10.5005/jp-journals-10052-0157

REVIEW ARTICLE

Standardizing Shade Matching with Technology-based Shade Matching Systems and Color Formulation

Pavithra K Ramanna

ABSTRACT

Precision in shade matching and color reproduction is vital for esthetic success of prostheses. Conventional shade matching technique is subjective and can provide inconsistent results. However, technology-based systems allow for standardization and repeatability in shade matching.

This study reviews technology-based shade matching systems and their role in standardized shade determination. It also discusses the concept of computer color matching (CCM) using Kubelka-Munk theory, which correlates the concentration of dyes or pigments in a colored layer to the reflectance properties of that layer. Computer color formulation has been used with success in various industries, such as printing and textile industries. This study considers its applicability in dentistry.

Keywords: Color measurement, Colorimeter, Computer color matching, Kubelka-Munk theory, Spectrophotometer.

How to cite this article: Ramanna PK. Standardizing Shade Matching with Technology-based Shade Matching Systems and Color Formulation. Int J Prev Clin Dent Res 2018;5(1):83-86.

Source of support: Nil

Conflict of interest: None

INTRODUCTION

Color experience is in the eye of the beholder; it is an individual experience and not an inherent property of either the object or the eyes.[1] Accurate shade matching of a restoration/prosthesis is critical to the success and acceptance of the restoration.[2]

Conventionally, matching of tooth color to ceramic restorations is accomplished by empirical comparison with shade guides.[3] These comprise color tabs that are compared in succession with the designated tooth until the tab with the greatest chromatic similarity to the tooth is found. It is a subjective process.[4]

Instrumental color measurement can make the process of color matching faster and less subjective.[2]

Senior Lecturer

Department of Prosthodontics, Crown and Bridge, Vydehi Institute of Dental Sciences and Research Centre, Bengaluru Karnataka, India

Corresponding Author: Pavithra K Ramanna, Senior Lecturer Department of Prosthodontics, Crown and Bridge, Vydehi Institute of Dental Sciences and Research Centre, Bengaluru Karnataka, India, e-mail: pavitrakr@yahoo.com

TECHNOLOGY-BASED SHADE MATCHING SYSTEMS

Development

The early 1980s saw the introduction of the Chromascan (Sterngold, Stamford, Connecticut), but due to its inadequate design and accuracy, success was limited.[5] Later, the Shofu ShadeEye chromameter and, subsequently, the Shofu natural color concept (NCC) system was developed by Yamamoto, in the late 1990s.[6] The late 1990s also saw the introduction of a prototype developed by Cortex Machina that employed a red, green, and blue (RGB) digital camera technology that inferred color properties.

The SpectroShade system (MHT Optic Research), a spectrophotometer, introduced in 2001, and the ShadeVision system (X-Rite), a colorimeter, introduced in 2002 were the first shade matching systems with the capability to map the whole surface of the tooth.[7]

Types

The three types of systems available include spectrophotometers, colorimeters, and digital camera and imaging systems.

Spectrophotometers

They are among the most accurate instruments for overall color matching in dentistry.[8] They measure the quantity of light energy reflected at 1 to 25 nm intervals, from an object, along the visible spectrum.[9,10] This data is used to produce spectral reflectance and/or transmission curves. These measurements are then keyed to dental shade guides and converted to shade tab equivivalent,[11] e.g., Vita Easyshade Compact (Vita Zahnfabrik, Bad Sackingen, Germany).

Colorimeters

These instruments measure the tristimulus values. They filter light in RGB areas of the visible spectrum.[12] Colorimeters are less accurate than spectrophotometers as they do not register spectral reflectance. The aging of the filters also affects accuracy,[13] e.g., ShadeVision (X-Rite, Grandville, MI).

Digital Cameras

Consumer video or digital still cameras can be utilized to create color images by acquiring RGB image information.[12]

They analyze captured digital image for color and achromatic mapping. These are least accurate as they are reliant on quality of image captured,[1] e.g., ClearMatch (Smart Technology, Hood River, OR).

SPOT MEASUREMENT DEVICES *VS* COMPLETE TOOTH MEASUREMENT SYSTEMS

Spot measurement devices measure a small area.[14] As a result, they cannot deliver all the information necessary to create an overall image. They have a smaller sensor and require more time to gather the necessary data. They generally require three points of reference, each for the gingival, body, and incisal areas of the tooth (a total of nine reference measurements), e.g., EasyShade, Shade X.

