primescan, to the dental shade-matching spectrophotometer, VITA Easyshade. The null hypotheses were that there would be no difference in (1) accuracy or (2) reliability between CEREC Primescan and VITA Easyshade based on the type of shade tab.

Materials and Methods

A spectrophotometer, VITA Easyshade, and an intraoral scanner, CEREC Primescan, were evaluated. The VITA Easyshade calibration was performed according to the manufacturer's instructions before each recording session. The VITA Easyshade calibration was completed by placing the VITA Easyshade tip on the calibration block. "Shade tab" mode was used when taking shade measurements. The VITA Easyshade tip was placed perpendicularly to the middle one-third of the shade tab. The CEREC

Primescan sleeve was calibrated, and color calibration was performed according to the manufacturer's instructions before each recording session.[20]

Two commercial shade guides were used: Vitapan Classical (VITA North America) with 16 shade tabs and Vitapan 3D Master (VITA North America) with 26 shade tabs. Measurements were taken only after two consecutive readings were completed for each tab.

This study was modeled after a study that examined the reliability and accuracy of four dental shade-matching devices.[7] To simulate clinical conditions, several modifiers were implemented. First, the shade tab was placed in a medium gingiva-colored matrix (Shofu GUMY; Shofu Dental Corp, San Marcos, CA) to simulate gingiva. Second, identical shade tabs were placed adjacent to the original shade tab to simulate adjacent teeth. Finally, the device was placed in a box with a black interior to simulate the oral cavity. The device was fixed in the box with a positioning jig to reduce variability.

To test accuracy, each shade tab from 10 Vitapan Classical and 10 Vitapan 3D-Master shade guides was tested by both the VITA Easyshade and the CEREC Primescan. Each shade tab was measured once and considered accurate if the reading matched the shade tab. The accuracy of each device was calculated as the percentage of correct readings over the total number of readings. To test reliability, each tab from 10 Vitapan Classical and 10 Vitapan 3D-Master shade guides was tested by both the VITA Easyshade and the CEREC Primescan. The number of identical shades out of 10 was recorded, regardless if the shade was correct. For example, a shade-matching device could have 100% reliability even if it read an A1 shade tab as B2 10 times in a row. Accuracy and reliability for each shade-matching device were calculated as the percent median accuracy or reliability across both shade tab types and a combination of both types. A Shapiro-Wilk test determined that the data were not normally distributed ($p<0.05$). A mean and standard deviation and a median and interquartile range (IQR) were determined per group. The data were analyzed with Mann-Whitney U tests ($\alpha = 0.05$) using a statistical software program (SPSS 20, IBM SPSS, Chicago, IL).

Results

Accuracy

The overall accuracy was low for both spectrophotometer, VITA Easyshade, and intraoral scanner, CEREC Primescan. For the Vitapan Classical shade tabs, the Vita Easyshade detected 5/16 tabs with 100% accuracy and 11/16 with 0% accuracy. See Table 1. Only four shades had 100% accuracy: A1, A3, A4, B3, and C3. 100% accuracy means that all 10 shade tab readings were correct. The data was bimodal, having either 100% or 0% accuracy. The median accuracy was 0% with an IQR of 100%. See Graph 1. The CEREC Primescan had more variability in its data, detecting 6/16 tabs with a range of 20 – 100% accuracy and 10/16 tabs with 0% accuracy. Two shades had 100% accuracy: A1 and C4. See Table 1. The median accuracy was 0% with an IQR of 37.5%. See Graph 1. The medians were 0 for both machines, showing that both machines had very low accuracy for the Vitapan Classical shade tabs. Interestingly, there were almost no overlaps in shades accurately detected by both devices except for A1. The Mann-Whitney U test found no statistical difference between the two devices for the Vitapan Classical shade tabs ($p = 0.956$).

For the Vitapan 3D Master shade tabs, the Vita Easyshade detected 11/26 tabs with an range of 40 – 100% accuracy and 15/26 tabs with 0% accuracy. Six shades had 100% accuracy: 1M1, 2M2, 2R1.5, 2R2.5, 3M2, and 3R2.5. See Table 2. The median accuracy was 0% with an IQR of 75%. See Graph 2. The CEREC Primescan detected 15/26 tabs with a range of 10 – 100% accuracy and 11/26 tabs with 0% accuracy. Four shades had 100% accuracy: 1M1, 1M2, 2L2.5, 2M2, 5M1, and 5M2. See table 2. The median accuracy was 30% with an IQR of 90%. See Graph 2. For the Vitapan 3D Master

shade tabs, most of the readings had 0% accuracy for both devices. Only a few shades with 100% accuracy overlapped for both devices and they were: 1M1, 2M1, 2M2. The Mann-Whitney U test found no statistical difference between the two devices ($p=0.386$) for the Vitapan 3D shade tabs.

