



Accuracy and Repeatability of Intraoral Scanner for
Tooth Shade Determination: In Vitro Study

Nigool Chumsena

A Thesis Submitted in Fulfillment of the Requirements for the
Degree of Master of Science in Oral Health Sciences

Prince of Songkla University

2024

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Determination: In Vitro Study

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ชื่อวิทยานิพนธ์	ความถูกต้องและความแม่นยำในการเลือกสีฟันด้วยเครื่องพิมพ์ปากดิจิทัล (การศึกษาในห้องปฏิบัติการ)
ผู้เขียน	นายนิกุล ชุ่มเสนา
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ปีการศึกษา	2566

บทคัดย่อ

วัตถุประสงค์: เพื่อศึกษาเปรียบเทียบความถูกต้องและความแม่นยำในการเลือกสีฟันด้วยเครื่องสเปกโตรโฟโตมิเตอร์และเครื่องพิมพ์ปากดิจิทัล

บทนำ: การเลือกสีฟันในงานทันตกรรมประดิษฐ์เป็นสิ่งสำคัญอย่างยิ่งเพราะเป็นปัจจัยหนึ่งที่ก่อให้เกิดความสำเร็จในการรักษา วิธีที่ได้รับการยอมรับและใช้กันมาอย่างยาวนานคือเลือกโดยเทียบสีฟันในช่องปากกับแถบเลือกสีฟัน แต่เนื่องจากมีปัจจัยหลายอย่างจากตัวมนุษย์เองที่อาจก่อให้เกิดความผิดพลาดในการเลือกสีฟันด้วยวิธีนี้ การนำเครื่องพิมพ์ปากดิจิทัลมาช่วยในการเลือกสีฟันจึงน่าจะช่วยลดปัจจัยรบกวนเหล่านั้นได้

วัสดุและวิธีการทดลอง: วัดค่าพารามิเตอร์ L^*a^*b ของวิต้าบลอคมาร์กทู (VITABLOCS® Mark II) แล้วนำไปสร้างสีฟันควบคุมการทดลอง โดยการดิงสีฟัน (ซี 11) ออกจากแบบจำลองฟันและพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิทัลเพื่อสร้างสีฟันทดแทนด้วยระบบ CAD-CAM (จำนวน 10 ซี สีละ 1 ซี) หลังกลึงและขัดสีฟันทดสอบ วัดค่าพารามิเตอร์ L^*a^*b ซ้ำเพื่อเปรียบเทียบค่าความต่างสีก่อนและหลัง นำสีฟันไปใส่ในแบบจำลองฟันและหุ่นจำลอง วัดสีฟันโดยใช้เครื่องสเปกโตรโฟโตมิเตอร์วิต้าอีชีเนด แอดวานซ์ 4.0 (VITA Easys shade Advance 4.0) และเครื่องพิมพ์ปากแบบดิจิทัล 2 ยี่ห้อ ซีเรคไพรม์สแกนและทรีเชฟทริออสห้า (Cerec Primescan and 3Shape Trios V) สีละ 10 ครั้ง ประเมินความถูกต้องในการวัดสีฟันของเครื่องมือทั้งสามด้วยสถิติอนพาราเมตริกและประเมินความแม่นยำของเครื่องด้วยการใช้สัมประสิทธิ์ครอนบาคแอลฟา

ผลการทดลอง: เครื่องสเปกโตรโฟโตมิเตอร์มีความถูกต้องในการเลือกสีฟันที่ 84% ซึ่งมีความถูกต้องมากกว่าเครื่องพิมพ์ปากดิจิทัลซีเรคไพรม์สแกน (66%) และทรีเชฟทริออสห้า (71%) ส่วนความแม่นยำของเครื่องสเปกโตรโฟโตมิเตอร์เท่ากับ 94% และเครื่องพิมพ์ปากดิจิทัลทั้งสองยี่ห้อ มีค่าเท่ากับ 92% โดยค่าสัมประสิทธิ์ครอนบาคแอลฟาเท่ากับ 0.839

สรุปผลการทดลอง: สเปกโตรโฟโตมิเตอร์มีความถูกต้องในการเลือกสีฟันที่มากกว่าเครื่องพิมพ์ปากดิจิทัลจึงเหมาะสมในการนำไปใช้เลือกสีฟันมากกว่า ส่วนความแม่นยำของเครื่องทั้งสามไม่แตกต่างกัน

คำสำคัญ: การวัดสีฟัน, เครื่องพิมพ์ปากดิจิทัล, เครื่องสเปกโตรโฟโตมิเตอร์

Thesis Title	Accuracy and Repeatability of Intraoral Scanner for Tooth Shade Determination: In Vitro Study
Author	Mr. Nigool Chumsena
Major Program	Oral Health Sciences
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ABSTRACT

Objective: To compare the accuracy and repeatability in shade determination between intraoral spectrophotometers and two intraoral scanners.

Introduction: The color of the restoration must be carefully chosen. The application of shade guidelines is a subjective process with several elements that can all influence the outcome. To solve these concerns, digital shade evaluation has been recommended above visual shading assessment. Shade determination capabilities are now available with intraoral scanning. As a result, the purpose of this study is to compare the accuracy and repeatability of an intraoral spectrophotometer to that of an intraoral scanner.

Materials and method: Prepare the control tooth shade by designing a tooth to replace the upper right central incisor with computer-aided design. The identical-sized VITA BLOCS® Mark II was machined using computer-aided manufacturing, and it was polished for 60 seconds at a speed of 300 rounds per minute by a single person. All shades were calibrated with a VITA BLOCS® Mark II and compared to the mean average of the color difference. Replace the edentulous area with the teeth. Shade determination by intraoral scanners and Vita Easyshade 4.0 Evaluating the accuracy and repeatability of the instruments.

Results: The VITA Easyshade Advance 4.0 (84%) performed better in terms of accuracy than the 3Shape Trios V (71%) and Cerec Primescan (66%), according to the study's findings. The overall repeatability score of the evaluated devices ranges from 92% for two intraoral scanners to 94% for the spectrophotometer.

Conclusion: Intraoral scanners prove to be unreliable for assessing dental shades; dental spectrophotometers are suitable for matching shades. On the contrary, there was no appreciable difference in repeatability between two intraoral scanners and spectrophotometers.

Keyword: Shade determination, Intraoral scanner, spectrophotometer

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Nigool Chumsena

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LIST OF ABBREVIATIONS AND SYMBOLS

CAD	=	Computer Aid Design
CAM	=	Computer Aid Manufacturing
SP	=	Spectrophotometer (VITA Easyshade Advance 4.0)
CP	=	CEREC Primescan
T5	=	3Shape Trios V
$L^*a^*b^*$	=	Parameters of color
L^*	=	Lightness
a^*	=	Axis of red-blue color
b^*	=	Axis of green-yellow color
ΔE	=	Color difference

PUBLICATION AND PROCEEDING

Proceeding

Andaman Dental Congress, 18-20 October 2023, Duangjit Resort and Spa,
Phuket, Thailand.

