Comparison of colour differences in visual versus spectrophotometric shade matching

SADJ October 2015, Vol 70 no 9 p402 - p407

DS Moodley[1], N Patel[2], T Moodley[3], H Ranchod[4]

ABSTRACT

Introduction: The challenge of achieving accurate colour matching in restorative dentistry is central to success in aesthetics. For many years selection of tooth colour in both restorative and prosthodontic dentistry have relied on shade guides which present a number of tabs of differing hue. Signal difficulties do arise with their use, notably in terms of accuracy and variability under differing circumstances. The use of a digital device to evaluate and record tooth colour offers an advanced option.

Aim: There is merit in assessing the extent of agreement between the digital and the human assessment methods.

Method: Twenty five patients were selected who had all upper anterior teeth, with the right central being pristine. Colour assessments were undertaken using a variety of guides and devices. The measurements were recorded and subjected to statistical comparisons.

Results: In general there were significant differences recorded between the systems but it appears that these results may not be of clinical import.

Conclusions: The advice to practitioners is that it would be best practice to use both human assessment and digital evaluation to ensure that acceptable aesthetics are achieved.

INTRODUCTION

Colour matching remains one of the most challenging tasks in clinical dentistry. The ability of a dentist to select and communicate an acceptable shade match is an important factor for the success of treatment especially in meeting patient expectations and demands for accuracy in aesthetic dentistry.[1,2]

Traditionally, shade matching of teeth in dentistry is done by visually comparing the colour of tooth/teeth with standard shade guide tabs, the operator choosing that which he/she deems to be the best or closest match. These shade guides offer relatively quick and cost effective methods of shade matching, offset by the major problems of the subjective variability of shade matching, the polychromatic nature of teeth, and the limitations of dental shade guides that incompletely represent the colour range of natural teeth.[3] The inconsistencies between commercially available shade guides and actual tooth shades are influenced by the variety of materials used to fabricate these guides.[4]

Differences in perception of colour (operator subjectivity), operator experience,[5,6] fatigue and colour blindness are human physiological factors affecting visual tooth matching. Colours appear different when viewed under varying light sources, which may have different colour distribution. This phenomenon is known as metamerism and may result in perceptible and unacceptable colour differences in changing settings.[7] Thus, ambient light has to be standardised before tooth colour is assessed, to minimise the influence of variables such as the light source, time of day, the surrounding background colour of the walls and the angle and distance at which the tooth is viewed by the operator.[8]

Recently, various clinical colour-measuring devices have become available. These are efficacious in quantifying the natural tooth colour and also enable communication between technicians and dentists to be more uniform and accurate.[9] A number of colour-measuring instruments are commercially available such as ShadeVision (X-Rite, Grand Rapids, MI, USA), which is a colorimeter; Easyshade (Vita Zahnfabrik, Bad Sackingen, Germany), which is a spectrophotometer that does not provide images; and SpectroShade Micro (MHT, Verona, Italy) and Crystal-eye, which are spectrophotometers that also provide images.[2] The advantages of a digital shade-matching system include objective readings and accuracy. The spectrophotometer can be used consistently to accurately measure the natural tooth colour in reference to a known colour, and it can be used based on the settings of other shade matching systems. It evaluates the colour characteristics of the tooth by measuring the different light intensities in various parts of the tooth/colour distribution. These data are then transmitted to software which maps the different shades on a digitised tooth. In this way, the instrument develops an accurate interpretation of the tooth shade on a given colour system, which can then be related to an existing dental shade tab or to a colour that is interpolated between the shade tabs.

1. **DS Moodley:** *PhD, MSc, PDD, BDS.* Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, Cape Town, South Africa.
2. **N Patel:** *MChD.* Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, Cape Town, South Africa.
3. **T Moodley:** *BChD.* Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, Cape Town, South Africa.
4. **H Ranchod:** *BChD.* Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, Cape Town, South Africa.

Corresponding author

DS Moodley:
Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape, Private Bag X1, Tygerberg, 7505, Cape Town, South Africa. Tel: +27 21 937 3090. E-mail: dmoodley@uwc.ac.za

SOUTHERN IMPLANTS

EXPANDING PROVEN CONCEPTS

Southern Implants invites you to participate in a forum with academic opinion leaders covering relevant and current topics, debated at International Conferences and consensus meetings.

cape town 2016

SOUTH AFRICA

3rd & 4th April 2016

At The Westin Hotel, Cape Town, on the South Western Coast of South Africa.

