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A COMPARISON BETWEEN VISUAL SHADE MATCHING AND DIGITAL SHADE ANALYSIS SYSTEM USING K-NN ALGORITHM

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ABSTRACT

Objective: One of the major challenges in dentistry is the correct selection of tooth color as close to the natural adjacent tooth color as possible so this study was directed to develop an alternative way to traditional methods for shade matching. **Subjects and Methods:** A smartphone application was developed, a total of 1300 shade tab images (50 per shade tab) were captured using a smartphone camera with auto-mode settings and special ring light which emits 5500 k light temperature. The images were shot at angled distances of 14 – 20 cm from a shade guide. Color features were extracted and classified using K nearest neighbor classification algorithm (K-NN) to form a software training dataset. Sixty two upper central incisors were captured by smartphone and the shade of these teeth were matched using developed software and, visual methods compere to the spectrophotometer. **Results:** The matching accuracy using software gives 70% matching compare to the visual method which gives 65 % matching accuracy**.** **Conclusions**: Shade matching using a Smartphone application and Digital photography can emerge as a viable alternative to the use of spectrophotometers for shade selection in a clinical setup.

KEYWORDS: Digital shade matching**,** photographic shade matching, learning, spectrophotometer, EasyShade

INTRODUCTION

Increase patient awareness with an ever-increasing emphasis on esthetic led to an increase in the demand of both patients and clinicians for indistinguishable restorations that mimic adjacent natural teeth. The ability to correctly evaluate tooth shade information and effectively communicate it to the ceramist is now more critical than ever. Correctly evaluating tooth shade is as much an art as a science and problems with shade analysis is the second reason given for remakes, with impression/ preparation problems being the first (1).

Visual shade selection by different commercial or even custom-made shade guides is influenced by several external factors such as surrounding illumination, environment, the tooth including its textures, layers as well as vitality, the dentist's judgment, and patient factors. It is a very subjective assessment that changes from person to person. Furthermore, the commercially available shade guides manufactured by various companies differ from each other with respect to hue, value, and chroma (2, 3).

Instrumental measurements (objective methods) of color were developed using either colorimeters or spectrophotometers (4). A colorimeter is a device that mimics the way humans perceive color using an internal light source, a colorimeter shines light

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down onto the surface of the sample. As the light reflects on the device, it passes through three filters: red, green, and blue (RGB). These filters distill tri-stimulus values that match how our eyes see color. Spectrophotometer works the almost same way, except for one main difference, the filters. Instead of using three filters to determine the RGB values of the color like a colorimeter, modern-day spectrophotometers typically have 31 filters to measure the full-color spectrum. These filters measure light in each of 31 different wavelengths to determine the color of the sample [(5)]. In spite of it being more accurate than the visual shade guides, the quantitative spectrophotometric evaluation is limited to reading one point at a time [(6)]. Incorrect color reading from the loss of a fraction of light entering the tooth when used on curved teeth surfaces, i.e., the "edge loss error," is a frequent shortcoming of contact type spectrophotometric devices [(7)].

Shade selection through digital photography has enabled ease of communication between the clinician and the laboratory technician [(8)]. The primary advantage with this technique is that it provides the entire spectrum of color for the tooth or even a part of it, which when analyzed by an appropriate software can provide the color values in various formats. This is cost-effective as compared to instruments such as spectrophotometers or colorimeters as well as time-saving and convenient. Digital cameras can be divided into three groups: amateur, semiprofessional, and professional cameras. Obviously, in dental photography, only semiprofessional and professional cameras should be used [(9)].

K-Nearest Neighbor (K-NN) is one of the simplest Machine Learning algorithms based on the Supervised Learning technique. K-NN algorithm assumes the similarity between the new case/data and available cases and puts the new case into the category that is most similar to the available categories. I stores all the available data and classifies a new data point based on the similarity. This means when new data appears then it can be easily classified into a good suite category by using K- NN algorithm. K-NN algorithm can be used for Regression as well as for Classification but mostly it is used for Classification problems [(10)]. Classification of captured images of shade guides using K-NN give the high percent of learning accuracy [(11)].

