Original Articles

# The Study of Difference in Clinical Tooth Color Measurement among Visual Method Using White Light Box, Intraoral Scanner and Spectrophotometer

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## Abstract

The aims of study were to compare visual method using white light box, intraoral scanner and spectrophotometer in clinical tooth color measurement and to determine the reliability of tooth shade selection among visual method using white light box, intraoral scanner and spectrophotometer. Forty maxillary right central incisors and canines of 18 – 40 years old volunteers which no pathologic and restoration teeth were included in this study. Each tooth shade was measured six times, twice for each method with at least one day apart. Tooth color measurements were described in L* a* b*and tooth color difference (ΔE) according to CIELAB color system. In this system 'L' is a lightness coordinate, 'a' is a redness-greenness coordinate and 'b' is a yellowness-blueness coordinate. The Kruskal – Wallis statistic was used to verify the significant difference of average color difference (ΔE) at $P<0.05$. Results indicated significance difference in L* a* b* among all three methods. The average color difference (ΔE) of visual method were higher than the intraoral scanner method on both maxillary central incisor (8.05 versus 4.99) and canine (9.5 versus 4.95). Average reliability of visual method was 0.63 (range 0.56-0.69) in maxillary right central incisor and 0.63 (range 0.61-0.53) in canine while average reliability of intraoral scanner method was 0.70 (range 0.60-0.76) in maxillary right central incisor and 0.82 (range 0.63-0.91) in canine. Average reliability of tooth shade selection using spectrophotometer was highest at 0.87 (range 0.70-0.96) in maxillary right central incisor and 0.88 (range 0.76-0.95) in canine. In conclusion, average color difference (ΔE) from visual method is higher than intraoral scanner. Tooth color measurement using spectrophotometer is the most reliable method followed by intraoral scanner and visual method is the lowest.

**Keywords:** Intraoral scanner, spectrophotometer, tooth color measurement

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## Introduction

Contemporary practice in prosthetic dentistry is to restore the patient's dentition to normal function and esthetics. Esthetic dentistry had become a concern in modern dental practice. 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.[1,2] 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 difference, or $\Delta E_{ab*}$) 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 difference.[3] It has been reported that average observers can detect color difference of 1 unit under standardized laboratory conditions whereas the spectrophotometer reveal 0.48.[4] 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.[5-7]

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 and quality of light and experience of clinicians.[8] Different light sources will express difference lights and effect the object causing the same object to appeared different colors.[9] The ideal temperature of light source for tooth color selection is 5500 K which is spectrally balanced throughout the visible spectrum. Color rendering index (CRI) is another important aspect of light which should be greater than 90. Such light source is recommended for shade matching.[10] There are many commercial products of color-corrected ambient lighting which are suitable for shade matching in the dental operation field.[11] Instrumental measurements reveal color by quantified the object and the shade result is shown instantly.[12] There are many instruments those can assist in shade matching which are colorimeter, digital cameras as filter colorimeter, spectrophotometer and intraoral scanner.[13,14] Spectrophotometers such as Spectroshade, Easy shade, and Crystaleye are the most accurate color measurement. They are differed in shade measurement area and cost.[13,15]

Nowadays, the chairside intraoral scanners can be used as an alternative to conventional impression and communicate oral information with laboratories. They can be separated in two types. The first type is single image camera recording individual image of dentition such as the iTero, E4D and Trios. The Trios camera records images at a rapid rate and able to capture color of dentition while scanning. The other is a video camera for example the Lava.[16] However, this method is not commonly used in daily clinical practice because of high cost and inconsistency.[17] Hence, the author aimed to compare the difference in color parameters, and the reliability of color measurement in clinical situation between conventional visual method by using white light box, intraoral scanner method that use 3 shapes (TRIOS 3, Copenhagen, Denmark), and spectrophotometer (Vita Easyshade® V, Vident, Brea, California, USA) which was high reliable and accurate[15,18] at the Prosthodontics Department, Faculty of Dentistry, Khon Kaen University.