Complete tooth measurement systems measure the whole tooth surface area and provide a topographic color map of tooth. The main disadvantage is that it can be used for anterior teeth only as it is bulkier, and the large sized sensor has restricted access to the molar tooth area, e.g., ShadeVision, SpectroShade.

When Sarafianou et al[15] studied two intraoral spectrophotometers (EasyShade—a spot measurement device and SpectroShade—a complete tooth measurement system) for their matching repeatability and interdevice agreement, they concluded that different illuminants had a more pronounced effect on SpectroShade than on Easyshade and also the interdevice agreement was poor.

PRECISION AND ACCURACY

Precision of a device is evaluated by testing the repeatability (same method, operator, or instrument) and reproducibility (different method, operator, and/or instrument) of the instrument.[12]

Kim-Pusateri et al[16] found a varying degree of reliability and accuracy with ShadeScan system, depending on the shade guide used. ShadeScan was most reliable with VITA Classical and least with Chromascop. However, it was most accurate with Chromascop and least with Vita 3D-Master shade guide.

Lagouvardos et al[11] also found on comparing two portable color selection devices (ShadeEye NCC and VITA EasyShade) for their repeatability and interdevice reliability that the lightness (L*) factor and shade guide system used with the device affect interdevice reliability.

Kim-Pusateri et al[13] found high reliability (>96%) between the four dental color matching devices they compared. However, the accuracy of the devices (67–93%) demonstrated marked variability. The EasyShade system was most accurate.

Đozic et al[17] compared the performance of EasyShade, ShadeScan, Ikam, IdentaColor II, and ShadeEye, both *in vitro* and *in vivo*, and concluded that in clinical setting, the EasyShade and Ikam systems were the most reliable, whereas others were more reliable *in vitro* than *in vivo*.

VISUAL *VS* INSTRUMENTAL METHODS OF SHADE MEASUREMENT

Several studies have found instrumental methods for determining tooth color to be more objective and rapid than visual methods.[18]

Paul et al[8] found that in 9 of 10 cases, crowns fabricated after shade selection using spectrophotometric methods were preferred over crowns fabricated after shade selection using conventional visual methods, for definitive cementation. In another study by Da Silva et al,[19] crowns fabricated using a spectrophotometer demonstrated better color match and a lower rate of rejection due to shade mismatch than those fabricated using conventional methods.

Fani et al[20] observed that spectrophotometer provided more accurate results than visual selection in approximately 47% of cases. Gehrke et al[21] also found in their study that spectrophotometric shade determination was more reproducible than conventional methods.

Browning et al[22] evaluated the efficiency of EasyShade and found it comparable or better, in terms of the number of exact matches and matches within a half-shade, than that of dentists.

Okubo et al[23] concluded from their study that shade determination by visual means was inconsistent. However, accuracy of the colorimeter (Colortron II) they tested was only slightly better.

Hugo et al,[24] on the contrary, found agreement among the observer groups better than that of each device they tested and that color matching instruments did not reflect human perception.

LIMITATIONS OF TECHNOLOGY-BASED SHADE MATCHING SYSTEMS[5]

- Tooth surface: The surface of tooth affects perceived value of shade. Some systems use filters to adjust surface gloss of the tooth.
- Edge loss results due to light lost primarily through translucent tooth and ceramic enamel layers. Algorithms which are incorporated in the shade matching devices to accommodate for different light scattering properties of the shade tabs, dentition, and restorations do not fully compensate.
- Translucency mapping is inadequate.
- Positioning of probe is critical to repeatability.
- Small diameter probes cannot provide a detailed shade map.
- Access is limited with larger mouthpiece.

- Accuracy of the target shade to be measured is dependent on the database of reference shades in the shade matching system used. The reading will provide inaccurate results if the tooth to be matched is not close in the color space of a designated shade.
- The instruments are not sophisticated enough to formulate the actual color designation of any tooth color measured, by specifying the powders and layering required, or measure the translucency distribution.

Computer Color Formulation

One of the challenges of modern dentistry is the color matching of restorative materials with natural teeth. Color in dental porcelain is generated by incorporating pigments and opacifiers in the material. When a color intermediate to two shades is desired, a common dental laboratory practice is to mix shades by weight or volume.[25,26] It would be useful to be able to predict the color of the resulting porcelain from the color of the pigments and opacifiers in it, and to analyze the color of the porcelain based on the amounts of pigments used. The Kubelka-Munk theory is applied in color matching by correlating reflectance data of porcelains to reflectance of the individual pigments.[26]

Computer color matching has been used in the paint, plastics, print, and textile industries, with success for several years. It utilizes a color measuring instrument and computer software to calculate a prescription for combining pigmented materials to reproduce the color of a given object. The Kubelka-Munk theory has been commonly used for predicting these color matches.[27,28]