Basically, the color of teeth is a white color with a different value. A color can be produced by a combination of its basic elements which is called color space parameter [(12)]. There are several color spaces that have been widely used in some research. According to the basic elements of color; 1) red, green and blue (RGB), 2) hue, saturation, and value (HSV) and 3) the International Commission on Illumination (CIELAB) are the simplest parameters that are used in the color analysis system. However, the color space properties of teeth are non-uniform and involve a complex layering of tooth structure, it is required addition technique for determining specific features of each tooth. Analysis technique using color moment with the simple mathematical calculation can be applied for determining the specific features based on its color space properties[(13)].

Taking a perfect digital image consider a challenge as this requires specific camera settings, light energy, and complicated processing and correcting techniques [(14)]. So, the development of new software which will be able to facilitate image correction, specular removal, and shade matching consider very important to be an easy alternative solution for dental shade matching.

The hypothesis of this study is shade matching by photographic analysis system using image calibration and K-NN machine learning algorithm will be highly accepted and can be used in clinical trials.

METHODOLOGY

Software development

Android studio development software was used to develop smartphone application using the JAVA programming language, (Figure 1).

Main application tasks were designed to capture images, crop predefined areas, calibrate cropped areas, specular correction of the cropped areas, and save samples to form a training dataset.

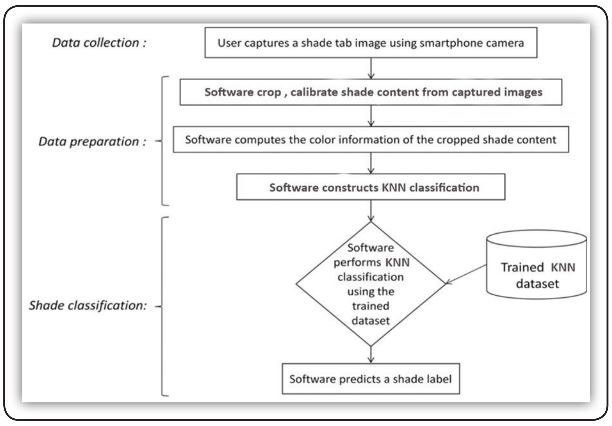

FIG (1) System flow

The software main page consists of the following areas:

A-Camera area (Figure 2 label A)

The camera area takes the top half of the mobile screen and responsible for real-time analysis of captured images, it includes:

1. Smart Rectangle: a blue rectangle with default 8 mm width and 11mm height placed at the center of the camera area. It is designed to enable the captured tooth to be completely inside the rectangle border to ensures the fixed tooth camera distance before capturing, (Figure 2 number 1).
2. Calibration Box: small red box located under smart rectangle designed to capture calibration reference by default 18% grey card and responsible for calibration of the smart rectangle area which contains captured tooth. (Figure 2 number 2)

B-Calibration area (Figure 2 label B):

A small area located under the camera area and include:

1. Shade content-box: small box shows the cropped area from the middle-middle part of the smart rectangle. (Figure 2 number 5)
2. Specular Removal Box: small box shows shade content-box content after specular reflection correction. (Figure 2 number 4)

C-Data area (Figure 2 label C)

The area shows processing results of captured images it includes:

1. Labels for HSV, LAB color spaces calculated from shade content-box pixels,
2. Label for samples count,
3. VITA 3D master dropdown list (Figure 2 number 6) which includes all labels of the Vita 3D Master shade guide