## Materials and Methods

This study evaluated the three color measurements by L*a*b* value of maxillary right central incisor and canine in 18 – 40 years old of 40 participants. The Ethical Committee in Human Research of Khon Kaen University approved of the research protocol (HE602274). There were exclusion criteria including the pathological discolor tooth, the presence of carious lesion, the non-vital tooth, the presence of crowns or veneers related to the tooth to be matched, the patient with smoking habit, the patient that previously undergone whitening procedures, and the patient undergone orthodontic treatment at the time of the shade determination. An observer in this study was a dentist who was tested with the Fransworth – Munsell 100 hue test to rule out inherent color deficiencies and had accuracy and examination test to test validity in tooth color selection. Since the results of the color analysis of shade guides in the same environment are different from each other. In other words, the shade guides analyzed in the study are not identical with each other.[19,20] Therefore, a new full set of shade tabs from Vitapan 3D master shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) which was made in August 2016 were cleaned with an ultrasonic cleaner for 15 minutes before experiment then converted the shade tab to L* a* b* by spectrophotometer and recorded the data for creating the color library in this study. Participants received teeth polishing with the pumice before all tooth color selection procedure; Visual Method Using White Light Box, Intraoral Scanner and Spectrophotometer, respectively. Then all of procedures were repeated again in the same patient on another day for reliability test.

### Visual method using white light box

The white light box is set to be a constant environment which has neutral grey cloth as walls and mounted ring light in side (Aputure®, Amaran Inc, China). The ring light was selected because it has light temperature at 5500 K and CRI more than 95 tested with CL-500 light measurement instruments (Konica Minolta, Inc., Japan) (Fig. 1A, 1B). The participant position was set in the same level of the examiner's eyes and the distance of white light box was fixed at 20 centimeters (Fig. 1C, 1D).[21] Participants were suggested to keep their teeth wet by tongue licking to get accurate measurement.

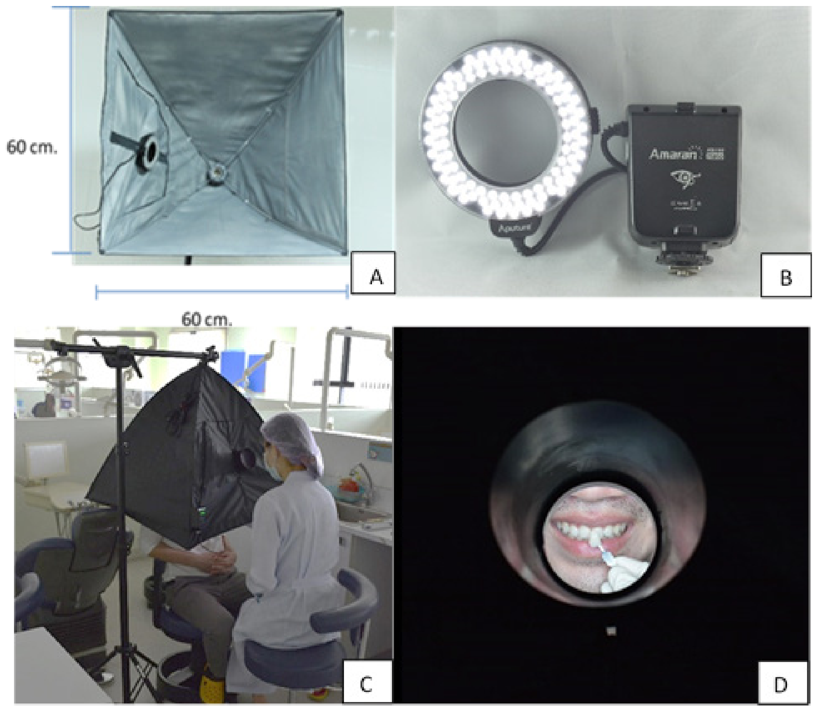


*Figure 1* *The internal of White light box (A), The ring light (B). The tooth color was selected by the observer with the conventional visual method using white light box (C). The tooth color when the observer looked through the white light box (D).*

To avoid eyes fatigue, the shade of each tooth was selected by the observer within 3 minutes at the center of tooth.[10] Every two shade selection procedures was given a five-minute break and 20 minutes break was given after every four selection procedures. The measurement data was recorded by using shade tab code number, then data was converted to L*, a*, b* value by using the color library.