CHAPTER I

INTRODUCTION

Dental professionals employ intraoral scanners for a variety of purposes, including caries detection, digital impressions, imaging for orthodontics, dental education, guided implant surgery, periodontal defect diagnosis, and shade matching. They were introduced to improve communication between the dentist and the laboratory, promote patient comfort, save chair time, and produce high-quality and accurate impressions. The process of fabricating a restoration can be simplified by taking an optical impression of the teeth after they have been prepped.^(1,2) Aesthetics is one of the most important and difficult issues facing dental professionals today. A thorough treatment strategy, treatment process, and communication are crucial for achieving the desired aesthetic result.⁽²⁾ In order to blend the restoration's color in with the surviving natural teeth, this is a crucial clinical step.^(1,2,3) The visual and instrumental approaches are the two ways that tooth color can be evaluated. Typically, a visual method using shade guides is used to measure tooth color.^(1,2,6) The process of using shade guides is subjective, and a number of factors, including the light source, the teeth's angle of view, prior eye exposure, metamerism, eye fatigue, and education and training^(1,2,4) procedure and communication are crucial, could influence the outcome.⁽²⁾ Commercial shade guides have been used to determine the color of a tooth. Vita Classic (VITA Zahnfabrik, Bad Sackingen, Germany) is a widely used shade guide that mimics the color of actual teeth. In markets like Dentsply Sirona, Bioform, Ivoclar Vivadent AG, and Chromascop, other shade guides have competed. More reliability than the others has reportedly been reported for the new shade guide, Vita 3D-Master (VITA Zahnfabrik, Bad Sackingen, Germany), which is organized according to the CIELCh color scale.⁽³⁾ But the visual method has a complexity of factors interfering with individual color perception.⁽⁴⁾

Spectrophotometric shade assessment has been proposed as a solution to these problems, with the aim of enhancing communication and visual aids between the dental laboratory and the dental office to increase the efficiency of aesthetic outcomes. Previous research has reported using spectrophotometers as a reference in color matching studies because they are more reliable than visual shade matching techniques.^(3,5-6) The spectrophotometer (Vita Easyshade Advance 4.0, VITA Zahnfabrik, Bad Sackingen, Germany) was found to have an estimated accuracy of 92.6% and precision of 96.4% in the study by Pusateri et al.⁽⁷⁾ Software for intraoral scanners has

included the ability to determine color shade since 2015.⁽⁵⁾ This function of the scanner may increase the accuracy and repeatability of shade determination due to the digital instrument, which can eliminate some factor of human error.

Therefore, this study aims to evaluate the accuracy and repeatability of an intraoral spectrophotometer compared to an intraoral scanner. The null hypothesis of this study is that the accuracy and repeatability of intraoral scanners would be no different from intraoral spectrophotometers.

OBJECTIVE

To compare the accuracy and repeatability in shade determination between intraoral spectrophotometer and two intraoral scanners.

RESEARCH QUESTION

Does different of accuracy and repeatability in shade determination by using intraoral spectrophotometer and intraoral scanners?

HYPOTHESES

1) Accuracy of shade determination by using intraoral spectrophotometer would be no difference to intraoral scanners.

2) Repeatability of shade determination by using intraoral spectrophotometer would be no difference to intraoral scanners.

REVIEW OF LITERATURES

The average differences between the actual quantitative color values were used to evaluate the accuracy of dental shade matching instruments, such as spectrophotometers and colorimeters. The color coordinates they use are $L^*a^*b^*$, which stand for lightness, chromaticity along the red-green axis (a), and chromaticity along the yellow-blue axis (b). These are provided by the Commission Internationale de l'Eclairage (CIE). These devices were used to gather data on teeth or specimens based on the $L^*a^*b^*$ parameters. They then recorded quantitative color values for the same tooth or specimens and/or calculated the device's accuracy rate in determining the quantitative or qualitative color data for the specimens. ⁽⁶⁻⁹⁾

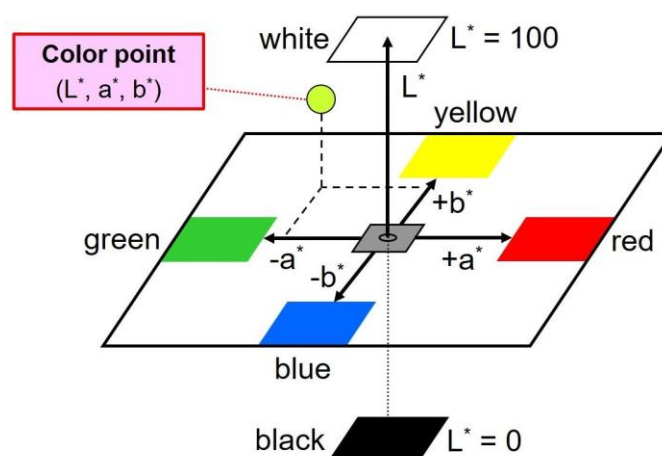


Figure 1: $L^*a^*b^*$ Color space

Source; <https://stackoverflow.com/questions/47483951/how-can-i-define-a-threshold-value-to-detect-only-green-colour-objects>.

The degree to which a measuring tool yields consistent results is known as repeatability. A color matching device's repeatability can be assessed by calculating the percentage of repeatable or reproducible color determination records made by the devices for the same specimens, or by calculating the average differences between the quantitative color results of the device in repeated measurements for similar specimens under similar conditions. As a result, the percentages and color difference units computed ^(7,10) from a

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

There have been reports of excellent accuracy and repeatability with spectrophotometers. They calculate how much light energy is reflected off of various objects. The instruments' measurements are often converted to shade tab equivalents