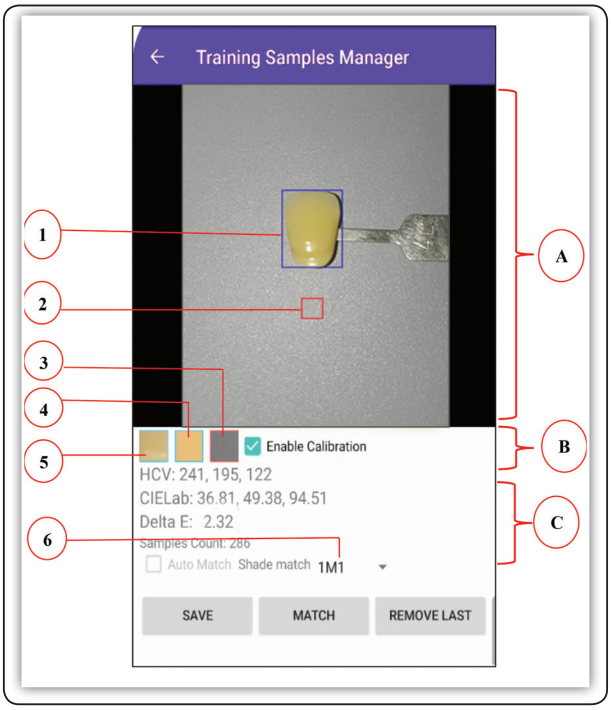

FIG (2) Developed application main page contents **A-camera area** includes 1: smart rectangle, 2: calibration box **B-Calibration area** includes 3: calibration box content, 4: specular removal box,5: shade content box **C-Data area** includes output information's, 6: vita 3D Master dropdown labels

Training sample collection

A commercial dental shade guide (3D-MASTER, Germany) was selected in this study, which has been reported as a reliable guide for instrumental analysis, generally distributed and familiar to most dentists [15]. Shade tabs were labeled in numeric order, from 1 to 26, sorted by value and chroma respectively.

Every tab in the shade guide was fixed above the grey card balance (Grey card white balance, SELENS, CN model GC-01;China) and the camera area of the developed application was adjusted to be the shade tab confined completely inside the smart rectangle.

The label of the captured shade tab was selected from the VITA 3D master dropdown list (Figure 2 number 6) and the save button was clicked to save the captured image as a training sample. This process was repeated to take 50 samples per shade tab to get 1300 samples saved in the dataset and ready for color feature extraction and classification.

Color features extraction

RGB (red green and blue) colors were measured through software from training samples after calibration, specular reflection correction.

HSV (hue saturation and value) calculated from RGB value using this equation

$$H = \cos^{-1}\left(\frac{\frac{1}{2}2R - G - B}{R - G^2 - R - GB - B}\right)$$

$$S = \frac{\max\{R,G,B\} - \min\{R,G,B\}}{\max\{R,G,B\}}$$

$$V = \max\{R,G,B\}$$

LAB is the color model based on the wavelength of light. The transformation of RGB color models to the LAB is calculated using the following equation:

x = 0,412453R + 0,357580G + 0,180423B

Y = 0,212671R + 0,71S160G + 0,072169B

Z = 0,019334R + 0,119193G + 0,950227B

The value of LAB can be defined as following equation:

$$L = 116f\left(\frac{Y}{Y_n}\right) - 16$$
$$A = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right]$$
$$B = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right]$$

The calculated color spaces were recorded for each sample and saved to form a training dataset.

KNN Classification Algorithm

After color spaces (RGB, HSV, and LAB) calculation from training samples these color spaces were classified using the K-NN classification algorithm.

Software evaluation

Study setting

This study was completed in the out-patient's clinic Faculty of Dental Medicine, Al-Azhar University. By using a two-sided hypothesis test (Kappa); the power analysis determined that the current study has high acceptability with the power value of (85%) when the sample size (n= 62) for each group [16]. The ethical approval of this study was by the Ethics Committee of Faculty of Dental medicine, Al-Azhar University, Cairo, Egypt (EC Ref No: 164/230/8/7/18).

Procedures

Sixty-two upper vital central incisors were selected in the current study. All teeth were captured by developed software in standard condition and divided into two groups according to the light source used in this study (ring light and mounted camera flash).

