A Comparison of Tooth Color Measurement by Conventional Visual under Artificial Light Source, Intraoral Scanner and Spectrophotometer Methods

การเปรียบเทียบสีฟันด้วยเทคนิคการใช้สายตาจากผู้สังเกตภายใต้แหล่งกำเนิดแสงไฟประดิษฐ์ การใช้เครื่องสแกนในช่องปาก และการใช้เครื่องสเปคโตรโฟโตมิเตอร์

Paweena Sangaseng (ปวีณา สง่าแสง)* Chaivut Prunkngarmpun (ไชยวุฒิ พฤกษ์งามพันธุ์)**
Wilawan Weraarchakul (วิลาวัลย์ วีระอาชากุล)***

ABSTRACT

The aims of study were to compare the difference in color parameters, the accuracy, and the reliability of tooth shade selection under different methods, which are conventional visual under artificial light source, intraoral scanner and spectrophotometer. The ten shade tabs from the Vitapan 3D master shade guide were selected and placed on a gingiva model as one by one between shade tabs from other shade guides. Each shade tab was measured by every methods. Color parameters were described in L* a* b*and color difference (ΔE) according to CIELAB color system. The statistical analysis was set the significant level at $P<0.05$. The Kruskal – Wallis statistic was indicated that there was no significant difference in L* a* b* among three methods. In addition, Spearman correlation were analyzed for validity of visual and intraoral scanner = 0.88 (0.72-1.0) and reliability in three methods = 0.89 (0.57-1.0).

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบความแตกต่างพารามิเตอร์ของสี ความถูกต้องและความเที่ยงของการเลือกสีฟันด้วยวิธีที่แตกต่างกัน ได้แก่การใช้สายตาจากผู้สังเกตภายใต้แหล่งกำเนิดแสงไฟประดิษฐ์ การใช้เครื่องสแกนในช่องปาก และการใช้เครื่องสเปคโตรโฟโตมิเตอร์ โดยใช้แถบสี 10 ชิ้น) จากแถบวัดสีฟันวิตาร์ทรีดีมาสเตอร์ วางบนเหงือกจำลองทีละชิ้นระหว่างแถบสีสองข้างที่มาจากแถบวัดสีแผงอื่น แถบสีทุกชิ้นจะถูกนำมาเลือกสีทุกเทคนิค จากนั้นบันทึกพารามิเตอร์สีโดยใช้ค่า L* a* b* และค่าผลรวมความต่างของสี (ΔE) ตามระบบสีของ CIELAB วิเคราะห์ข้อมูลโดยใช้สถิติ กำหนดนัยสำคัญที่ระดับ 0.05 การวิเคราะห์ครัสคัลและวัลลิสพบว่าทั้งสามเทคนิคมีความแตกต่างของ L* a* b* อย่างไม่มีนัยสำคัญทางสถิติ และเมื่อดูความสัมพันธ์ด้วยการวิเคราะห์สหสัมพันธ์สเปียร์แมน ของพบว่าความถูกต้องของการใช้สายตาจากผู้สังเกตภายใต้แหล่งกำเนิดแสงไฟประดิษฐ์ และเครื่องสแกนในช่องปาก พบว่ามีค่า 0.88 (0.72-1.0) และยังพบว่าทั้งสามเทคนิคมีความสามารถในการวัดซ้ำเท่ากับ 0.89 (0.57-1.0)

Keywords: Intraoral scanner, Spectrophotometer, Tooth color measurement
คำสำคัญ: เครื่องสแกนในช่องปาก เครื่องสเปคโตรโฟโตมิเตอร์ การเลือกสีฟัน

* *Student, Master of Science Program in Prosthodontics, Faculty of Dentistry, Khon Kaen University*
** *Lecturer, Department of Prosthodontiscs, Faculty of Dentistry, Khon Kaen University*
*** *Associate Professor, Department of Community Dentistry, Faculty of Dentistry, Khon Kaen University*

Introduction

Contemporary practice in prosthetic dentistry is to restore dental patients to normal function and esthetics. The esthetic dentistry had become a concerning point in modern dental practice. It is one of the major complications in fixed prosthodontics. Color selection of a restoration or prosthesis is an important clinical procedure to harmonize with the remaining natural dentition (Geary, Kinirons, 1999; Goodacre et al., 2003). There are two steps color selection. Initially, the clinician selects a match color of the restoration intra-orally, then the information of selected color is sent to the dental technician to fabricate the restoration following the selected color.