**Intraoral scanner method**

Prior to measurement, the intraoral scanner was calibrated according to the manufacturer's instructions. A procedure was begun by tooth scaning which the scanner tip need to be stabilized until the blue overlay clears; slowly move the scanner 90 degrees from occlusal to buccal of maxillary right incisor and canine (Fig.2). The scanner was also recalibrated after every ten consecutive scans for standardization. The participant's tooth colors were recorded three times per one tooth continuously at the center of the tooth. The data were converted to the L*, a*, b* by using L*a*b* library and average L*, a*, b* values.

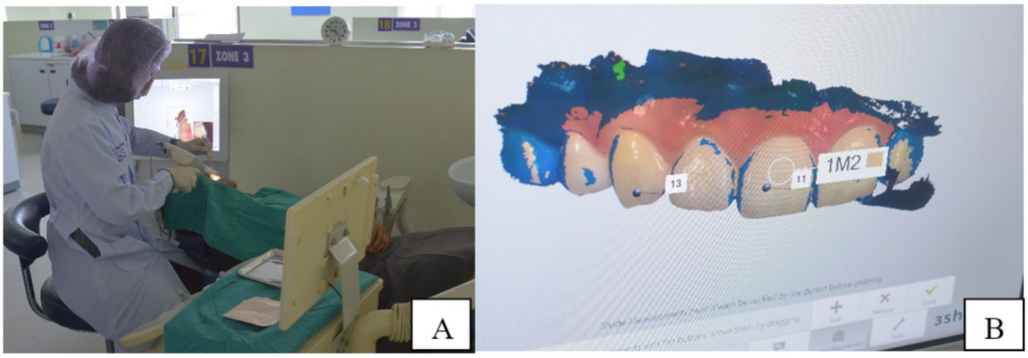


*Figure 2* *The intraoral scanner was used by the observer to do the tooth color measurement (A). A scanned picture and tooth color were shown in the monitor. (B)*

**Spectrophotometer method**

The probe tip of spectrophotometer was held 90° contact the middle third of the tooth (Fig. 3). The measurement of this method was repeated three times per each tooth and recorded to average L*, a*, b*. The device was recalibrated after every after ten scans.

*Figure 3* *The spectrophotometer was used by the observer to do the tooth color selection.*

Descriptive statistic demonstrated median and interquartile range of L*, a*, b* which collected from three different techniques. The color difference (ΔE) were compared between conventional visual method under artificial light source and spectrophotometer, and intraoral scanner and spectrophotometer using the equation as follow[3] :

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

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

S is spectrophotometer.

All analysis were done using statistical analysis program SPSS 19.0. Analytical statistic were used to compare median of the descriptive data by using Kruskal – Wallis statistic which was set significant level at $p<0.05$. If any of the data was significant, the Mann-Whitney U statistic will be used to identify which value was difference. Moreover, Spearman Rank correlation were used to determine reliability of each parameter.