by keying them to dental shade guides.^(7,9,10) Compared to visual methods, they have been shown to have higher accuracy and repeatability when used to aid in color determination.^(6,9,10) Their working principle involves the transmission of white light, which is divided into wavelength intervals of 1 to 25 nanometers using a triangular prism. The light is then reflected off the tooth's surface and returns to the device's receptor, which records the total amount of color spectrum energy. Dental professionals require the manipulation and translation of data obtained from spectrophotometers into something of value. The dental shade guides and L*a*b* color space are the measurements that the instruments measure.⁽⁸⁻¹²⁾ Spectrophotometers were found to provide 33% more accuracy^(11, 14) and more objective color matching in 93.3% of cases when compared to observations made with the human eye or conventional techniques.^(13, 14) While the investigators have assessed the accuracy and repeatability of a variety of spectrophotometers, they have not been consistent in identifying the most accurate instrument or evaluation condition. The precision of the Olympus MSC-2000 multispectral camera and CrystalEye® was measured in a study by Odaira⁽¹⁴⁾ and compared to the color Analyzing spectrophotometer-Iwate (CAS-ID1), which was used as a standard device. The devices' recorded L* and C* values showed no discernible variations. In both light and dark environments, Crystaleye demonstrated the highest precision, exhibiting acceptable accuracy (44.05%-91.25%), excellent repeatability (88.81%-98.97%), and appropriate reproducibility. The middle region of the tooth performed the best for measurement, according to Chen et al.⁽¹⁵⁾ Easyshade and Ikam were found to have the highest repeatability among the five color measuring devices (ShadeScan, Easyshade, Ikam, IdentaColor II, and ShadeEye) compared in a study by Dozić et al.⁽⁷⁾ But in both cases, Easyshade was the most accurate gadget.^(5,7,10,16) In the study of Klotz⁽¹⁷⁾, VITA Easyshade Advance 4.0 and V provide accuracy and precise for color measurement surpassing a photo-colorimetric method. The upper incisor has been measured with the highest precision, while the lower central incisor and upper first premolar has shown the largest color difference.⁽²¹⁾ The negative impact on light reflected to the devices may be caused by the curvature of the tooth surface.⁽²¹⁻²²⁾ The CIELab values obtained using digital and visual methods show low agreement, ranging from 3.62 to 4.54 ΔE units and 38.8% to 67.4%, respectively.⁽²⁶⁾ Units and the range of 4.06 to 16.04 ΔE units measured by those colorimeters or spectrophotometers.⁽²⁷⁾ The color difference is compared with visual thresholds in order to assess the accuracy and repeatability clinically. When 50% of observers perceive a color difference between two objects and the other 50% do not, this is referred to as a 50:50% perceptibility

threshold. When 50% of observers find a color difference acceptable, and the other 50% find it unacceptable, this is referred to as a 50:50% acceptability threshold.^(10,11,12,13,14) A perceptibility threshold of $\Delta E=1.2$ and acceptability threshold of $\Delta E=2.7$ have been established (ISO/TR 28642:2016).^(12,15,40) The spectrophotometer shows high precision and accuracy^(17,18,20,22,24,26,27) in shade determination and the future study may help to overcome their limitations and produce the best result of tooth shade determination.

Based on a dental shade guide, an intraoral scanner can identify the color of teeth. According to a study by Liberato et al.⁽²¹⁾ evaluating VITA Advance 4.0 and a TRIOS intraoral scanner, the scanner performed best when set up in Vita 3D-master mode. A study by Yoon et al.⁽²²⁾ revealed notable distinctions between the ShadeEye colorimeter and the TRIOS Pod intraoral scanner. Similarly, the study by Rutkunas et al.⁽³⁾ reported the shade selection result of TRIOS (3Shape, Copenhagen, Denmark) do not exactly match those of spectrophotometers, other conclude unacceptable shade matching for intraoral scanner such as the study by Culic et al.⁽²³⁾ reported the difference result for shade matching by using CEREC Omnicam and spectrophotometer. Godfredsen et al.⁽²⁹⁾ reported that TRIOS 3 outperformed Spectro Shade Micro in shade selection results. Additionally, some studies of new scanners, like TRIOS 3 (3Shape, Copenhagen, Denmark), demonstrate superiority over the visual method in addition to comparable results to spectrophotometers. When used with or without a light-correcting device, intraoral scanners and spectrophotometers are more accurate than visual methods when shade guides are used by skilled clinicians.^(19,28) Currently, intraoral scanners that utilize color matching tools are limited to evaluating qualitative color data. The manufacturers have advertised them for choosing tooth shades, but it's unclear how well they match shades when using intraoral scanners. Therefore, this study aims to evaluate the accuracy and repeatability of intraoral spectrophotometer compare to intraoral scanner. The null hypothesis of this study is accuracy and repeatability of intraoral scanners would be no different to the spectrophotometer.

Authors (year)	Spectro- photometer	Scanner	Study	Outcomes		
				parameters	Accuracy	Repeatability
Gotfredsen (2015)	MHT SpectroShade™	TRIOS Pod color-P13	In vivo	Vita 3D-master	No significant	No significant
Mehl et al, (2017)	VITA Easyshade Advance 4.0 SpectroShade	3Shape Trios	In vitro	Vita 3D-master L*a*b parameters	Significant	No significant
Yoon et al, (2018)	Colorimeter (ShadeEye)	(TRIOS Pod)	In vivo	L*a*b* parameters	Significant	Significant
Brandt (2017)	VITA Easyshade Advance 4.0	TRIOS 3Shape	In vivo	Vita 3D-master L*a*b parameters	Significant	*Significant
Liberato (2019)	VITA Easyshade Advance 4.0	TRIOS 3Shape	In vivo	Vita Classical Vita 3D-master	No significant	No significant
Rutkunas (2020)	SpectroShade ™	TRIOS 3	In vivo	Vita 3D-Master Vita Classic	Significant	Significant
(Culic) 2018	VITA Easyshade Advance 4.0	CEREC Omniscam	In vivo	Vita classic Vita 3D-Master	Significant	Significant
Ebeid K 2022	VITA Easyshade Advance V	CEREC Omniscam CEREC Primescan Trios 3	In vitro	Vita classic Vita 3D-Master	Significant	Significant

Table 1: Compared the accuracy and repeatability of scanners and spectrophotometers

CHAPTER II

MATERIAL AND METHODS

Research design: In vitro study

Preparation of control shade

Remove the right-upper central incisor (Tooth number 11) of the dental model (Nissin dental model, Nissin Dental Products INC, Kyoto, Japan) and take a digital impression with an intraoral scanner (CEREC Primescan AC, CEREC, Denstply Sirona, Bensheim, Germany). Then, design a tooth to replace the upper right central incisor with computer-aided design (CAD). VITABLOCS[®] Mark II was milled by computer-aided manufacturing (CAM) with the same shape and dimension (VITABLOCS[®] Mark II, VITA Zahnfabrik, Bad Sackingen, Germany). The control teeth shades are 0M1, 1M1, 1M2, 2M1, 2M2, 2M3, 3M1, 3M2, 3M3, and 4M2. They were the control specimens for this study. Measure the size and shape of all ceramic teeth with a Vernier caliper and polished samples, as recommended by the manufacturers. Each polishing step was carried out for 60 seconds at 300 rounds per minute by one single operator. All of teeth were calibration with VITABLOCS[®] Mark II by spectrophotometer (Vita Easyshade advance 4.0, VITA Zahnfabrik, Bad Sackingen, Germany). L* a* b* parameters were recording (3 times/tooth) and calculation to a color difference. Compare the mean average of the color difference between ceramic control shade teeth (ΔE_2) and VITABLOCS[®] Mark II (ΔE_1) (Use the same manufacturing lot numbers) by the formular;

$$\Delta E_{21} = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

The difference (ΔE_{21}) is less than or equal to 1.7 ΔE units, which is considered no difference in shade⁽³⁴⁾ and appropriate for standardization of study. All measurement was taken by one operator for reducing the error and standard calibration with senior lecturer at prosthetics department, Faculty of dentistry, Prince of Songkhla University.