Reliability

The overall reliability was high for both spectrophotometer, VITA Easyshade, and intraoral scanner, CEREC Primescan. For the Vitapan Classical shade tabs, VITA Easyshade had consistent readings for all 16 tabs with a range of 90 - 100% reliability. See Table 3. 100% reliability means that every reading was consistently the same, but not necessarily correct. The median reliability was 100% with an IQR of 0%. See Graph 3. The vast majority of VITA Easysahde's reliability was 100%, which explains why there are no boxes in the box plot. Similarly, the CEREC Primescan had consistent readings for all 16 tabs with a range of 60 – 100% reliability. The median reliability was 80% with an IQR of 30%. See Graph 3. The Primescan's data had a larger distribution than the VITA Easyshade's, but the data were still above 60% reliability. For the Vitapan Classical shade tabs, the vast majority had reliability near 100% for both devices. The Mann Whitney U test found that the Vita Easyshade was significantly more reliable than the CEREC Primescan for the Vitapan Classical shade tabs ($p=0.007$).

For the Vitapan 3D Master shade tabs, the VITA Easyshade had consistent readings for 25/26 tabs with a range of 40 - 100% reliability and only one tab with 0% reliability. See Table 4. The median reliability was 100% with an IQR of 40%. See Graph 4. The CEREC Primescan had consistent readings for all 26 tabs with a range of 40 –

100% reliability. See Table 4. The median reliability was 90% with an IQR of 20%. See Graph 4. The majority of the Vitapan 3D Master shade tabs had reliability near 100% for both devices. The Mann-Whitney U test found no statistical difference between the two devices for the Vitpan 3D Master shade tabs ($p=0.715$). The overall data for both accuracy and reliability were not normally distributed. Therefore, although means and standard deviations were recorded, they were not used in the analysis as they did not represent the data's distribution. Instead, median and interquartile ranges were used.

Table 1: Accuracy data of the Vita Easyshade and Cerec Primescan measurements using the Vita Classical Shade Tab

	Accuracy %	
	Easyshade	Primescan
A1	100	100
A2	0	0
A3	100	0
A3.5	0	0
A4	100	0
B1	0	20
B2	0	30
B3	100	60
B4	0	0
C1	0	0
C2	0	0
C3	100	0
C4	0	100
D2	0	70
D3	0	0
D4	0	0
mean	31.3	23.8
st dev	47.9	37.2
median	0	0
IQR	100	37.5
	p=0.956	

Graph 1: Boxplot of accuracy data of the Vita Easyshade and Cerec Primescan measurements using the Vita Classical Shade Tab

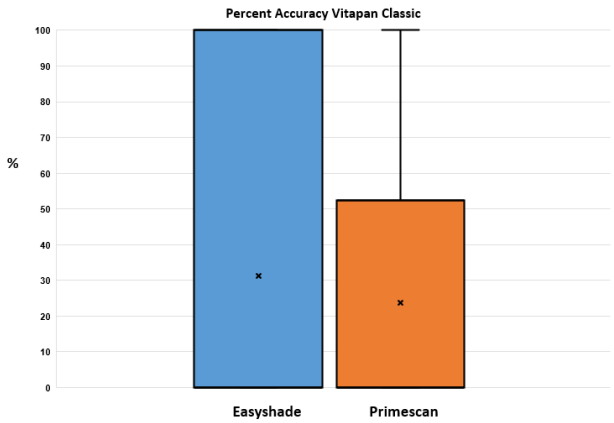


Table 2: Accuracy data of the Vita Easyshade and Cerec Primescan measurements using the Vita 3D Master Shade Tab

	Accuracy %	
	Easyshade	Primescan
1M1	100	100
1M2	40	100
2L1.5	0	90
2L2.5	0	100
2M1	80	80
2M2	100	100
2M3	60	0
2R1.5	100	0
2R2.5	100	0
3L1.5	0	10
3L2.5	0	30
3M1	0	30
3M2	100	0
3M3	0	0
3R1.5	0	0
3R2.5	100	0
4L1.5	0	0
4L2.5	0	0
4M1	50	90
4M2	0	0
4M3	50	80
4R1.5	0	60
4R2.5	0	0
5M1	0	100
5M2	0	100
5M3	0	70
mean	33.8	43.8
st dev	43.3	44.5
median	0	30
IQR	75	90
	p=0.386	

Graph 2: Boxplot of accuracy data of the Vita Easyshade and Cerec Primescan measurements using the the Vita 3D Master Shade Tab