Keynote Speakers

Dr Pär-Olov Östman

Prof. Hugo de Bruyn

and others

www.southernimplants.com

Whether by visual or digital means the evaluation of colour requires an understanding of how it is measured and expressed.[10] The Munsell scale has been traditionally used in dentistry where hue, chroma, and value parameters are used to express the colour of teeth. Most of the visual shade-matching guides use this scale. Commission Internationale de l'Eclarirage (CIE) defines colour in L*a*b* colour coordinates within a three dimensional colour space.[11] The L* represents the brightness, a* represents the red-green chroma and b* represents the yellow-blue chroma. Colour difference ΔE*(a*b*) quantifies the colour difference between any two objects.[11]

The limitations of the visual shade guide method can contribute to the dissatisfaction of patient, technician and clinician with inaccurate colour matching. There will be inconsistencies amongst dentists in matching tooth shades with shade guides, as is evidenced by the inability of some dentists to reliably duplicate their own previous shade selections.[6] Therefore, an exact colour match is rarely possible, and hence the need to determine the magnitude and direction of the differences or errors.

Several studies[21,22,24] have shown differences between visual shade matching guides and digital devices for shade matching but few[10,31] have looked at the clinical implications. Currently, very few studies have quantitatively assessed the errors or differences arising from visual shade matching using shade guides *in vivo* to determine colour of teeth. The aim of this study was to evaluate and compare the differences in colour selection between visual shade-taking using Vita Classical and Vita 3D Master (VITA Zahnfabrik GmbH, Germany) shade guides and the data recorded by a spectrophotometer (SpectroShade MHT, Verona, Italy).

MATERIALS AND METHODS

Twenty five patients aged between 20 and 25 years were randomly selected. The inclusion criteria for patients were a complete set of anterior teeth and a sound upper right central incisor (tooth number 11). The exclusion criteria were discoloured tooth/teeth, presence of any caries or restorations, non-vital teeth, presence of crowns or veneers related to the tooth to be matched, smokers, patients with poor oral hygiene, presence of any enamel or dentinal defects, patients that have previously undergone whitening procedures and patients that were using any form of orthodontic appliance at the time of the shade determination.

Figure 1: Spectrophotometer held at middle third of the tooth.

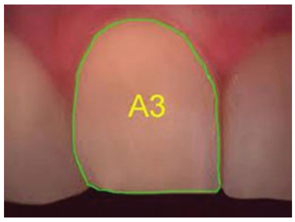


Figure 2: Green outer line around the tooth as seen on spectrophotometer.

All patients were seated in a dental chair set in the upright position with the patient's head firmly positioned in the headrest, in a room with grey walls and ceiling-mounted D65 daylight-corrected fluorescent lighting (K6500). Prior to shade matching the tooth surface was cleaned by asking the patient to brush the front teeth for one minute and then rinsing. The teeth were then thoroughly drenched with water spray to avoid a false reading due to extrinsic discolouration. The tooth surface was wiped with moistened gauze immediately prior to taking the reading. Care had also been taken not to dehydrate the teeth prior to colour measurements to avoid changes in opacity, which may occur as a result of intrinsic loss of humidity.

Spectrophotometer measurements

A reflectance spectrophotometer (SpectroShade, Handy Dental Type 71.3000, Serial No. HDL2173, MHT, Verona, Italy) was used in this study. For the first shade matching reference point the spectrophotometer (Figure 1) was set on Vita Classical. As per the instructions of the manufacturer a calibration of the spectrophotometer was performed before each reading was taken using a white and green ceramic block provided by the manufacturer.

The device was set on full tooth mode and was placed perpendicular to the tooth surface of the maxillary right central incisor (Figure 2), flush on the area between the middle third of the crown and the incisal edge as indicated by the cross lines seen on the image of the tooth on the device. The instrument was hand-held steadily against the tooth surface and the activation button on the hand piece was pressed until the machine beeped to indicate completion of the measurement and the result shown on the screen of the device. A reading was obtained only when the tooth was in full focus and an outer green line completely encircled the image of the tooth (Figure 3). These precautions enabled accurate and reproducible readings. Each reading was repeated several times by one examiner until two identical and sequential readings were achieved. That data was taken as the reference for the tooth in the Vita Classical Shade.