The value of L*, a*, and b* are used in the CIELAB color system to describe the color according by The Commission International de l'Eclairage (CIE). The L* value indicates lightness, where L* = 0 yields black and L* = 100 indicates perfect white. Negative values of a* correspond to green color, while the opposing positive values indicate red color. Similarly, negative values of b* reflect the blue color, and the opposing positive values indicate the yellow color. This system defines the color space in approximately uniform steps of human color perception. The CIELAB color space (color differences, or ΔE_{ab*}) represents approximately equally perceived shade gradations, an arrangement that makes interpretation of color measurements more meaningful color difference can be expressed as a single numerical value which indicates the size of the color difference but not in what way the colors are different (Fig. 1) (Robertson, 1977). It has been reported that the observers can be expected to detect color differences of 1 unit under standardized laboratory conditions whereas the spectrophotometer reveal 0.48 (Paul et al., 2002). The perceptible color difference ranges from 1 in an in vitro test to 3.7 in an in vivo test, while the acceptable difference ranges from 2.72 in an in vitro study to 6.8 in an in vivo study (Kuehni, Marcus, 1979; Johnston, Kao, 1989; Ragain, Johnston, 2000).

Therefore, an accuracy measurement for intraoral determination of tooth color matching would be beneficial to the dentist (Cal et al., 2004). There are two available methods to assess the color of dental restoration, which are visual and instrumental approach. Visual color measurement is still the most common clinical approach, however it might be negatively influenced by several factors such as type, quality of light and experience of the clinicians (Curd et al., 2006). The different light sources will express different lights and effect the object, so the same object will reveal different colors (Chu et al., 2010). A light source which has 5500 K color temperature is spectrally balanced throughout the visible spectrum is ideal for color measurement (Paravina et al., 2002). Color temperature is related to the standard black body when heated and reported in Kelvin (K) or absolute (0 K 273° C). A light source with a color rendering index (CRI) greater than 90 is recommended for shade matching (Miller, 1994; Sorensen, Torres, 1987). There are many commercial color-corrected ambient lighting which are proper for shade matching for the dental operation field (Paravina, Powers, 2004). The instrumental measurements reveal color by objective can be quantified, and resulted in instant. However, this method is not commonly used in daily clinical practice because of high cost and limited utility (Bentley et al.,1999). This method is also useful in quantifying color differences between specimens with a high precision of repeatability, but there is still some inaccurately (Dozic et al., 2007).

Nowadays, the chairside intraoral scanners can scan a patient's dentition as an alternative to conventional impression and communicate oral information with laboratories. They can be separated in two types. The first one is single image camera record individual image of dentition such as the iTero, E4D and trios. The other one is video camera for example the Lava (Fasbinder, 2013). Some of intraoral scanners are able to capture color of dentition while scanning as well (Johnston, 2009).

Hence, the author aimed to invent an affordable white light box to control the environment and light source to improve the color measurement by conventional visual under artificial light. It was compared to the intraoral scanner method that use 3shape (TRIOS 3 , Copenhagen, Denmark) at Prosthodontics Department, Faculty of Dentistry, Khon Kaen University. Both techniques were control with Vita Easyshade® V (Vident, Brea, California, USA). All methods were measure reliability of their technique.