## Results

The median and interquartile range of the L* of visual method using white light box, intraoral scanner, and spectrophotometer methods for maxillary right incisor were 77.77±2.60 82.6±0.27, and 83.11±5.54, respectively. The a* were 0.60±1.02, 0.13±0.06, and -0.98±1.70, respectively and the b* were 14.50±3.69, 16.70±0.00, and 22.77±5.96, respectively. While the L* of visual method using white light box, intraoral scanner, and spectrophotometer for maxillary right canine were 73.86±7.16, 78.18±5.50 and 78.19±6.21, respectively. The a* were 2.00±1.24, 1.09±0.13, and 1.09±0.78, respectively and the b* were 19.84±7.12, 25.53±7.00 and 26.56±7.02, respectively as shown in Table 1. The data was tested for normal distribution by Shapiro-Wilk Test and the result showed that it was not normally distributed. The result from Kruskal-Wallis test revealed that there was significantly difference in L*, a* and *b from different color measurement methods ($p$=0.001). Then the multiple comparison by Mann Whitney U test revealed that there were significantly differences in L* a* and b* value of maxillary right central incisors and canine when compared the visual method using white light box and the spectrophotometer ($p$=0.001). There were significantly differences in L* a* and b* value of maxillary right central incisors and canine when compared visual method using white light box compared to intraoral scanner ($p$=0.001). On the contrary, the intraoral scanner method compared to the spectrophotometer method revealed that there were no statistically significant differences between L* value of maxillary right central incisors and L* a* b* value of the maxillary right canines ($p>0.05$) while the a* and b* value of maxillary right central incisors revealed the significant difference in each method ($p$=0.001).

The color differences of maxillary right central incisor and canine were revealed in figure 4. It was indicated that mean color difference between visual method using white light box and spectrophotometer was higher than the color difference between intraoral scanner and spectrophotometer.

The reliability of tooth color measurement in three methods on maxillary right central incisor was estimated by Spearman Rank's correlation as shown in figure 5. It was indicated that the mean L* a* b*of visual method using white light box method was 0.63 and the lowest correlation was shown in L*value = 0.56 and the highest correlation was revealed in a* value = 0.69. The mean L* a* b* of the intraoral scanner method was 0.68 and the lowest correlation was shown in b*value = 0.55 and the highest correlation was revealed in a* value = 0.76. The mean L* a* b* of the spectrophotometer method was 0.86 and the lowest correlation was shown in L*value = 0.67 and the highest correlation was revealed in a* and b*value = 0.96. The maxillary right canine was indicated that the mean L* a* b* of visual method using white light box was 0.62 and the lowest correlation was shown in b*value = 0.53 and the highest correlation was revealed in a* value = 0.72. The mean L* a* b* of the intraoral scanner method was 0.81 and the lowest correlation was shown in b* value = 0.63 and the highest correlation was revealed in a* and b* value = 0.91. The mean L* a* b* of the spectrophotometer method was 0.88 and the lowest correlation was shown in L*value = 0.76 and the highest correlation was revealed in b*value = 0.97.

*Table 1* The comparison of color values on maxillary right central incisors and maxillary right canines by three methods.

| Color values | Technique | N | Median | Interquartile Range | Minimum | Maximum | Kruskal-Wallis *P*-value |
|---|---|---|---|---|---|---|---|
| L1 | Visual method | 40 | 77.77 | 2.60 | 71.57 | 84.20 | |
| | Intraoral scanner | 40 | 82.60 | 0.27 | 72.01 | 82.60 | <0.0001 |
| | Spectrophotometer | 40 | 83.11 | 5.54 | 70.24 | 89.87 | |
| a1 | Visual method | 40 | 0.60 | 1.02 | -0.8 | 2.07 | |
| | Intraoral scanner | 40 | 0.13 | 0.06 | 0.13 | 1.85 | <0.0001 |
| | Spectrophotometer | 40 | -0.98 | 1.70 | -2.76 | 2.87 | |
| b1 | Visual method | 40 | 14.5 | 3.69 | 11.57 | 26.29 | |
| | Intraoral scanner | 40 | 16.7 | 0.0 | 16.47 | 27.38 | <0.0001 |
| | Spectrophotometer | 40 | 22.77 | 5.96 | 9.2 | 28.92 | |
| L3 | Visual method | 40 | 73.86 | 7.16 | 64.3 | 79.55 | |
| | Intraoral scanner | 40 | 78.18 | 5.50 | 66.12 | 82.60 | <0.0001 |
| | Spectrophotometer | 40 | 78.19 | 6.21 | 68.69 | 85.10 | |
| a3 | Visual method | 40 | 2.0 | 1.24 | 0.17 | 3.70 | |
| | Intraoral scanner | 40 | 1.09 | 0.97 | 0.13 | 2.97 | <0.0001 |
| | Spectrophotometer | 40 | 1.09 | 0.78 | -2.12 | 4.06 | |
| b3 | Visual method | 40 | 19.84 | 7.12 | 12.57 | 27.55 | |
| | Intraoral scanner | 40 | 25.53 | 7 | 16.68 | 31 | <0.0001 |
| | Spectrophotometer | 40 | 26.56 | 7.02 | 13.7 | 33.82 | |