For the ring light (RL) group, light energy 5500 k-6000 k was selected and handled in the special standing device. Shade matching for all teeth was performed by manual method, vita EasyShade spectrophotometer, and our software.

Shade selection By VITA EasyShade

A Clinical Spectrophotometer (VITA EasyShade, Germany) was used for shade selection by the instrumental method.

The manufacturer's instructions were followed for the calibration of the device and for shade recordings, which were practiced before the final evaluations. The measuring tip (probe) was covered by an anti-infection cover and placed on the middle one-third of the matched tooth. The "Tooth single" program was selected for recording the shade and the L* a* b* values of the tooth.

Visual shade matching

For the visual method, 3 well-trained operators with ormal color vision were selected for visual shade matching. The VITAPAN® 3D master shade guide (VITA, Germany) was used for the visual shade selection method for all teeth. All the shade matching was carried out under a standard light source using a special ring light device (Dental shade matching light device B1uu,China) that emits light at 5500 C.

Photographic Shade selection:

The software matching page was navigated and auto-match mode was selected for auto shade detection. The patients were instructed to hold a grey card balance to be contacted with the incisal edge of the matched tooth.

The smartphone was fixed on the front of the matched tooth with distance adjusted to be the matched tooth confined inside the smart rectangle.

The application start processing and the resulted shade and L* a* b* values were recorded.

Statistical analysis of the data

The statistical analysis was carried out using the software SPSS program, version 20 (Statistical Package for Social Sciences). Kappa coefficient and Z-test were used to statistically compare the collected data in both groups at a level of significance of $p<0.05$.

RESULTS

A combination of tooth color data (shade and L* a* b* values) was collected by the spectrophotometer, visual, and digital photography methods. An evaluation of the accuracy of shade matching using a new digital photography technique and the conventional visual method was done as compared to a spectrophotometer.

Assesment between spectrophotometer and visual shade matching

For comparison of shades between the visual and spectrophotometric methods, the coefficient of agreement (using the Kappa coefficient) was checked.

Results revealed a high agreement between the shades as determined by these two methods (Kappa coefficient = 0.221) (Table 1).

On comparing the agreement between spectrophotometric and visual methods using Z test for proportions, the total Z score was 3.2, agreement frequency 65% and P-value was 0.00125 (P < 0.01) The results were statistically significant with a higher proportion of "yes" (agreement) Table (1).

TABLE (1): Accuracy of visual shade matching related to the spectrophotometer

	Visual	Z Score	Agreement frequency	Kappa coefficient
Agreement	43			
no agreement	19	3.2	65%	0.221
Total	62			

Assesment between spectrophotometer and digital photography

On comparing the agreement between spectrophotometric and digital photography with ring light method using Z test for proportions, the total Z score was 4.1 and P-value = 0.00138 (P < 0.05). The results were statistically significant with a higher proportion of "yes" (agreement). (Table 2).

On comparing the agreement between spectrophotometric and digital photography with the camera flash method using Z test for proportions, the Z score was -0.8 and P = 0.0638 (P > 0.01). The results were statistically insignificant with a fair proportion of "no" (agreement). (Table 2).

TABLE (2): Accuracy between spectrophotometric method and photographic method

Light source	Agreement frequency	Z Score	P value	ΔE > 2	ΔE < 2
Ring light	70%	4.1	0.00118	18%	82%
Camera flash	49%	-0.8	0.0638	52%	48%

Comparison of Visual with photographic shade matching

The results of this study revealed that both visual shade matching and photographic shade matching (using ring light) have a high agreement with spectrophotometer results with increase agreement in photographic method but the difference between them was insignificant p-value > 0.05 (Table 3).