For the second shade matching reference reading, the spectrophotometer (Spectroshade MHT, Verona, Italy) was set on Vita 3D Master Shade and the colour matching procedure was then repeated for each patient.

Both the Vita Classical and Vita 3D Master readings were then converted to the L*a*b* scale using the SpectroShade software (Spectroshade MHT, Verona, Italy).

The third set of reference readings were obtained when the spectrophotometer was set on L*a*b* colour system to obtain an objective (actual) colour of the tooth and the colour matching procedure was repeated for each patient.

Tooth colour determination by shade tab selection

The colour of the test teeth were also matched using two shade guide systems, Vita Classical (16 shade tabs) and Vita 3D Master with 26 shade tabs Two experienced male operators (each with about 25 years clinical experience), independently recorded the colour of the maxillary right central incisor under the same conditions as for the spectrophotometer. Prior to this study, both operators had taken an online colour test (X-rite Pantone Test based on the Farnsworth Munsell 100 Hue Test) and had shown high accuracy for visually assessing shade.

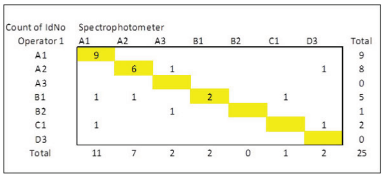
Table 1: Mean CIE L*a*b* color differences, ΔE*a*b* with standard deviation between the actual color of the tooth and the selected shade of the spectrophotometer, operator 1 and operator 2 in Vita Classical and Vita 3D Master.

	SpectroShade	Operator 1	Operator 2
Vitapan Classical	2.22 (0.65)	2.78 (1.08)	2.80 (1.01)
Vitapan 3D Master	2.18 (0.65)	3.33 (1.26)	3.30 (1.28)

Validation of L*a*b* colour measurements

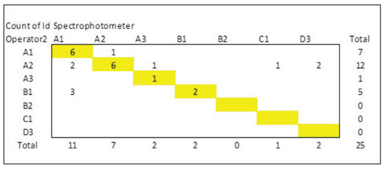
To validate the repeatability of the spectrophotometric analysis of L*a*b* data of the upper central incisor, separate measurements of the shade tabs of both the Vita Classic and Vita 3D Master were taken with the device. Mean colour differences (ΔE*a*b*) between the shade tab data and the spectrophotometer readings were then analysed using the Commission Internationale de l'Eclarirage[11] colour coordinates and described using the following calculations:

1. $\Delta L^* = L^*_2 - L^*_1$
   L*: lightness-brightness difference in lightness/darkness value + = *lighter and* – = *darker*
2. $\Delta a^* = a^*_2 - a^*_1$
   a*: green-red difference on red/green axis + = *redder and* – = *greener*
3. $\Delta b^* = b^*_2 - b^*_1$
   b*: yellow-blue difference on yellow/blue axis + = *yellower and* – = *bluer*
4. $\Delta E^*_{(a^*b^*)} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$ (total colour difference value)



Count of IdNo Operator 1	A1	A2	A3	B1	B2	C1	D3	Total
A1	9							9
A2		6	1				1	8
A3								0
B1	1	1		2		1		5
B2			1					1
C1	1						1	2
D3								0
Total	11	7	2	2	0	1	2	25

Figure 3: Operator 1 vs. spectrophotometer on Vita Classical shade guide.



Count of Id Operator2	A1	A2	A3	B1	B2	C1	D3	Total
A1	6	1						7
A2	2	6	1			1	2	12
A3			1					1
B1	3			2				5
B2								0
C1								0
D3								0
Total	11	7	2	2	0	1	2	25

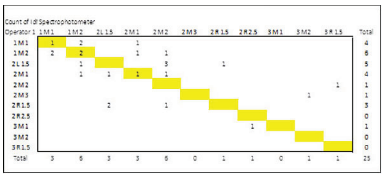
Figure 4: Operator 2 vs. spectrophotometer on Vita Classical shade guide.