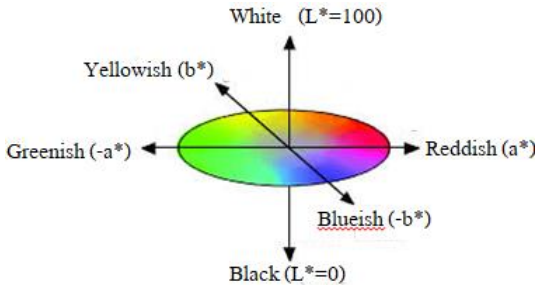


Figure 1 The CIELAB color space

Objectives of the study

The aims of study were to compare the difference in color parameters, the accuracy, and the reliability of tooth shade selection under different methods, which are conventional visual under artificial light source, intraoral scanner and spectrophotometer.

Methodology

This study was an *in vitro* study which was simulated clinically relevant conditions. An observer in this study was a dentist, who was test with the Fransworth – Munsell 100 hue test to rule out inherent color deficiencies and had accuracy and validity in tooth color selection by using examination test. The tooth color measurement was done in three techniques: conventional visual under artificial light source, intraoral scanner and spectrophotometer. The processes were as follows:

Specimen preparation

The experimental shade model was fabricated by placing ten shade tabs (1M2, 2L1.5, 2M2, 2R1.5, 3L1.5, 3M2, 3R1.5, 4L1.5, 4M2 and 4R1.5) from the Vitapan 3D master shade guide on a gingiva silicone model as one by one into the middle blank, the left and right teeth were same tooth color shade tab from others shade guide as shown in figure 2. All the shade tabs were cleaned with an ultrasonic cleaner for 15 minutes. The gingiva model was mount on black cardboard. The experimental shade tabs were blinded in the alphabet from A to J.

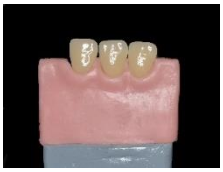


Figure 2 The experimental shade model which simulated clinically relevant conditions.

Another full set of shade tabs from Vitapan 3D master shade guide as shown in figure 3 (Vita Zahnfabrik, Bad Sackingen, Germany) were cleaned with an ultrasonic cleaner for 15 minutes before experiment then converted to L* a* b* by spectrophotometer and recorded the data for creating the color library.

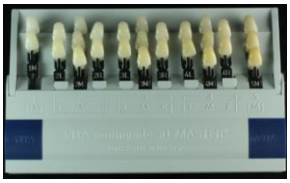
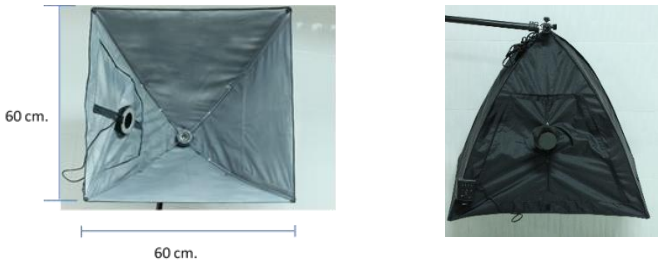


Figure 3 The Vitapan 3D master shade guide.

Conventional visual under artificial light source method

All specimens were set vertically at the eye level in the white light box (Fig. 4) with neutral grey walls and a ring flash (Aputure®, Amaran Inc, China) was mounted inside cover box. The lamp was recommended to use in 20 - centimeter distance from the specimen (Pizzamiglio, 1991). The light temperature was selected at 5500 K which is a suitable light for tooth color matching and CRI more than 95 which was test with light measurement instruments (CL-500A, Konica Minolta, Inc., Japan). The another set of Vitapan 3D master shade guide was used for matching the color to the middle tab in the gingival model. While selecting the color, place the selected shade tab besides the middle tab (Fig.5). The observer was given to select the shade of each specimen in three minutes at the center of tooth (Miller, 1994). To avoid eye fatigue, the study was designed to give a five-minute break after one shade selection procedure and a 20 minute break after every four selection procedures. A separated shade guide was used with each test specimen or person, and replaced shade tabs in the shade guide's holder after completed shade measurement (Alshiddi, Richards, 2015). The measurement data was recorded by using shade tab code number, then converted data to L*, a*, b* value by using the color library of each shade tab which was done in specimen preparation method.