TABLE (3): Visual shade matching vs Photographic shade matching

	Visual shade matching	Photographic shade matching	P-value
Agreement frequency	65%	70%	0.5124

DISCUSSION

JAVA programming language was selected for software development as JAVA was designed to be easy to write, compile, debug, and learn than other programming languages. [17].The mobile platform was selected for software development as the worldwide distribution of smartphones equipped with high-definition cameras and flash, this allows using smartphone cameras for image capturing and analyzing at the same time. Further more ease of using the mobile camera in compare to DSLR digital camera which needs complicated setting adjustment and long learning curve [18].

The upper central incisor was selected in this as the upper central incisor can be easily focused during capturing images or shade selection, on the other hand, the posterior teeth have difficulty in shade matching and image capturing as the vision and control field decrease in posterior teeth. Upper central incisors have a flat surface which permits easy visual and digital shade matching, on the other hand, the upper canines and premolars have curved surfaces which may affect correct shade matching. All shade guides are designed to simulate the upper central incisor which makes shade selection easier for the upper central incisor than other teeth [19, 20].

The Vita 3D-Master Guide was used for visual shade matching in this study because it is commonly used among clinicians, associated with a high degree of repeatability and success in achieving an acceptable color match, and includes uniform shade distribution. Since shade guides may vary between batches, all shade tabs were measured with a spectrophotometer to ensure that the shade corresponding to the color code [21].

Vita EasyShade spectrophotometer used in this study as its repeatability, reliability, accuracy, and ease of use [22], The precise positioning of the mouthpiece gives accurate measurements in the form of L* a* b* values and [23].

The results of this study reflected on the percent of agreement between the visual and the instrumental methods of shade selection. The percent of agreement between the spectrophotometric method and the conventional visual shade selection method was 70%, which is statistically significant. This result is supported by Gómez et al. study which concludes agreement between spectrophotometer and visual method related to lightness [24], and Miyajiwala and colleague's study [16], They concluded that visual shade matching in agreement with a spectrophotometer (Easyshade). In 2008, Da Silva *et al*. compared EasyShade spectrophotometer with three visual shade guide systems. They concluded that crowns fabricated using spectrophotometer had a significantly better color match and a lower rate of rejection due to shade mismatch compared to crowns fabricated with a conventional shade-matching method[25]. Several other studies are supporting instrumental methods in comparison with visual ones [22, 23]. In contrast with Da Silva *et al*., Yilmaz and Karaagaclioglu [26] show that the visual method is more accurate than the instrumental method.

The percent agreement between the spectrophotometric method and the photographic method using a developed smartphone was 67% which is statistically significant when using ring light device as light source, and 48% which is statistically insignificant when using camera flash as a light source. Similar findings were reported by Miyajiwala and colleagues [16]. They concluded that digital photography is a potential alternative to the use of spectrophotometers for shade selection.

Numerous studies have demonstrated an improved selection of correct shade by digital methods when compared to the conventional visual method [27, 28]. Lars Schropp [29] conducted a study using a professional camera and visual shade matching and found that the correct shade match with the visual and digital method was 32% and 67% respectively. He concluded that shade matching assisted with digital photographs and computer software is significantly more reliable compared to the conventional visual methods. The results of this study are comparable to his study. In a similar study by Jarad and colleagues [30], digital imaging and conventional visual methods were compared. The correct match was observed in 43% and 61.1% by conventional and digital methods respectively. They also found that color parameters determined by the spectrophotometer and digital photography methods were in agreement with each other and therefore digital radiography can be used for shade selection clinically. Similar results were obtained by study conducted by Farah [31] The results of these studies are also in agreement with our study.

On the other hand, another study concluded that shade matching using the photographic method with clear match software gives unreliable results and cannot be used in clinical use [32].

The percentage of agreement between shades taken by digital photography and the Vita EasyShade (spectrophotometer) was high (70%), which could be attributed to the standardized setup, image correction, and specular removal.

In this study using ring light give high agreement compare to camera flash, this finding is supported by E. CAL finding [33] the explanation might be ring light have controlled color temperature and well color distribution than a camera flash and also using camera flash during image capturing lead to overexposure due to the narrow distance between the flash and captured tooth.