STATISTICAL ANALYSES

The level of agreement for shade-matching techniques were determined using the Pearson's Correlation Coefficient using IBM SPSS ver21 statistics program (SPSS Inc., Chicago IL, USA). Multiple comparisons between the groups were analysed using the Wilcoxon Signed Rank Test. All non-parametric statistical analyses were performed at a 95% confidence interval (CI) with the level of probability set at alpha = 0.05.

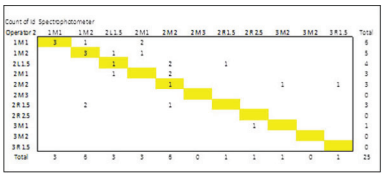
RESULTS

Figures 3 and 4 show the relationship of the data between operators 1 and 2 compared with those of the spectrophotometer set on the Vita Classical scale. The yellow band shows the number of teeth whose readings were in agreement between the operators and the spectrophotometer. The data of 17 teeth were in agreement between operator 1 and the spectrophotometer while a total of eight teeth (four above and four below the yellow band) showed disagreements (Figure 3). Operator 2 was in agreement with the spectrophotometer 15 times (Figure 4) and showed a differences on 10 readings (five above and five below the yellow band of agreement).



Count of Id Operator 1	1M1	1M2	2L1.5	2M1	2M2	2M3	2R1.5	2R2.5	3M1	3M2	3R1.5	Total
1M1	1	2		1								4
1M2	2	2		1	1							6
2L1.5		1			3		1					5
2M1		1	1	1	1							4
2M2											1	1
2M3										1		1
2R1.5			2		1							3
2R2.5												0
3M1								1				1
3M2												0
3R1.5												0
Total	3	6	3	3	6	0	1	1	0	1	1	25

Figure 5: Operator 1 vs. spectrophotometer set on Vita 3D Master shade guide.



Count of Id Operator 2	1M1	1M2	2L1.5	2M1	2M2	2M3	2R1.5	2R2.5	3M2	3M2	3R1.5	Total
1M1	3	1		2								6
1M2		3	1	1								5
2L1.5			1		2		1					4
2M1			1		2							3
2M2					1				1		1	3
2M3												0
2R1.5		2			1							3
2R2.5												0
3M1								1				1
3M2												0
3R1.5												0
Total	3	6	3	3	6	0	1	1	1	0	1	25

Figure 6: Operator 2 vs. spectrophotometer set in Vita 3D master shade guide.

When using the Vita 3D Master shade guide, operator 1 was in agreement in four instances and out of agreement 21 times with the spectrophotometer (Figure 5) while operator 2 was in agreement nine instances and out of agreement with the spectrophotometer 16 times (Figure 6).

When the colour differences between the actual colour of the tooth and the readings of the operators in the L*a*b* scale (ΔE*a*b*) were compared there was no significant difference between the data of the operators in both the shade guide systems (Wilcoxon Signed Rank Test, $p>0.05$).

There was a significant difference, however, between the colour differences between the visual shade guides and the spectrophotometer (Wilcoxon Signed Rank Test, $p<0.05$). The mean CIE L*a*b* colour difference (ΔE*a*b*) between the actual colour of the tooth in Vita Classical and the shade selected by the spectrophotometer, and by operator 1 and by operator 2 were 2.22(SD±0.65), 2.78(SD±1.08) and 2.8(SD±1.01) respectively, while the colour differences in the Vita 3D Master system were 2.18(SD±0.65), 3.33(SD±1.26) and 3.30(SD±1.28) for the spectrophotometer, operator 1 and operator 2 respectively (Table 1).