Figure 2: L*a*b measurement by spectrophotometer



Figure 3: VITA Bloc® Mark II

(Source; <https://www.straumann.com/digital/in/en/home/consumables/blocs/vita-mark-ii.html>)



Figure 4: Milling of Vita Bloc® Mark II by CEREC Primemill®

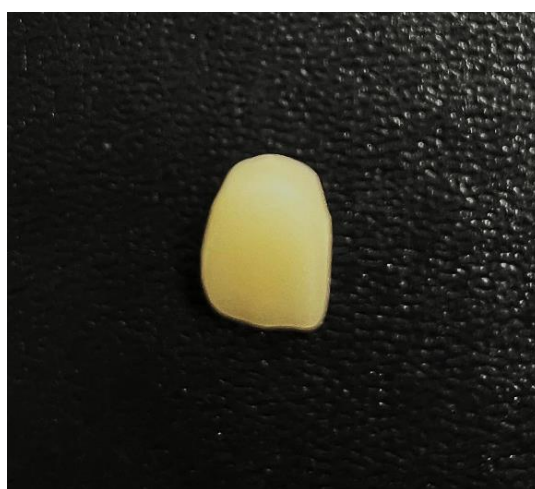


Figure 5: Control tooth shade after milling and polishing.

All control shades showed variances in color difference before and after preparing the control tooth (Table 2). However, the color difference (ΔE_{21}) in the control shade range of 0.33–0.73 units is less than the acceptable criterion in prior experiments. Ruyter et al. reported 3.3 E units⁽³⁰⁾, while Ragain and Johnston acquired an acceptable threshold value of 2.7 units.⁽³¹⁾ Douglas and Brewer showed a lower acceptance threshold (mean of 1.7 DE units)⁽³²⁾ for prosthodontists examining metal-ceramic crowns with varying color variations. Comparing clinical perceptibility and acceptability thresholds to clinical perceptibility and acceptability research was the goal of Johnston and Kao's study. The authors found that there was an average color difference of 3.7 ΔE units between a composite resin veneer restoration that perfectly matched the adjacent or contralateral tooth.⁽³³⁾

Shade	L*a*b parameter								ΔE_{21}
	VITABLOCS® Mark II				Control tooth				
	E ₁	L ₁	a ₁	b ₁	E ₂	L ₂	a ₂	b ₂	
0M1	83.54	83.3	0.1	6.4	83.44	83.2	-0.2	6.3	0.33
1M1	82.22	81.4	-0.3	11.6	81.57	80.8	-0.4	11.2	0.73
1M2	81.05	79.4	-0.4	16.3	80.58	79.0	-0.4	15.9	0.56
2M1	77.57	76.6	0.4	12.2	77.62	76.7	0.3	11.9	0.33
2M2	78.80	76.9	0.6	17.2	78.48	76.5	0.5	17.5	0.51
2M3	79.86	76.8	0.5	21.9	79.53	76.4	0.3	22.1	0.49
3M1	73.00	71.6	1.5	14.2	72.76	71.3	1.6	14.4	0.37
3M2	74.33	71.4	1.5	20.6	73.89	71.0	1.7	20.4	0.49
3M3	76.42	71.5	2.1	26.9	76.01	71.1	2.2	26.8	0.42
4M2	70.96	67.3	3.0	22.3	70.42	66.9	2.8	21.8	0.68

Table 2: L*a*b parameter of control shade

Instruments/Materials	Manufacturer
	Intraoral scanner CEREC Primescan AC (Cerec, Denstply Sirona, Bensheim, Germany) The abbreviation in this study is “CP.”
	Intraoral scanner 3Shape TRIOS V (3Shape, Copenhagen, Denmark) The abbreviation in this study is “T5.”
	Spectrophotometer VITA Easyshade advances 4.0 (VITA Zahnfabrik, Bad Sackingen, Germany). The abbreviation in this study is “SP.”
	VITABLOCS® Mark II (VITA Zahnfabrik, Bad Sackingen, Germany).

Table 3: Shade matching instruments and material of control shade.

Shade determination

Keep the teeth in a box (1 tooth per box) and record the true shade under the box and random numbers 1-10 (by the other person who is not involved in the study) for record the number of the box.



Figure 6: record true shade under the box.



Figure 7: random and record number of boxes.



Figure 8: Control tooth shade with a maxillo-mandibular model.

First, replace the edentulous with a ceramic control tooth shade with box number 1 in the human model. Then, scan the upper right lateral to upper left lateral tooth by using an intraoral scanner (Cerec Primescan, Denstply Sirona, Bensheim, Germany) from the labial, palatal, and incisal aspects. ⁽⁴¹⁾ The impression data shown on display and shade determination by shade selection menu established for the VITA 3D master shade and record results. Repeat the impression for shade determination 10 times per one control tooth shade.

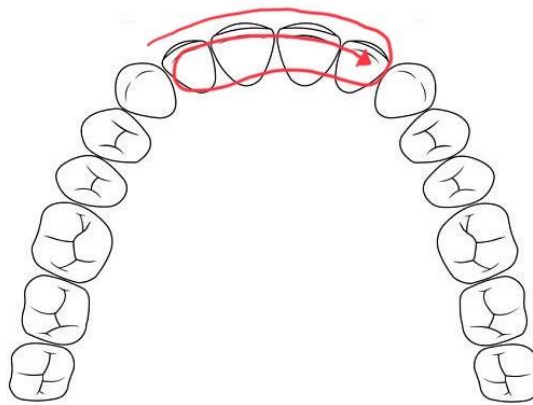


Figure 9: pattern of scanning

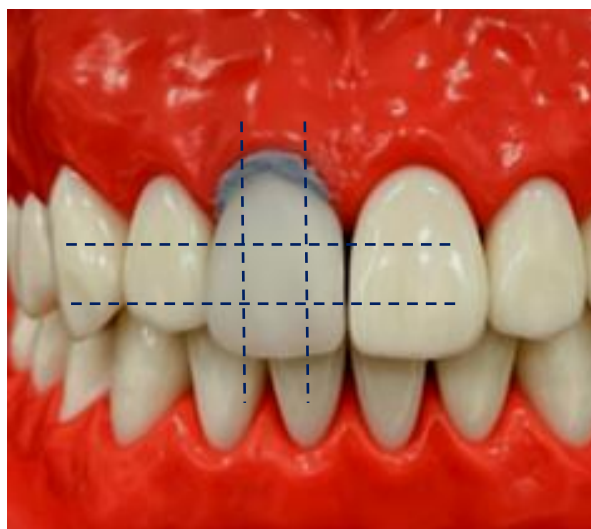


Figure 10: Middle of the tooth surface for shade determination



Figure 11: Shade determination by Cerec Primescan

Scan ceramic control tooth shade by using an intraoral scanner (3shape Trios V, 3Shape, Copenhagen, Denmark) with the same protocol and record the results.