The results of this study reveal that the newly emerging digital photography technique was as accurate when used with ring light as the most commonly used method for shade selection.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

1. Both visual and digital photography methods showed a high (statistically significant) percentage of agreement with the clinical spectrophotometer for the shades selected.
2. Digital photography can emerge as a viable alternative to the use of spectrophotometers for shade selection in a clinical setup.
3. Smartphone camera flash cannot be used as a light source during image capturing.

REFERENCES

1. Llena, C., E. Lozano, J. Amengual and L.J.J.C.D.P. Forner, Reliability of two color selection devices in matching and measuring tooth color. 2011. 12(1): p. 19-23.
2. Greta, D.C., H.A. Colosi, C. Gasparik and D.J.T.j.o.a.p. Dudea, Color comparison between non-vital and vital teeth. 2018. 10(3): p. 218-226.
3. Pop-Ciutrila, I.-S., H.A. Colosi, D. Dudea and M.E.J.C.M. Badea, Spectrophotometric color evaluation of permanent incisors, canines and molars. A cross-sectional clinical study. 2015. 88(4): p. 537.
4. Sîmpălean, D., M. D PETRIŞOR, M.Ş. Măruşteri, D. Ghiga, V. Bacârea, T. Calinici, et al., A software application to detect dental color. 2015. 37(3): p. 31-38.
5. Chu, S.J., R.D. Trushkowsky and R.D.J.J.o.d. Paravina, Dental color matching instruments and systems. Review of clinical and research aspects. 2010. 38: p. e2-e16.
6. Kalantari, M.H., S.A. Ghoraishian and M.J.E.j.o.d. Mohaghegh, Evaluation of accuracy of shade selection using two spectrophotometer systems: Vita Easyshade and Degudent Shadepilot. 2017. 11(02): p. 196-200.
7. Bolt, R., J. Ten Bosch, J.C.J.P.i.M. Coops and Biology, Influence of window size in small-window colour measurement, particularly of teeth. 1994. 39(7): p. 1133.
8. Odaira, C., S. Itoh and K.J.J.o.p.r. Ishibashi, Clinical evaluation of a dental color analysis system: the Crystaleye Spectrophotometer®. 2011. 55(4): p. 199-205.
9. Bengel, W.M.J.J.o.E. and R. Dentistry, Digital photography and the assessment of therapeutic results after bleaching procedures. 2003. 15: p. S21-S32.
10. Batista, G.E. and M.C.J.H. Monard, A study of K-nearest neighbour as an imputation method. 2002. 87(251-260): p. 48.
11. Justiawan, D.A.W., R.P. Hadi, A.P. Nurhayati, K. Prayogo, R. Sigit and Z.J.M.D. Arief, Comparative Analysis of Color Matching System for Teeth Recognition Using Color Moment. 2019. 12: p. 497.
12. Singh, S.M. and K.J.I.J.o.C.A. Hemachandran, Image retrieval based on the combination of color histogram and color moment. 2012. 58(3).
13. Sigit, R. and Z.J.E.I.J.o.E.T. Arief, Tooth Color Detection Using PCA and KNN Classifier Algorithm Based on Color Moment. 2017. 5(1): p. 139-153.
14. McLaren, E.A., J. Figueira and R.E.J.C.C.E.D. Goldstein, A technique using calibrated photography and photoshop for accurate shade analysis and communication. 2017. 38(2): p. 106-13.
15. Corciolani, G., A. Vichi, C. Goracci and M.J.J.o.d. Ferrari, Colour correspondence of a ceramic system in two different shade guides. 2009. 37(2): p. 98-101.
16. Miyajiwala, J.S., M.G. Kheur, A.H. Patankar and T.A.J.T.J.o.t.I.P.S. Lakha, Comparison of photographic and conventional methods for tooth shade selection: A clinical evaluation. 2017. 17(3): p. 273.
17. Eiband, B.J., B. Bergande, A. Schedel and P. Brune, Game of Codes: Towards Learning Java by an Educational Mobile Game Adapted to Female Programming Novices, in Proceedings of the Evaluation and Assessment on Software Engineering. 2019. p. 362-363.
18. Kadner, N., RED: the ultimate guide to using the revolutionary camera. 2010: Peachpit press.
19. OKAMURA, M., K.-K. CHEN, H. KAKIGAWA and Y.J.D.m.j. KOZONO, Recommendations on uniform color spaces, color-difference equations, psychometric color terms. Supplement No. 2 of publication CIE No. 15 (E-1.3. 1) Recommendations on uniform color spaces, color-difference equations, psychometric color terms. Supplement No. 2 of publication CIE No. 15 (E-1.3. 1), 1978. 2004. 23(2): p. 180-183.
20. Igiel, C., M. Weyhrauch, S. Wentaschek, H. Scheller and K.M.J.D.m.j. Lehmann, Dental color matching: A comparison between visual and instrumental methods. 2016. 35(1): p. 63-69.
21. WEE, A.C., E.Y. Kang, D. Jere, F.M.J.J.o.E. Beck and R. Dentistry, Clinical color match of porcelain visual shade-matching systems. 2005. 17(6): p. 351-357.