A B

Figure 4 The internal of White light box (A), the external of White light box (B).

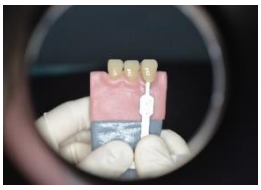


Figure 5 The tooth color measurement by visual method in the White light box.

Intraoral scanner method

The 3Shape intraoral scanner (TRIOS 3, Copenhagen, Denmark) (fig. 6) was used to scan on the shade tab for creating 3D image by scanning from incisal to buccal surface of the shade tab. All of shade tabs were placed on a background for preventing the possibility of visual disruption. The intraoral scanner was calibrated in every after ten scanning times. The shade tab colors were recorded in three times per one specimen immediately at middle one third of the tooth. The data was converted to the L*, a*, b* by using L*a*b* library and averaged L*, a*, b* value.

Figure 6 The 3Shape cart is used in tooth color measure.

The spectrophotometer method

Vita Easyshade is a portable clinical spectrophotometer (Vita Easyshade® V, Vident, Brea, California, USA) which used to identify the tooth shade (Fig.7). The probe tip of spectrophotometer was held 90º to contact the middle one third of the tooth for measuring the color of shade tabs. The measurement of this method was repeated three times per each shade tab and recorded to averaged L*, a*, b*. The device was recalibrated in every after ten scanning times.

Figure 7 The Vita Easyshade® V.

Descriptive statistic demonstrated median and interquartile range of L*, a*, b* which collected from three different technique. The color difference (ΔE) were compared between conventional visual under artificial light source and spectrophotometer, and intraoral scanner and spectrophotometer using the equation as follow (Robertson, 1977) :

$$\Delta E^*_{vs} = \sqrt{(L^*_v - L^*_s)^2 + (a^*_v - a^*_s)^2 + (b^*_v - b^*_s)^2}$$

V is a conventional visual method. This data will change if use a deference device.

S is spectrophotometer.

All data were used statistical analysis program (SPSS 20.0, SPSS, Munich, Germany). Analytical statistic were compared median of the descriptive data by using Kruskal – Wallis statistic which was set significant level at $P < 0.05$. Moreover, Spearman Rank correlation were used to determine accuracy and reliability of each parameter.

Results

The median and interquartile range of the L* of conventional visual under artificial light source, intraoral scanner and spectrophotometer methods were 72.47±9.52, 74.21±9.91 and 72.54±9.81, respectively. The a* were 1.71±2.10, 1.54±1.81 and 1.94±2.10, respectively and the b* were 17.13±5.09, 19.69±5.96 and 17.18±2.63, respectively as shown in table 1. The data was abnormal distribution, the Kruskal-Wallis statistic was used and analysis revealed no significant differences in L*, a* and *b from different color measurement methods ($p>0.05$) as shown in figure 8-10.

The highest ΔE value among the three methods is ΔE the between conventional visual under artificial light source and spectrophotometer methods that measured on 4L1.5 shade (8.65) at first time measurement. The lowest ΔE values is conventional visual and spectrophotometer methods at second time on 1M2 shade (0.48) as shown in table 2.

The analysis of L*, a* and b* in the conventional visual and intraoral scanner methods were strongly positive correlated with the spectrophotometer method (Spearman Rank's correlation $r_{Lv} = 1$, $r_{av} = 0.93$, $r_{bV} = 0.78$, $r_{LI} = 0.95$, $r_{aI} = 0.72$, $r_{bI} = 0.92$, $p< 0.05$) as shown in table 3. The reliability of L* value in the conventional visual under artificial light source is 0.97, intraoral scanner is 0.91 and spectrophotometer is 0.98. The a* are 0.88, 0.96 and 1, respectively. The b* are 0.82, 0.57 and 0.90, respectively as shown in table 4.