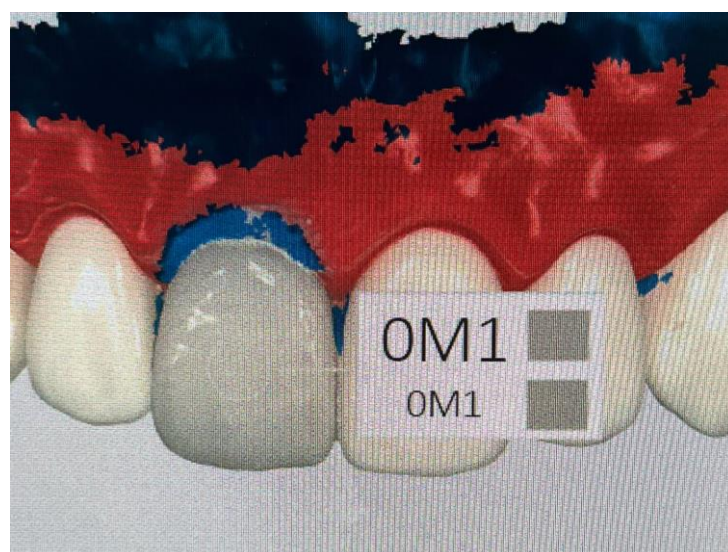


Figure 12: Shade determination by 3Shape Trios V

Determine the shade using the spectrophotometer VITA Easyshade Advance 4.0 according to the same protocol, then note the findings. Intraoral scanners and a spectrophotometer were always calibrated using a calibration block prior to the subsequent measurement of additional teeth.



Figure 13: Shade determination by spectrophotometer

The spectrophotometer can be turned on by pressing the on/off button. Position the tip perpendicular to the tooth surface and near the center. Press the test button and listen for the sound device to finish. The shade determinant's outcome was displayed. After shade determination by three instruments for the control tooth (Number 1), remove the old control tooth shade, place control tooth shade of box number 2, and follow the same step as before until box number 10. All instrument shade matching procedures in the study were conducted in the same environment with the same trained operator.

A comparison of the reference shade for each subject tooth tested was used to assess the accuracy of the instruments. By dividing the total number of agreements by the total number of comparisons, the accuracy percentage was determined. The consistency of the system in yielding consistent results across multiple testing sessions was used to evaluate the repeatability of the instrument. By dividing the total number of shade measurements in each group by the number of repeated shades, the repeatability percentage was determined.

CHAPTER III

RESULTS

If the shade chosen by the instruments matched the control shades, it was considered "true," and if the shade did not match, it was considered "false." In this study spectrophotometer (SP) shown accuracy of shade determination in 84%, Cerec Primescan (CP) 66 % and 3shape Trios V (T5) 71 % The data is presented in Table 3. The power analysis adopted an alpha level of 5%, a beta level of 20%. Categorical data were presented as frequencies (n) and percentages (%). Measurement accuracy was compared using the Cochran Q test, followed by pairwise comparisons with Bonferroni's correction. Instrumental measurement repeatability was analyzed using Cronbach's alpha. The significance level of 0.05 was set for all statistical tests.

Control shade	Parameters				SP		CP		T5	
	ΔE	L*	a*	b*	T	F	T	F	T	F
0M1	83.44	83.2	-0.2	6.3	8	2	6	4	7	3
1M1	81.57	80.8	-0.4	11.2	9	1	7	3	7	3
1M2	80.58	79.0	-0.4	15.9	8	2	6	4	8	2
2M1	77.62	76.7	0.3	11.9	9	1	8	2	7	3
2M2	78.48	76.5	0.5	17.5	8	2	7	3	7	3
2M3	79.53	76.4	0.3	22.1	9	1	6	4	8	2
3M1	72.76	71.3	1.6	14.4	8	2	7	3	7	3
3M2	73.89	71	1.7	20.4	8	2	6	4	6	4
3M3	76.01	71.1	2.2	26.8	9	1	7	3	8	2
4M2	70.42	66.9	2.8	21.8	8	2	6	4	6	4
Summary					84	16	66	34	71	29

Table 4: Accuracy of shade matching by instruments "T" means true, and "F" means false.

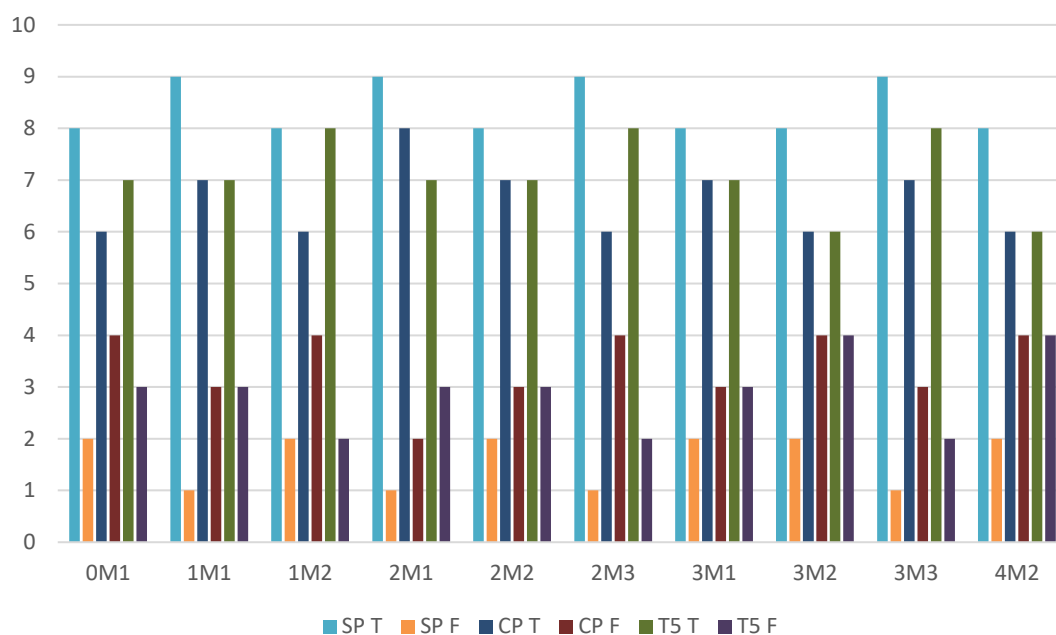


Figure 14: Accuracy of shade matching “T” means true, and “F” means false.

The instrumental accuracy of repeated measurements for 10 different shades of control tooth specimens is presented in Figure 14. All instruments do not have 100% accuracy for each shade. For the spectrophotometer, the accuracy range is 80%–90%, and for the two intraoral scanners, Cerec Primescan and 3Shape Trios V, it was 60%–80%. There was no significant difference in terms of instrumental accuracy when comparing all instruments in each shade determination ($p < 0.05$).