Although tooth color is polychromatic,[29] studies have been undertaken with the goal of achieving enhanced color matching and color prediction, to apply the Kubelka-Munk color theory for accurate tooth color reproduction using dental restorative materials. Some of the first studies that applied the Kubelka-Munk theory for color prediction in dentistry, with success, were performed using layered composite specimens.[30,31]

A CCM software program that utilized the Kubelka-Munk theory[27] and Saunderson's correction[32] for tooth color reproduction of ceramic restorations, employing a dental spectrophotometer, was developed by Ishikawa-Nagai et al.[33] Kubelka-Munk theory calculated the amount and color of each porcelain layer of specified thickness. Accurate colors were reproduced using Shofu porcelains in metal/ceramic restorations with color difference [ΔE] < 3.

Kristiansen et al[28] assessed the precision of a prototype CCM system for reproducing the tooth color of natural maxillary centrals with dental ceramics. The color of natural teeth was reproduced with a mean ΔE^* of 2.58. They concluded that the system had the potential to be used as an efficient tool in the reproduction of natural tooth color.

Ishikawa-Nagai et al[34] further evaluated the reproducibility of tooth color gradation using this CCM system with ceramic restorations. The results of the study showed that tooth color gradation from the incisal region to the precervical region could be reproduced with clinically acceptable results.

Ishikawa-Nagai et al[35] updated the CCM system by generating a new ceramic shade system that covered the entire spectrum of natural tooth color and had an efficient design with homogeneity to the Vita 3D-Master. Wang et al[36] tested this CCM system with the established 21 new shades and found that it was accurate and effective for reproducing tooth shades.

CONCLUSION

The goal of technology-based color assessment and color formulation is to achieve accurate, reproducible results, which are minimally influenced by lighting conditions and surroundings, thereby making the shade selection process an objective science. However, color is inherently subjective and greatly influenced by cerebral interpretation as a result of which the clinician's skill in understanding the patient's requirements will always play a role.

REFERENCES

1. Ahmed, I. Protocols for predictable aesthetic dental restorations. Oxford: Blackwell Munksgaard; 2006. p. 78.
2. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007 Apr;97(4):200-208.
3. Miller L. Organising colour in dentistry. J Am Dent Assoc 1987 Dec;Spec No:26E-40E.
4. Gómez-Polo C, Gómez-Polo M, Celemin-Viñuela A, Martínez Vázquez De Parga JA. Differences between the human eye and the spectrophotometer in the shade matching of tooth colour. J Dent 2014 Jun;42(6):742-745.
5. Brewer JD, Wee A, Seghi R. Advances in colour matching. Dent Clin N Am 2004 Apr;48(2):341-358.
6. Yamamoto M. Development of the vintage halo computer colour search system. Quintessence Dent Technol 1998;21:9-26.
7. Chu, SJ.; Devigus, A.; Mieleszko, AJ. Fundamentals of colour: shade matching and communication in esthetic dentistry. Chicago (IL): Quintessence Publishing Co, Inc.; 2004. p. 79
8. Paul SJ, Peter A, Rodoni L, Pietrobon N. Conventional visual vs spectrophotometric shade taking for porcelain-fused-to-metal crowns: a clinical comparison. Int J Periodont Restorat Dent 2004 Jun;24(3):222-231.
9. Khurana R, Tredwin CJ, Weisbloom M, Moles DR. A clinical evaluation of the individual repeatability of three commercially available colour measuring devices. Br Dent J 2007 Dec;203(12):675-680.
10. Kielbassa AM, Beheim-Schwarzbach NJ, Neumann K, Nat R, Zantner C. *In vitro* comparison of visual and computer aided