22. Kalantari, M.H., S.A. Ghoraishian and M.J.E.j.o.d. Mohaghegh, Evaluation of accuracy of shade selection using two spectrophotometer systems: Vita Easyshade and Degudent Shadepilot. 2017. 11(2): p. 196.

23. Kim-Pusateri, S., J.D. Brewer, E.L. Davis and A.G.J.T.J.o.p.d. Wee, Reliability and accuracy of four dental shade-matching devices. 2009. 101(3): p. 193-199.

24. Gómez-Polo, C., M. Gómez-Polo, A. Celemin-Viñuela and J.A.M.V.J.J.o.d. De Parga, Differences between the human eye and the spectrophotometer in the shade matching of tooth colour. 2014. 42(6): p. 742-745.

25. Da Silva, J.D., S.E. Park, H.-P. Weber and S.J.T.J.o.p.d. Ishikawa-Nagai, Clinical performance of a newly developed spectrophotometric system on tooth color reproduction. 2008. 99(5): p. 361-368.

26. Yilmaz, B. and L.J.T.J.o.p.d. Karaagaclioglu, In vitro evaluation of color replication of metal ceramic specimens using visual and instrumental color determinations. 2011. 105(1): p. 21-27.

27. Choi, J.H., J.M. Park, S.-G. Ahn, K.Y. Song, M.H. Lee, J.Y. Jung, et al., Comparative study of visual and instrumental analyses of shade selection. 2010. 25(1): p. 62-67.

28. Parameswaran, V., S. Anilkumar, S. Lylajam, C. Rajesh and V.J.T.J.o.t.I.P.S. Narayan, Comparison of accuracies of an intraoral spectrophotometer and conventional visual method for shade matching using two shade guide systems. 2016. 16(4): p. 352.

29. Schropp, L.J.J.o.P.I., Esthetic and R. Dentistry, Shade matching assisted by digital photography and computer software. 2009. 18(3): p. 235-241.

30. Jarad, F., M. Russell and B.J.B.d.j. Moss, The use of digital imaging for colour matching and communication in restorative dentistry. 2005. 199(1): p. 43-49.

31. 31. Farah, R.f.I.J.T.i.j.o.e.d., Agreement between digital image analysis and clinical spectrophotometer in CIEL* C* h° coordinate differences and total color difference (ΔE) measurements of dental ceramic shade tabs. 2016. 11(2): p. 234-245.

32. Khoo, T.S.J., A comparison between a photographic shade analysis system and conventional visual shade matching method. 2015.

33. Cal, E., M. Sonugelen, P. Guneri, A. Kesercioglu and T.J.J.o.o.r. Kose, Application of a digital technique in evaluating the reliability of shade guides. 2004. 31(5): p. 483-491.