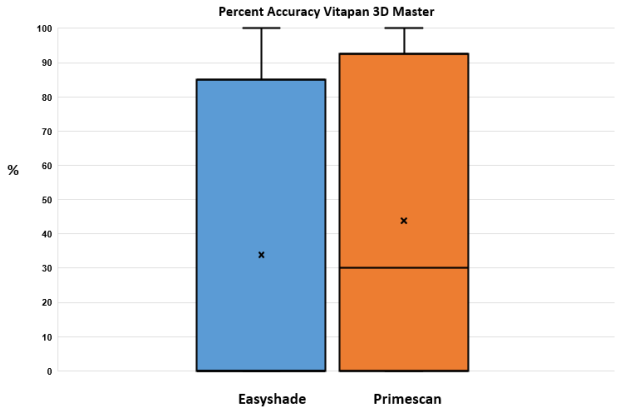


Table 3: Reliability data of the Vita Easyshade and Cerec Primescan measurements using the Vita Classical Shade Tab

	Reliability %	
	Easyshade	Primescan
A1	100	100
A2	100	80
A3	100	100
A3.5	100	100
A4	100	60
B1	100	80
B2	100	70
B3	100	60
B4	90	90
C1	100	100
C2	100	70
C3	100	100
C4	100	100
D2	100	70
D3	90	80
D4	90	60
mean	98.1	82.5
st dev	4.0	16.1
median	100	80
IQR	0	30
	p=0.007	

Graph 3: Boxplot of reliability data of the Vita Easyshade and Cerec Primescan measurements using the Vita Classical Shade Tab

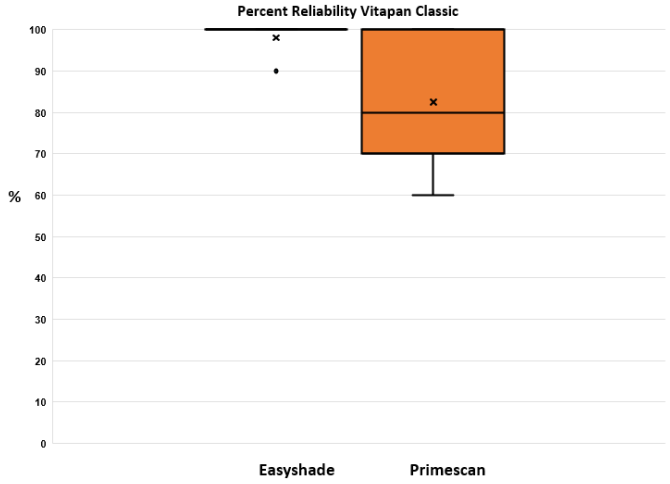
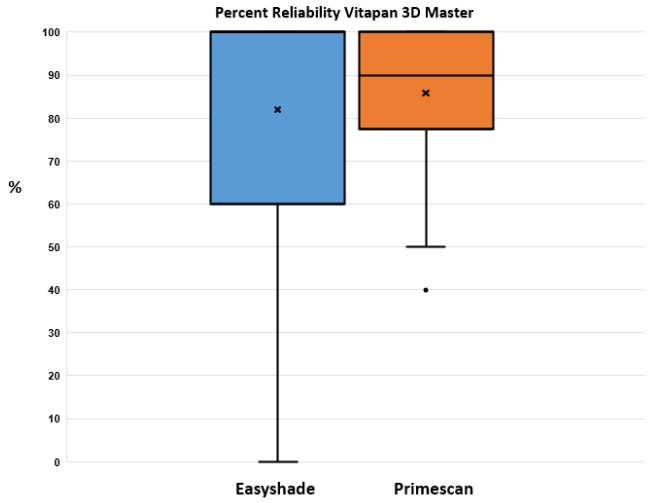


Table 4: Reliability data of the Vita Easyshade and Cerec Primescan measurements using the Vita 3D Master Shade Tab

	Reliability %	
	Easyshade	Primescan
1M1	100	100
1M2	40	100
2L1.5	100	90
2L2.5	100	100
2M1	80	80
2M2	100	100
2M3	60	100
2R1.5	100	90
2R2.5	100	70
3L1.5	0	90
3L2.5	50	50
3M1	60	70
3M2	100	40
3M3	100	100
3R1.5	100	100
3R2.5	100	80
4L1.5	60	100
4L2.5	100	80
4M1	50	90
4M2	100	100
4M3	50	80
4R1.5	100	60
4R2.5	100	90
5M1	100	100
5M2	100	100
5M3	80	70
mean	81.9	85.8
st dev	27.0	17.0
median	100	90
IQR	40	20
	p=0.715	

Graph 4: Boxplot of reliability data of the Vita Easyshade and Cerec Primescan measurements using the the Vita 3D Master Shade Tab



Discussion

This study's aim was to determine the the accuracy and reliability of the shade detection feature on a new intraoral scanner, Primescan, and compare it to a spectrophotometer, VITA Easyshade V. In our study, accuracy was lower than expected for both the spectrophotometer, VITA Easyshade, and the intraoral scanner, CEREC Primescan. Low accuracy for the spectrophotometer was an unexpected finding, disagreeing with most studies including the Kim-Pusateri et al. study, which this study was modeled after.[7] That study had VITA Easyshade's mean accuracy at 92.6% ± 1.05. However, it should be noted that our data were not normally distributed. Therefore, means and standard deviations were not used because they were not representative of our data.