*L1 = L* value of maxillary right central incisor*
*a1 = a* value of maxillary right central incisor*
*b1= b* value of maxillary right central incisor*
*L3 = L* value of maxillary right canine*
*a3 = a* value of maxillary right canine*
*b3= b* value of maxillary right canine*

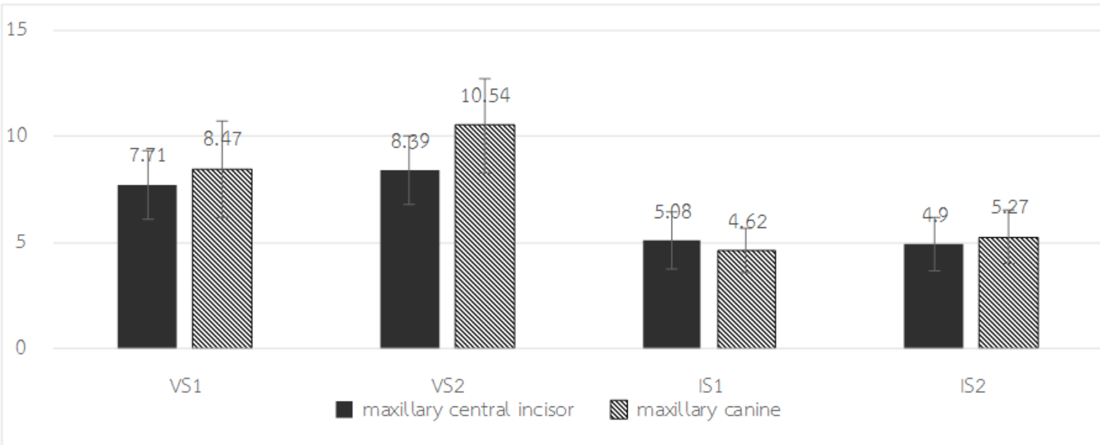


***Figure 4*** *CIELAB color difference (ΔE) of maxillary central incisor and canine between visual method using white light box and spectrophotometer and between intraoral scanner and spectrophotometer.*

VS1: *ΔE between visual method using white light box and spectrophotometer in first test*
VS2: *ΔE between visual method using white light box and spectrophotometer in second test*
IS1: *ΔE between intraoral scanner and visual method using white light box in first test*
IS2: *ΔE between intraoral scanner and visual method using white light box in second test*