Table 1 Descriptive of color values in by three methods

Color values	Technique	N	Median	Interquartile Range	Minimum	Maximum
L	Visual	10	72.47	9.56	68.35	81.90
	Intraoral scanner	10	74.21	9.91	68.17	82.60
	Spectrophotometer	10	72.54	9.81	67.70	83.19
a	Visual	10	1.71	2.10	0.17	3.70
	Intraoral scanner	10	1.54	1.81	0.13	2.58
	Spectrophotometer	10	1.94	2.10	0.07	4.0
b	Visual	10	17.13	5.09	14.37	23.97
	Intraoral scanner	10	19.69	5.96	16.38	27.23
	Spectrophotometer	10	17.18	2.63	15.10	24.20

Table 2 CIELAB color differences (ΔE) between conventional visual under artificial light source and spectrophotometer, intraoral scanner and spectrophotometer.

Shade tab	VS1	VS2	IS1	IS2
1M2	7.51	0.48	0.82	0.48
2L1.5	2.92	1.88	2.34	0.61
2M2	0.68	1.6	8.07	1.77
2R1.5	0.71	0.7	1.84	1.16
3L1.5	0.40	0.63	3.13	1.91
3M2	1.12	1.02	5.19	6.43
4L1.5	8.65	1.08	2.61	5.62
4M2	0.49	0.55	3.55	3.41
4R1.5	0.95	0.91	6.83	6.81

VS1: ΔE between conventional visual and spectrophotometer in first test.

VS2:ΔE between conventional visual and spectrophotometer in second test.

IS1: ΔE between intraoral scanner and conventional visual in first test,

IS2: ΔE between intraoral scanner and conventional visual in second test.

Table 3 Spearman correlation of validity of L*, a*, b by visual under artificial light source and intraoral scanner.

		Correlation coefficient	p-value
L* value in visual	L* value in spectrophotometer	1.00	<0.001*
a* value in visual	a* value in spectrophotometer	0.93	0.001*
b* value in visual	b* value in spectrophotometer	0.78	0.170
L* value in intraoral	L* value in spectrophotometer	0.95	0.002*
a* value in intraoral	a* value in spectrophotometer	0.72	0.002*
b* value in intraoral	b* value in spectrophotometer	0.92	0.316

**Statistical significant at P-value < .005*

Table 4 Spearman correlation of reliability of L*, a*, b* values between visual under artificial light source, intraoral scanner and spectrophotometer.

First test	Second test	Correlation coefficient	p-value
L* value in visual	L* value in visual	0.97	<0.001*
L* value in intraoral scanner	L* value in intraoral scanner	0.91	<0.001*
L* value in spectrophotometer	L* value in spectrophotometer	0.98	<0.001*
a* value in visual in	a* value in visual in	0.88	0.001*

Table 4 Spearman correlation of reliability of L*, a*, b* values between visual under artificial light source, intraoral scanner and spectrophotometer. (Cont.)

First test	Second test	Correlation coefficient	p-value
a* value in intraoral scanner	a* value in intraoral scanner	0.96	<0.001*
a* value in spectrophotometer	a* value in spectrophotometer	1.00	<0.001*
b* value in visual	b* value in visual	0.82	0.004*
b* value in intraoral scanner	b* value in intraoral scanner	0.57	0.089
b* value in spectrophotometer	b* value in spectrophotometer	0.90	<0.001*