pre- and post-tooth shade determination using various home bleaching procedures. J Prosthet Dent 2009 Feb;101(2):92-100.
11. Lagouvardos PE, Fougia AG, Diamantopoulou SA, Polyzois GL. Repeatability and interdevice reliability of two portable color selection devices in matching and measuring tooth colour. J Prosthet Dent 2009 Jan;101(1):40-45.
12. Chu SJ, Trushkowsky RD, Paravina RD. Dental colour matching instruments and systems: review of clinical and research aspects. J Dent 2010 Aug;38(Suppl 2):e2-e16.
13. Kim-Pusateri S, Brewer J, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent 2009 Mar;101(3):93-99.
14. Apratim A, Eachempati P, Kiran Kumar KS. Digital shade matching: an insight. RJPBCS 2015 Mar-Apr;6(2):1072-1079.
15. Sarafianou A, Kamposiora P, Papavasiliou G, Goula H. Matching repeatability and interdevice agreement of 2 intraoral spectrophotometers. J Prosthet Dent 2012 Mar;107(3):178-185.
16. Kim-Pusateri S, Brewer JD, Dunford RG, Wee AG. *In vitro* model to evaluate reliability and accuracy of a dental shade-matching instrument. J Prosthet Dent 2007 Nov;98(5):353-358.
17. Đozic´ A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth colour measuring devices. Journal of Prosthodontics 2007;16:93-100.
18. Horn DL, Bulan-Brady J, Hicks ML. Sphere spectrophotometer versus human evaluation of tooth shade. J Endod 1998 Dec;24(12):786-790.
19. Da Silva JD, Park SE, Weber HP, Ishikawa-Nagai S. Clinical performance of a newly developed spectrophotometer system on tooth colour reproduction. J Prosthet Dent 2008 May;99(5):361-368.
20. Fani G, Vichi A, Davidson CL. Spectrophotometric and visual shade measurements of human teeth using three shade guides. Am J Dent 2007 Jun;20(3):142-146.
21. Gehrke P, Riekeberg U, Fackler O, Dhom G. Comparison of *in vivo* visual, spectrophotometric and colorimetric shade determination of teeth and implant-supported crowns. Int J Comput Dent 2009 Feb;12(3):247-263.
22. Browning WD, Chan DC, Blalock JS, Brackett MG. A comparison of human raters and an intra-oral spectrophotometer. Oper Dent 2009 May-Jun;34(3):337-343.
23. Okubo SR, Kanawati A, Richards MW, Childress S. Evaluation of visual and instrument shade matching. J Prosthet Dent 1998 Dec;80(6):642-648.
24. Hugo B, Witzel T, Klaiber B. Comparison of *in vivo* visual and computer-aided tooth shade determination. Clin Oral Investig 2005 Dec;9(4):244-250.
25. Ecker GA, Moser JB. Visual and instrumental discrimination steps between two adjacent porcelain shades. J Prosthet Dent 1987 Sep;58(3):286-292.
26. Wozniak WT, Siew ED, Lim J, McGill SL, Sabri Z, Moser JB. Color mixing in dental porcelain. Dent Mater 1993 Jul;9(4):229-233.
27. Judd, DB.; Wyszecki, G. Color in business, science and industry. 3rd ed. New York: John Wiley & Sons; 1975. p. 197.
28. Kristiansen J, Sakaia M, Da Silva JD, Gil M, Ishikawa-Nagai S. Assessment of a prototype computer colour matching system to reproduce natural tooth colour on ceramic restorations. J Dent 2011 Dec;39(Suppl 3):e45-e51.
29. O'Brien WJ, Hemmendinger H, Boenke KM, Linger JB, Groh CL. Color distribution of three regions of extracted human teeth. Dent Mater 1997 May;13(3):179-185.
30. Miyagawa Y, Powers JM. Prediction of colour of an esthetic restorative material. J Dent Res 1983 May;62(5):581-584.
31. Miyagawa Y, Powers JM, O'Brien WJ. Optical properties of direct restorative materials. J Dent Res 1981 May;60(5):890-894.
32. Saunderson LJ. Calculation of the colour of pigmented plastics. J Opt Soc Am 1942 Dec;32(12):727-736.
33. Ishikawa-Nagai S, Sawafuji F, Shiraishi A, Sato R, Tsuchitoi H, Takebe J, Tachibana N, Satodate T, Ishibashi K, Ikeno H, et al. Clinical Application of the Computer Color Matching (CCM) system on metal ceramic restorations part. 2 color reproducibility of metal ceramic restorations by CCM to the Conventional Shade Guides. J Jap Pros Soc 1993 Jan;37(6):1238-1245.
34. Ishikawa-Nagai S, Ishibashi K, Tsuruta O, Weber H. Reproducibility of tooth colour gradation using a computer colour-matching technique applied to ceramic restorations. J Prosthet Dent 2005 Feb;93(2):129-137.
35. Ishikawa-Nagai S, Wang J, Seliger A, Lin J, Da Silva J. Developing a custom dental porcelain shade system for computer colour matching. J Dent 2013 Aug;41(Suppl 3):e3-e10.
36. Wang J, Lin J, Gil M, Seliger A, Da Silva JD, Ishikawa-Nagai S. Assessing the accuracy of computer colour matching with a new dental porcelain shade system. J Prosthet Dent 2014 Mar;111(3):247-253.