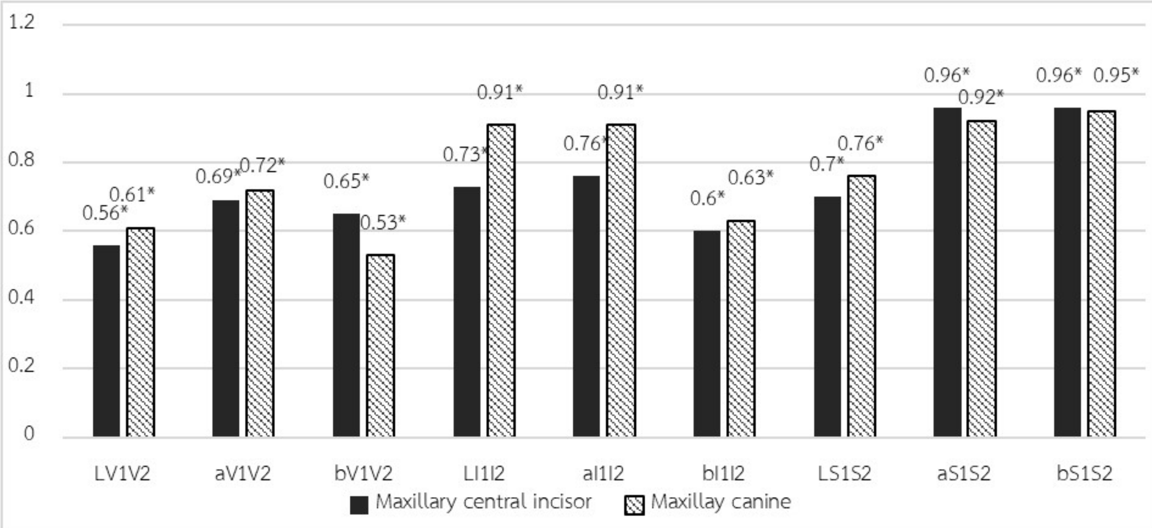


*Figure 5* *The spearman correlation reliability of L*, a*, b* values of maxillary right central incisor and canine among tooth color measurements of visual method using white light box and between intraoral scanner and spectrophotometer method.*

*LV1V2: L*value of visual method in first test and second test*

*aV1V2: a* value of visual method in first test and second test*

*bV1V2: b* value of visual method in first test and second test*

*LI1I2: L*value of intraoral scanner method in first test and second test*

*aI1I2: a*value of intraoral scanner method in first test and second test*

*LS1S2: L* value of spectrophotometer method in first test and second test*

*aS1S2: a* value of spectrophotometer method in first test and second test*

*bS1S2: b* value of spectrophotometer method in first test and second test*

** statistical significance at p-value < 0.05*

## Discussion

Since there were no standard methods to evaluate the shade-detecting function of visual method and intraoral scanner measurement. The color value from these two methods were converted to L*a*b* value by using the spectrophotometer to correspond with shade tab of the Vitapan 3D master in visual measurement.

Previous study demonstrated the Vitapan 3D-Master shade guide has more uniform color space than other systems.[22] In addition, the reliability of commercial shade guides that produced by the same manufacturer should be re-evaluated.[19] Hence, the L*a*b* color value library in this study was converted from the Vita 3D master which was tested by the Vita Easyshade V®. There were studies that proved the excellent repeatability of Vita Easyshade as well as the laboratory spectrophotometer (PSD1000).[15,23] Although the Vitapan 3D master shade guide consist of 26 shade tabs; this system does not cover all range of normal teeth color which leads to limitation of visual measurement. However, this method is still commonly used.

An earlier *in vitro* study comparing L* a* and b* which use shade tab as a specimen found no statistically difference among intraoral scanner, spectrophotometer and conventional visual method using the white light box was controlled environment. The study showed visual method and intraoral scanner measurement were strongly accurate compared to the Vita Easyshade® V.[24] However, the result was different in this clinical study, as the conventional visual method presented the lower accuracy and reliability than the intraoral scanner method. The a* and b* value obtained from maxillary right central incisors revealed the significant difference in each method although the management of the confounding factors was the same with *in vitro* study such as, (1) the environment which well controlled by white light box, (2) the experienced observer who was capable in color matching, (3) the relaxation time which was provided to avoid the observers eye fatigue and visual angle of the observer might be deceptive. However, there were several problems when clinical tooth color selection was performed. The tooth characteristic causes the difficulty for shade selection, such as, the double layering effect which caused by enamel translucency and dentin opacity, a curved tooth surface, and non-homogenous color.[25] Other factors that affected human color perception such as human emotion which can cause limitations in traditional visual shade selection.[26]