**Statistical significant at P-value < .005*

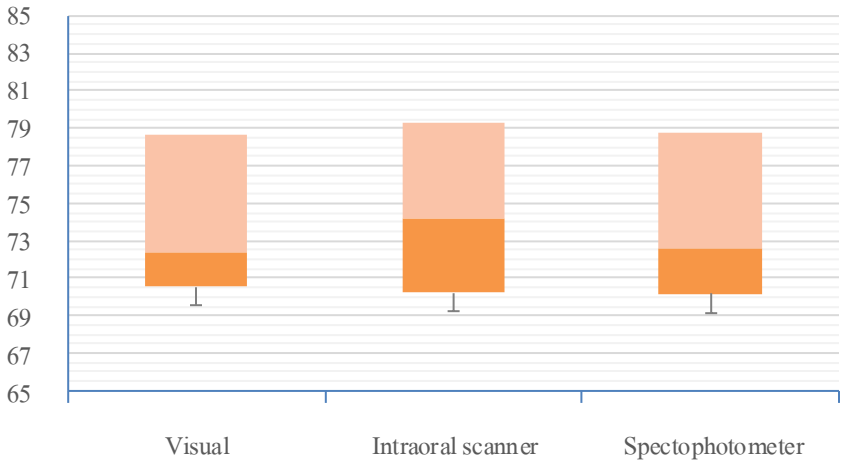


Figure 8 The L* was analyzed by the Kruskal – wallis statistic in three methods (p-value = 0.95).

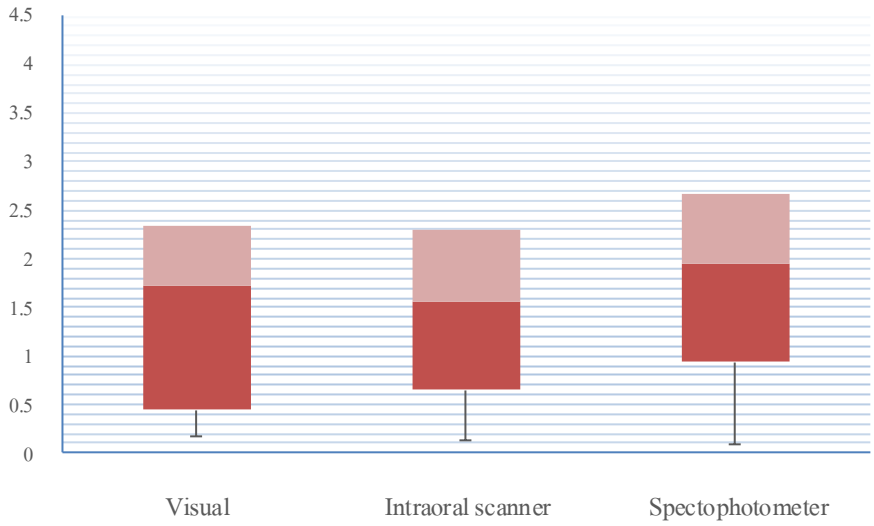


Figure 9 The a* was analyzed by the Kruskal – wallis statistic in three methods (p-value = 0.73).

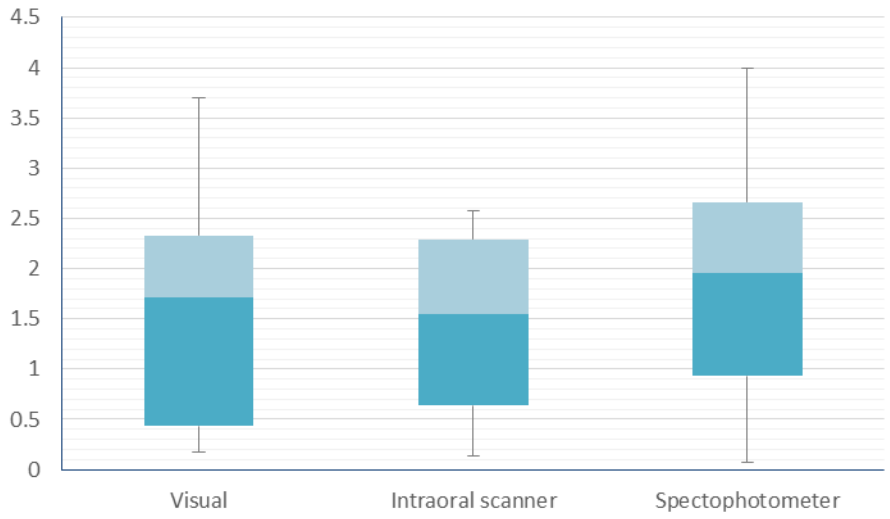


Figure 10 The b* was analyzed by the Kruskal – wallis statistic in three methods (p-value = 0.15).