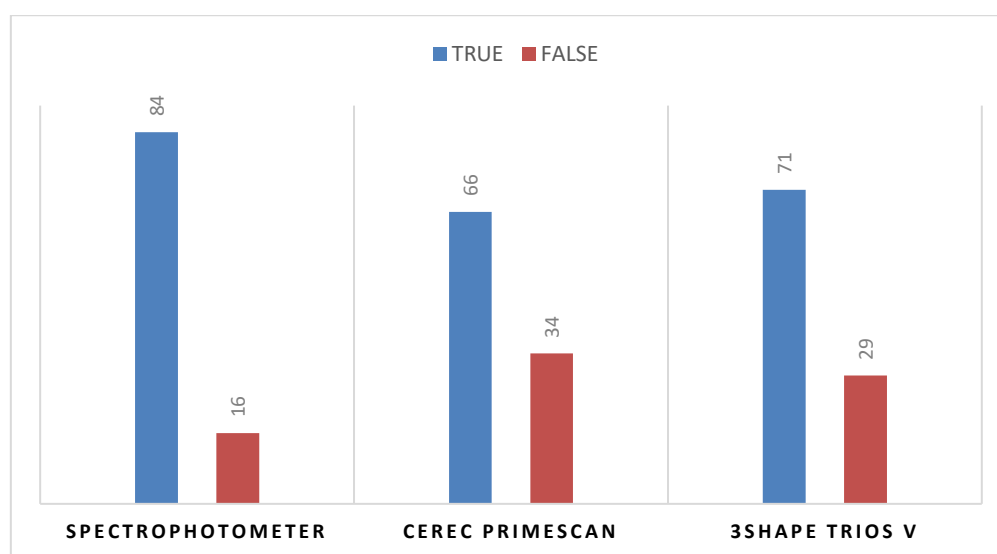


Figure 15: Accuracy of all shade determination by all instruments.

On the contrary, when comparing the instrumental accuracy (%) of repeated measurements for all control shades (Figure 15), there was a statistical difference in accuracy between the spectrophotometer VITA Easyshade advance 4.0 (84%) and two intraoral scanners, 3Shape Trios V (71%; $p = 0.015$) and CEREC Primescan (66%; $p = 0.000$). Spectrophotometers surpass intraoral scanners in terms of the accuracy of shade determination.

Shade	False shade results		
	VITA EasyShade	Cerec Primescan	3Shape Trios V
0M1	0M2, 0M2	0M2, 0M2, 0M2, 0M3	0M2, 0M2, 0M3
1M1	1M2	1M2, 1M2, 1M2	1M2, 1M2, 1M2
1M2	1M1, 1M1	1M1, 1M1, 1M1, 1M1	1M1, 1M1
2M1	2R1.5	2R1.5, 2R1.5	2R1.5, 2R1.5, 2L1.5
2M2	2L1.5, 2L1.5	2L1.5, 2L1.5, 2R1.5	2L1.5, 2L1.5, 2L1.5
2M3	2R2.5	2L2.5, 2L2.5, 2R2.5, 2L2.5	2R2.5, 2L2.5
3M1	3L1.5, 3M2	3M2, 3L1.5, 3L1.5	3M2, 3L1.5, 3M2
3M2	3L1.5, 3L1.5	3R1.5, 3M1, 3L1.5, 3L1.5	3M1, 3L1.5, 3L1.5, 3R1.5
3M3	3R2.5	3R2.5, 3R2.5, 3L2.5	3R2.5, 3L2.5
4M2	4R2.5, 4R2.5	4R2.5, 4R2.5, 4L2.5, 4R2.5	4R2.5, 4R2.5, 4R2.5, 4R2.5

Table 5: False shade reading of all instruments.

False shade readings of all instruments shown in Table 5. In shades 1M1, 1M2, and 4M2, each instrument had only one false reading shade result (1M1 false reading is 1M2, 1M2 false reading is 1M1, and 4M2 false reading is 4R2.5). In the other shade, more than one false result is shown. 3M2 and 4M2 control shades are the falsest readings of both intraoral scanners, and 2M1 and 3M3 control shades are the lowest false readings of both instruments. In addition, all false results of all instruments show the same level of light (L^* parameter) and are correct with the control shades; the first number of each Vita 3D-Master shade guide (0–5, 0 = lightest and 5 = darkest) is the level of lightness.

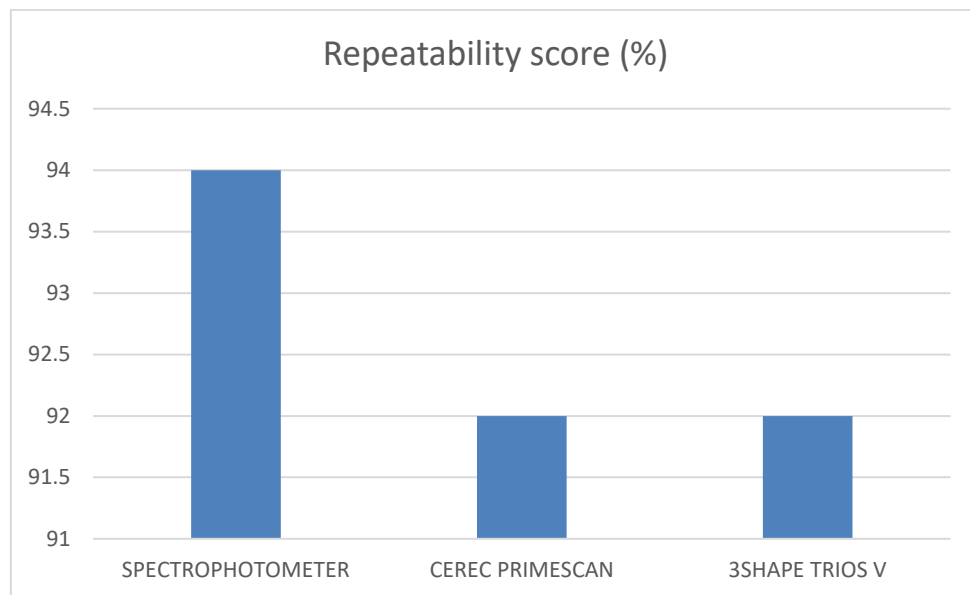


Figure 16: Repeatability score (%) of all instruments.

For comparison in terms of repeatability (Figure 16), the true and false shade reading more than once refers to the result of the repeatability score. Every shade was measured by each instrument 10 times in consecutive measurements. Two steps were taken to determine repeatability. First, the number of identical measurements for every instrument was used to calculate its repeatability. Whether or not the measurement matches the true shade of the tooth, repeated shade measurements were thought to be reliable. When measuring a 1M1 shade, for instance, a shade-matching device would be said to have 100% repeatability if all 10 measurements were the same, even if they weren't 1M1. ⁽⁵⁾ The only one-time wrong or true result for each control shade and each instrument refers to not being reliable and not being calculated to a repeatability score. The repeatability score of all instruments (%) was shown in Figure 9. The overall repeatability score of the evaluated devices ranges from 92% for two intraoral scanners to 94% for the spectrophotometer.