For the color accuracy evaluation, the mean color difference of visual method using white light box method on both maxillary right central incisor and canine (8.05 and 9.50) were higher than the intraoral scanner method (4.99 and 4.95). The color difference of both methods was higher than the perceptible color difference ($\Delta E = 3.7$). However, the intraoral scanner method was still in clinical acceptable difference range ($\Delta E = 6.8$).[5-7] The accuracy of a* and b* values by the intraoral scanner was slightly lower especially on maxillary central incisor. The data of the Trios intraoral scanner revealed as positive a*value and negative b*values which exhibited more redness and less yellowness hue than the Vita Easyshade® V while the visual method using white light box was not corresponding with the spectrophotometer in all value. The L*value of visual method was lower than the spectrophotometer which can be interpreted that the values of the visual method appeared to be darker than the Vita Easyshade® V while the a* and b* values were too varied to conclude. The laboratory study by Yoon *et al.,* 2016 found high degree of correlation between Trios Pod and Shade Eye – NCC for L*and b* values, except the a* value.[27]

In this study, the strong agreement of reliability was found among three color measurement methods which was 0.73 on maxillary central incisor and 0.77 on maxillary canine whereas the earlier *in vitro* study showed 0.96 on the Vita 3D master shade tab.[24] It had been stated that the data collected from spot-measurement devices may not be entirely accurate because of the non-homogenous shade structure of the natural teeth, and the errors of image which was taken on the arch curve of natural tooth; not on the flat plane. So, the curve position of natural tooth may affect the position of measurement devices. The color measurement of the exact same spot on a curved tooth surface also proved to be challenging, which might affected the consistency of the measurements.[18] However, one study explained that the spot measurements in particular were more accurate because the measurements were made with the tip of the probe.[28] For the intraoral scanner method, the reliability was slightly lower than the spectrophotometer since the spectrophotometer was aligned in parallel and contacted closely to the labial surface of each tooth. Moreover, the color was directly measured by the spectrophotometer from small regions in the individual teeth while the multiple angles of the entire labial surface were captured with the intraoral scanner. The entire tooth surface measurement devices provide the detailed color map of the tooth as well as an average shade value from the overlapping camera.[16,27] The scanning picture on the touch screen monitor of the Trios intraoral scanner was also difficult to point by finger in order to measure at the same position. Furthermore, after autoclaving, the drying mark on mirror of scanner tip was detected and affected to the tooth color measurement. The visual method using white light box was poorly reliable compared to the instrument tooth color measurement which is consistent with the previous study.[29]

The study of Culpepper found the maxillary canine was the most consistent matched utilizing all shade guides and light sources because the maxillary canine has the highest Chroma (intensity) of the dominant hue (color) of the teeth.[30] Similar to this study which found that the maxillary canine had higher accuracy and reliability than the maxillary central incisor, Lasserre, 2011 also found more errors on central incisors due to their high translucency property.[31]

Previous studies usually had more than one observer to ascertain the efficiency of tooth color measurement methods.[30-32] Unfortunately when there are many observers, the problem of positioning the device has occurred. Thus, most of studies have to limit the area of shade measurement by drawing the square or circle shape on tooth surface or covering the unselected area with silicone and leave 5 mm diameter hole with the same size as Vita Easyshade's tip. Nevertheless, the limited area may reduce the efficiency of visual color measurement. In this study, there is only one observer who did not have color deficiency, have experience in conventional tooth color selection, and also trained to use the color measurement instruments. This observer was trained and know where the area of measurement is, so the area of was fixed without reduction of efficiency of shade selection method. And this process can produce the reliability of methods.

## Conclusion

Results of this study indicated that there are significant differences in clinical tooth color measurement among the visual method using white light box, the intraoral scanner and the spectrophotometer. The visual method using white light box had low accuracy and reliability when compared to the spectrophotometer. The Intraoral scanner showed higher color difference than the perceptible range which has lower reliability than spectrophotometer but still could be use in clinical situation within acceptable range. Although, it was easier to find the variation in L* a* b* values, since there were difficulties to match the instrument's position of each method. The maxillary canines presented a strong agreement of accuracy and reliability in all tooth color measurement methods which was higher than maxillary incisors.

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