Low accuracy for intraoral scanners, however, is a relatively common finding in the literature. A 2021 literature review concluded that although digital methods showed higher accuracy and precision compared to visual methods, it did not advise using intraoral scanners as the sole shade selection method.[23] Ebeid et al. used a spectrophotometer, VITA Easyshade V, as a control and compared it to three intraoral scanners: 3Shape Trios (Copenhagen, Denmark), CEREC Omnicam (Dentsply Sirona), and CEREC Primescan.[19] The study used ten different shades of Vita Mark II blocks (VITA). Ten color measurements per specimen were performed by each instrument using the Vitapan Classical shade system. Accuracy and repeatability data were gathered. The study concluded that all intraoral scanners showed less than expected accuracy and repeatability. Therefore, the authors recommended that caution should be exercised when using the color detection feature for these intraoral scanners. Rutkunas et al. used a spectrophotometer, SpectroShade, as a control and compared it to the intraoral digital

scanner, 3Shape TRIOS.[21] Shades of 120 maxillary anterior teeth were recorded using the TRIOS. Using the SpectroShade spectrophotometer as a reference, they found the TRIOS only had a mean accuracy of only 27.5% for the Vitapan Classical shade tabs and 53.3% for the Vitapan 3D Master shade tabs. A similar study compared the CEREC Omnicam shade selection feature to the VITA Easyshade as a control.[22] Twenty teeth from four subjects were scanned and measured. A significant difference was found between the spectrophotometer and the intraoral scan measurements overall. The conclusion was that the Omnicam was not an accurate method for shade selection and that the scanner's capability in shade selection should be further evaluated. It is important to note that the prior two mentioned studies were in-vivo, using human teeth instead of shade tabs. The results of these studies showed low accuracy and high reliability for intraoral scanners and appear to be consistent with our study, but the controls for these studies were spectrophotometers, not shade tabs. Therefore, direct comparisons cannot be made.

It is important to note that in the literature, reliability is always higher than accuracy regardless of the instrument. A recent 2021 literature review of 259 articles on the accuracy and reliability of visual and digital tooth shade selection methods found that dental spectrophotometers had better reliability than accuracy.[21] The accuracy of the spectrophotometers ranged from a mean of 66.8% to 92.6%, while reliability ranged from a mean of 87.4% to 99.0%. Reliability was high for our study as well for both VITA Easyshade and CEREC Primescan. These results were consistent with the study by Rutkunas et al., where reliability was high for both SpectroShade spectrophotometer and the intraoral scanner 3Shape TRIOS.[21] For the Vitapan Classical shade tabs, the means

were 93.5% and 87.17% for the SpectroShade and TRIOS, respectively. For the VITA 3D Master shade tabs, the means were 92% and 90.33%, for the SpectroShade and TRIOS, respectively.

The first null hypothesis was not rejected because there was no difference in accuracy between the VITA Easyshade and CEREC Primescan for both Vitapan Classical and Vitapan 3D Master shade tabs. The second null hypothesis was rejected because there was a difference in reliability between the two devices based on the Vitapan Classical shade tabs. However, there was no difference in reliability between the two devices for the Vitapan 3D Master shade tabs.

Limitations to this study are that only one spectrophotometer and one intraoral scanner system were evaluated. Also, this study only used shade tabs and not other forms of shade-matching standards for the control, such as spectrophotometers or restorative materials. There are not many studies to compare this study to due to this study using shade tabs as the control instead of a spectrophotometer.

Conclusion

Both evaluated devices, the VITA Easyshade spectrophotometer, and the CEREC Primescan intraoral scanner, showed low overall accuracy and high overall reliability for both the Vitapan Classical and Vitapan 3D Master shade tabs. There were no significant differences between the two devices except in reliability with the Vitapan Classical shade tabs, in which the VITA Easyshade was found to be significantly more reliable than the CEREC Primescan. Based on the results of this study, the use of intraoral scanner,

CEREC Primescan, cannot be recommended as a primary shade-taking method at this time.

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