Instruments	Accuracy ^a	Repeatability ^a
VITA Easyshade 4.0	84% ^A	94% ^A
CEREC Primescan	66% ^B	92% ^A
3Shape Trios V	71% ^B	92% ^A

Table 6: Accuracy and repeatability score (%) of all instruments.

^aDifferent superscript letters indicate statistical difference with the same column ($p < 0.05$)

A measurement of internal consistency by Cronbach's alpha coefficient was used for the statistical analysis of repeatability. There was no statistical difference in the overall repeatability score of the evaluated devices, ranging from 92% for two intraoral scanners to 94% for the spectrophotometer, and the Cronbach's alpha coefficient is 0.839.

CHAPTER IV

DISCUSSION

The null hypothesis that the devices' reliability is equal was accepted for the reliability evaluation, while the null hypothesis that the devices' accuracy is equal was rejected for the two intraoral scanners and the spectrophotometer in the accuracy evaluation. In a study, the spectrophotometer (VITA Easyshade Advance 4.0) showed a higher accuracy in shade matching (84.0% correct matches) compared to the intraoral scanner 3Shape Trios V (71.0% correct matches) and the Cerec Primescan (66.0% correct matches). The VITA Easyshade Advance 4.0 demonstrated comparable accuracy, while the 3Shape Trios V and Cerec Primescan showed lower accuracy when compared to the spectrophotometer. This aligns with a previous study that also found the intraoral scanner to be less accurate than the spectrophotometer in shade determination.^(3,22,23,25,26) This result is in contrast to some study that concluded that intraoral scanners, spectrophotometers, and visual methods are all equally effective for determining tooth shade.^(27,29) This might be because, in this study, the true shade is determined by manufacturing shade (VITA blocks Mark II), and accuracy is defined as color trueness. In contrast, Gotfredsen et al. used visual methods as a reference color, meaning that, in cases where the color determined by an intraoral scanner and spectrophotometer did not match, the true color was determined by the single result obtained using the visual method.

The spectrophotometer showed notably better accuracy compared to Cerec Primescan ($p < 0.001$) and 3Shape Trios V ($p < 0.05$). This disparity could be attributed to their different methods of color evaluation. Intraoral scanners must meet two key criteria in order to be regarded as a practical method for selecting shades: color imaging and data processing. Even though intraoral scanners are capable of measuring tooth color and gathering three-dimensional data about the surface of teeth, certain emerging factors may contribute to deficiencies in color matching ability.^(21,22) Color results from intraoral scanners are displayed using dental shade guides and do not record parameters of color such as L^*a^*b . VITA Easyshade Advance 4.0 has a fundamental operation in that it emits and transforms received light from the target into tristimulus parameters (L^*a^*b and L^*c^*h parameters) using a D65 illuminant and a 20 W halogen bulb^(8,22), whereas Cerec Prime Scan uses video capture for a 3D-colored image. They may be described as measurement devices that operate according to the basic fundamentals of confocal microscopy and according to the active triangulation

technique.^(24,34,37,38) while the 3Shape Trios V captures clear images at specific depths using technology similar to confocal laser scanning microscopy^(34,37,38), a technique called optical sectioning. It acquires images point-by-point and reconstructs them using computer processing.^(5,25,26) However, there are no significant differences between the two intraoral scanners ($p=0.837$), but the Cerec Primescan has shown lower accuracy than the 3Shape Trios V. This aligns with the previous study that showed Trios 3 is more effective than Primescan, even though it is not the latest version of 3Shape.⁽⁴¹⁾ The accuracy of digital imaging in determining shade is affected by the quality of the camera and the method used for image processing, and VITA Classical and VITA 3D-Master modes are also influenced by different lighting conditions. According to Yoon et al., the 3Shape Trios intraoral scanner measured higher a^* and lower L^* and b^* values than the ShadeEye colorimeter, resulting in significant differences in color parameters between the two devices.⁽²²⁾ Other variables that affect the intraoral scanner shade method include the shade guide mode, the surrounding environment, and color analysis software. Therefore, it is advised to use an additional instrument to identify the shade using intraoral scanners.

The selection of tooth shades by intraoral scanners appears to be comparable to that of visual methods when comparing their accuracy. Czigola et al propose that Trios 3 is an alternate method of shade matching with a 3D-Master tooth color system.⁽¹⁾ The study by Ebeid et al. found that the accuracy of shade matching in the visual method by clinician experts was 65%–90%⁽²⁴⁾ and is similar to this result when compared to shade determination with intraoral scanners in this study. Additionally, studies that evaluated visual shade selection and instrument shade selection concluded that the results of both methods were similar.^(11,13) Nevertheless, combining the two methods produced the best accuracy.⁽⁴⁵⁾ In contrast, Yilmaz et al. used a few shades (A1, B1, C3, D3, and A3.5 in VITA Classic shade guides) of porcelain fused to metal crowns in the study⁽²⁷⁾, and the result shown Visual methods are more effective than instruments; the color difference between these shades is too great⁽⁴⁴⁾ and is easy to differentiate by visual; another study showed that Vita Classic shade guides are not accurate when compared to Vita 3D-Master shade guides.^(1, 3) These factors may have an effect on the result and are not covered for clinical situations.

The results of this study demonstrated that there was no discernible variation in the repeatability of any of the instruments, and that the repeatability of intraoral scanners and spectrophotometers is comparable. All of the instruments' repeatabilities are good (>92%). The assessed instruments' repeatability was more than 75%, which is sufficient.⁽²¹⁾ The repeatability score of the evaluated devices

ranges from 92% for two intraoral scanners to 94% for the spectrophotometer, and the Cronbach's alpha coefficient is 0.839. Cronbach's alpha is the number of values that range from 0 to 1, measuring internal consistency. The reliability generalization estimates of Cronbach's alpha show an acceptable to good degree of internal consistency because they are above the generally recognized cut-off point of 0.70.^(42,43) Its findings also aligned with those of an earlier study that produced comparable findings. Several studies have shown that the repeatability of tooth color determination with an intraoral scanner is on par with spectrophotometers.^(21,25,29)

According to this study, repeatability is the same for both spectrophotometer and intraoral scanners, but spectrophotometer offer the highest overall accuracy. The difficult process of choosing a tooth shade has a significant impact on how dental restorations appear. Numerous factors influence visual shade selection techniques, such as the absence of standard conditions, eye fatigue, and a strong reliance on individual experiences. Digital systems have proven useful in facilitating communication between dentists and technicians in dentistry, as well as between patients, due to their speed and capacity.^(37,38) This suggests that the use of intraoral scanners for shade determination should be associated with human visual evaluation.