Discussion

This study evaluated the accuracy, repeatability and linear relationship of the conventional visual under artificial light source, intraoral scanner and spectrophotometer method by measuring the *L*a*b** of ten shade guide tabs. Since there were no standardized methods to evaluate the shade-detecting function of conventional visual under artificial light source and intraoral scanner measurement, the color value from these two methods were converted to *L*a*b** by using the spectrophotometer, the spectrophotometer converted all the shades in Vita 3D master. There was high degree of correlation among three methods. Whereas the color differences (ΔE) of shade tabs in each measurement varied from 0.48 to 8.65. The ΔE between conventional visual under artificial light source and spectrophotometer was lower than 1. Moreover, ΔE of conventional visual method was lower than that of intraoral scanner. However, the highest ΔE was revealed in the conventional visual under artificial light source method.

Previous study showed an excellent repeatability, both for the clinical spectrophotometer (Easy shade® V) and the laboratory spectrophotometer (PSD1000) (Corciolani, Vichi, 2006). The L *, a* and b* of visual and intraoral scanner measurement method in this study showed strong accuracy comparing to the Easy shade® V which acts as control. Likewise, the validation test demonstrated no significant differences among the new Trios color system, the conventional visual method and the MHT Spectro Shade™ spectrophotometric systems (Gotfredsen et al., 2015). Although the intraoral scanner showed good accuracy of measurement, it still required advances in color image acquisition and data processing of the digital scanner to become a reliable method for shade selection in dentistry (Cal, et al., 2006). From this study showed no statistical difference among three methods, due to the controlled environment using white light box; that provided CRI more than 90 and color temperature at 5500 K. Not only the environment could be controlled, but also the observer who had no visual color deficiency and was experienced and was capable in color matching. During the color matching procedure, the period of color matching was limited within three minutes and also provided relaxation time in order to prevent the eye fatigue. Moreover, this experiment was

done by only one observer so that among the angle and position of equipment was maintained for repeatable measurements.

This study showed a high repeatability among three color measurement methods except the b* value of intraoral scanner, it was slightly lower than that of other methods. Despite the fact that, the spectrophotometer was aligned in parallel and closed contact to the labial surface of each tab; however, an intraoral scanner captured the entire labial surface from multiple angles, but a colorimeter measures the color directly from small regions in the individual teeth. The scanning tip of an intraoral scanner was also different from the standardized sizes of industrial shade-detecting devices and the measuring tip of spectrophotometers. Entire tooth surface measurement devices provide a detailed color map of the gingival, body, and incisal regions as well as an average shade value (Yoon et al., 2016).

In real clinical situation, the conventional visual under artificial light source may have the unpredictable accuracy and reliability due to the surrounding light was not well-controlled in CRI and color temperature. Moreover the observer may not rely on the color matching protocol, for example, the eye level of observer should be the same as the level of the measured specimen, the observer should stare on the specimen within limited period to prevent eye fatigue. One should select the color treating in that visit and should be qualified by visual color deficiency test. Additionally, one must follow the instruction of using Vita 3D master shade guide. By the way, the patient should be advised to provide the appropriate environment by shedding the lipstick. However, this study was an *in vitro* experimental study, the exact clinical situation cannot be stimulated. Hence, it needs further clinical study to claim the capacity of each color matching approach.

Conclusion

It can be concluded that the color measurements obtained by the conventional visual under artificial light source and intraoral scanner were corresponded with spectrophotometer measurement, regarding L*, a* and b*. This finding proved the color matching capability of the intraoral scanner. However, the conventional visual is still effective method within controlled environment and trained observer. The innovated white light box is an affordable tool for color selection which had high reliability in controlling the environment. It would provide more practical and consistent tooth color measurement method in clinics and to transmit this information to dental laboratories.