CHAPTER V

CONCLUSION

Regardless of the study's limitations, the findings show that the VITA Easyshade Advance 4.0 is superior to the 3Shape Trios V and Cerec Primescan in accuracy. Therefore, intraoral scanners prove to be unreliable for assessing dental shades; dental spectrophotometers are suitable for matching shades. On the contrary, there was no appreciable difference in repeatability between two intraoral scanners and spectrophotometer.

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APPENDIX





024

Title: Accuracy and repeatability of intraoral scanner for tooth shade determination (*in vitro* study)

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This *in vitro* study aimed to assess the accuracy and repeatability of an intraoral scanner for tooth shade determination. The study utilized a controlled setup involving all-ceramic teeth generated with VitaBlocs Mark II and known shade references. Spectrophotometers and two intraoral scanners were used to scan the teeth, generating digital color data. The acquired digital shades were recorded in Vita 3D Master Shade and then compared to the reference. Repeatability was assessed by performing multiple scans of the same teeth and analyzing the consistency of the obtained shade data. The percentage of repeatability was obtained by comparing the number of repeated shades with the number of shade measurements in each group. Accuracy was compared using the Cochran Q test, followed by pairwise comparisons using multiple McNemar's tests with Bonferroni correction. The repeatability of the instruments was evaluated using Cronbach's alpha.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distributions of ESresult, CPresult and T5result are the same.	Related-Samples Cochran's Q Test	<.001	Reject the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

Table 7: Cochran's Q test by IBM SPSS Statistics

Pairwise Comparisons

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig. ^a
ESresult-T5result	-.130	.046	-2.815	.005	.015
ESresult-CPresult	-.180	.046	-3.897	<.001	.000
T5result-CPresult	.050	.046	1.083	.279	.837

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Table 8: Pairwise comparisons with Bonferroni's correction by IBM SPSS Statistics

Case Processing Summary

	N	%
Cases Valid	100.0	100.0
Excluded ^a	0	.0
Total	100.0	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.839	100.0

Table 9: Cronbach's alpha coefficient by IBM SPSS Statistics

Box number	True shade	Measurement times	CP Reading	SP Reading	T5 Reading
1	3M3	1	3M3	3M3	3M3
		2	3R2.5	3M3	3R2.5
		3	3M3	3M3	3M3
		4	3M3	3M3	3M3
		5	3R2.5	3R2.5	3M3
		6	3M3	3M3	3M3
		7	3M3	3M3	3M3
		8	3M3	3M3	3M3
		9	3M3	3M3	3M3
		10	3L2.5	3M3	3L2.5
2	0M1	1	0M2	0M1	0M1
		2	0M1	0M1	0M2
		3	0M1	0M1	0M1
		4	0M2	0M2	0M1
		5	0M1	0M1	0M1
		6	0M1	0M1	0M1
		7	0M1	0M2	0M2
		8	0M2	0M1	0M1
		9	0M1	0M1	0M1
		10	0M3	0M1	0M3
3	1M2	1	1M2	1M2	1M1
		2	1M2	1M2	1M2
		3	1M1	1M1	1M2
		4	1M2	1M2	1M2
		5	1M1	1M2	1M2
		6	1M1	1M2	1M2
		7	1M2	1M2	1M2
		8	1M2	1M2	1M2
		9	1M2	1M2	1M2
		10	1M2	1M1	1M1

Box number	True shade	Measurement times	CP Reading	SP Reading	T5 Reading
4	1M1	1	1M1	1M1	1M2
		2	1M1	1M1	1M1
		3	1M1	1M1	1M1
		4	1M2	1M1	1M1
		5	1M2	1M1	1M2
		6	1M1	1M1	1M1
		7	1M1	1M1	1M1
		8	1M2	1M1	1M1
		9	1M1	1M2	1M2
		10	1M1	1M1	1M1
5	2M1	1	2M1	2M1	2R1.5
		2	2M1	2M1	2M1
		3	2M1	2M1	2M1
		4	2M1	2M1	2L1.5
		5	2M1	2M1	2M1
		6	2M1	2M1	2M1
		7	2R1.5	2M1	2M1
		8	2M1	2M1	2M1
		9	2M1	2M1	2M1
		10	2R1.5	2R1.5	2R1.5
6	2M2	1	2M2	2L1.5	2L1.5
		2	2M2	2M2	2M2
		3	2L1.5	2L1.5	2M2
		4	2M2	2M2	2M2
		5	2M2	2M2	2M2
		6	2L1.5	2M2	2M2
		7	2R1.5	2M2	2M2
		8	2M2	2M2	2M2
		9	2M2	2M2	2L1.5
		10	2M2	2M2	2L1.5

Box number	True shade	Measurement times	CP Reading	SP Reading	T5 Reading
7	4M2	1	4M2	4M2	4R1.5
		2	4M2	4M2	4M2
		3	4R2.5	4M2	4R2.5
		4	4M2	4M2	4M2
		5	4M2	4M2	4M2
		6	4L2.5	4R2.5	4R2.5
		7	4M2	4M2	4M2
		8	4M2	4M2	4R2.5
		9	4R2.5	4R2.5	4M2
		10	4R2.5	4M2	4M2
8	3M1	1	3M1	3M1	3L1.5
		2	3M1	3L1.5	3M1
		3	3M1	3M1	3M1
		4	3L1.5	3M1	3M1
		5	3M1	3M1	3M1
		6	3M1	3M1	3M1
		7	3L1.5	3M1	3M1
		8	3M1	3M1	3M1
		9	3M2	3M1	3M2
		10	3M1	3M2	3M2
9	2M3	1	2L2.5	2M3	2L2.5
		2	2M3	2M3	2M3
		3	2M3	2M3	2M3
		4	2M3	2M3	2M3
		5	2M3	2R2.5	2M3
		6	2L2.5	2M3	2M3
		7	2L2.5	2M3	2M3
		8	2M3	2M3	2M3
		9	2M3	2M3	2M3
		10	2R2.5	2M3	2R2.5

Box number	True shade	Measurement times	CP Reading	SP Reading	T5 Reading
10	3M2	1	3M2	3R1.5	3M1
		2	3R1.5	3M2	3M2
		3	3M2	3M2	3R1.5
		4	3M1	3M2	3M2
		5	3M2	3M2	3M2
		6	3L1.5	3M2	3M2
		7	3M2	3M2	3M2
		8	3M2	3M2	3M2
		9	3L1.5	3L1.5	3L1.5
		10	3M2	3M2	3L1.5

Table 10: Result of all instruments

VITAE

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Educational Attainment

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Doctor of Dental Surgery	Prince of Songkhla University	2019

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List of Publication and Proceeding (If Possible)

Proceeding-Andaman Dental Congress, 18-20 Oct 2023, Phuket, Thailand.