Acknowledgement

This study was granted by Faculty of Dentistry, Khon Kaen University, Thailand.

References

Alshiddi IF, Richards LC. A comparison of conventional visual and spectrophotometric shade taking by trained and untrained dental students. Australian dental journal 2015; 60(2):176-81.

Bentley C, Leonard RH, Nelson CF, Bentley SA. Quantitation of vital bleaching by computer analysis of photographic images. Journal of the American Dental Association 1999; 130(6): 809-16.

Cal E, Sonugelen M, Guneri P, Kesercioglu A, Kose T. Application of a digital technique in evaluating the reliability of shade guides. Journal of oral rehabilitation 2004; 31(5): 483-91.

Cal E, Guneri P, Kose T. Comparison of digital and spectrophotometric measurements of colour shade guides. Journal of oral rehabilitation 2006; 33(3): 221-8.

Chu SJ, Devigus A, Paravina RD, Mieleszko AJ. Elements Affecting Color. Fundanentals of color: shade matching and communication in esthetic dentistry 2ed. China: Quintessence; 2010. p. 24-5.

Corciolani G, Vichi A. Repeatability of colour reading with a clinical and a laboratory spectrophotometer. International Dentistry South Africa 2006; 8: 62-70.

Curd FM, Jasinevicius TR, Graves A, Cox V, Sadan A. Comparison of the shade matching ability of dental students using two light sources. Journal of Prosthetic Dentistry 2006; 96(6): 391-6.

Dozic A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color-measuring devices. Journal of Prosthodontics 2007; 16(2): 93-100.

Fasbinder DJ. Computerized technology for restorative dentistry. American journal of dentistry 2013; 26(3): 115-20.

Geary JL, Kinirons MJ. Colour perception of laboratory-fired samples of body-coloured ceramic. Journal of dentistry 1999; 27(2): 145-8.

Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JYK. Clinical complications in fixed prosthodontics. Journal of Prosthetic Dentistry 2003; 90(1): 31-41.

Gotfredsen K GM, Ben Brahem E, Hosseini M, Petkov M, et al. Effectiveness of Shade Measurements Using a Scanning and Computer Software System: a Pilot Study. International Journal of Oral and Dental Health 2015.

Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. Journal of dental research 1989; 68(5): 819-22.

Johnston WM. Color measurement in dentistry. Journal of dentistry 2009; 37 Suppl 1: e2-6.

Kuehni RG, Marcus RT. An Experiment in Visual Scaling of Small Color Difference. Color Research & Application 1979; 4: 83-91.

Miller LL. Shade selection. Journal of esthetic dentistry. 1994; 6(2): 47-60.

Paravina RD, Powers JM, Fay RM. Color comparison of two shade guides. The International journal of prosthodontics 2002; 15(1): 73-8.

Paravina RD, Powers JM. Color matching. Esthetic color training in dentistry. St. Louis: Mosby; 2004. p. 139-80.

Paul S, Peter A, Pietrobon N, Hammerle CH. Visual and spectrophotometric shade analysis of human teeth. Journal of dental research 2002; 81(8): 578-82.

Pizzamiglio E. A color selection technique. The Journal of prosthetic dentistry 1991; 66(5): 592-6.

Ragain JC, Johnston WM. Color Acceptance of Direct Dental Restorative Materials by Human Observers. Color Research & Application 2000; 25(4): 279-85

Robertson AR. 1976 Color-Difference Formulae. Color Research & Application 1977; 2(1): 7-19.

Sorensen JA, Torres TJ. Improved color matching of metal-ceramic restorations. Part I: A systematic method for shade determination. The Journal of prosthetic dentistry 1987; 58(2): 133-9.

Yoon HI, Bae JW, Park JM, Chun YS, Kim MA, Kim M. A Study on Possibility of Clinical Application for Color Measurements of Shade Guides Using an Intraoral Digital Scanner. Journal of Prosthodontics 2016.