Table 2: Pearson's Correlation matrix of color difference (ΔE*a*b*) units between Operator 1, Operator 2 and Spectrophotometer in Vita Classical (VC) and 3D Master shade guides

	Vita Classical			Vita 3DMaster		
	SpectroShade	Operator 1	Operator 2	SpectroShade	Operator 1	Operator 2
SpectroShadeVC	1	0.394	0.322	0.397	0.105	-0.038
Operator 1	0.394	1	0.633	-0.008	0.183	0.292
Operator 2	0.322	0.633	1	0.289	0.433	0.222
SpectroShade3D	0.397	-0.008	0.289	1	0.540	0.236
Operator 1	0.105	0.183	0.433	0.540	1	0.649
Operator 2	-0.038	0.292	0.222	0.236	0.649	1

Both operators were in agreement 64% of the time on the Vita Classical shade guide when compared with the spectrophotometer. There was a strong positive correlation in the colour differences (Table 2) between operator 1 and operator 2, both in the Vita Classical shade guide data (Pearson's coefficient of correlation, r = 0.63) and in the Vita 3D Master shade guide data (Pearson's coefficient of correlation, r = 0.649).

In L*a*b* scale there was a strong negative correlation in the L* and a* for both Vita Classical (Pearson's coefficient of correlation, r = -0,817) and Vita Master3D (Pearson's coefficient of correlation, r = -0,852).

DISCUSSION

Colour matching of a natural maxillary central incisor, even under ideal conditions, is one of the most difficult challenges in clinical dentistry.[2] Despite the fact that the inaccuracy and subjectivity of visual perception and the limitations of shade guides have been pointed out,[2,12,13] the technique is still one of the primary methods of colour matching in dentistry,[14,15] with the Vita Classical shade guide being the most popular.[12]

A colour-measuring device that produces constant values under any given condition would be most valuable.[9] In this study the spectrophotometer was sequentially set on the Vita Classical, Vita 3D Master and L*a*b* scales to compare those data with the results of the visual method of shade matching. The spectrophotometric reading is not affected by ambient light, and the amount of light reflected from objects is measured over a full spectral wavelength.[2] A high level of agreement was observed in the use of spectrophotometers confirming their reliability for use as a shade matching device in dentistry.[9,16,17] Most, including SpectroShade, had similar high reliabilities (over 96%), indicating predictable shade values from repeated measurements.[18,19] However, widespread use of spectrophotometers in clinical settings is hampered by the fact that the equipment is complex and expensive and that it is difficult to measure the colour of teeth *in vivo*.[29]

In this study the colour matching in both visual colour methods as measured by the operators using both the Vita Classic and Vita 3D Master systems differed from the spectrophotometer readings. Both operators were accurate 64% of the time when using the Vita Classical shade guide. Other studies showed inter-observer agreement in selecting the best shade match to be about 30% for both Vita Classical and Vita 3D Master.[20,21] In a study by Paul *et al*,[22] the human operators using Vita Classical shade tabs visually selected shades that were matched with shades measured by means of a reflectance spectrophotometer in only 26% of the tests.

In the Vita 3D Master shade scale data, a larger difference was noted between the human observers and the digital measurement, possibly as a result of the system having more shade tabs, making these smaller colour differences more difficult to detect by the human eye, especially when the data were closer to the yellow band of agreement (Figures 5 and 6). The distribution of the chroma, and the CIE L*, a* and b* values in the Vita 3D Master shade guide is more ordered and equally distributed[15] compared with the Vita Classic shade guide.[23] The intervals in the colour parameters between adjacent tabs are not uniform,[15,13] and the colour difference values between each pair of shade tabs in the Vita 3D Master shade guide study ranged between 0.9 and 18.6 ΔE units.[15] Furthermore, coverage errors and ΔE values in all of the five shade guide systems tested were all beyond the clinical threshold of ΔE = 3.3 units.[24] When considering 16 colours, there is a low agreement between visual assessment by the examiners and by the digital spectrophotometer, possibly explained by the predominance of shades of colour situated in the medium spectrum of the shade guide, impairing visual detection of small colour changes by the examiners.[25] Examiners find difficulty in identifying exact colours or differentiating between colours immediately adjacent on the Vita Classical shade scale.[25]

For a more accurate and predictable aesthetic outcome it has been suggested that both instrumental and visual colour matching methods should be used, as they complement each other[26] especially where there may be uncertainties from visual matching techniques.

In the current study the MHT SpectroShade was used as it can measure colour when set in the Vita Classical, Vita 3D Master or L*a*b* scales. The SpectroShade measures the complete tooth surface area providing a colour map of the tooth that can then easily be communicated to laboratories. Other devices that measure a limited tooth surface area (3 to 5 mm) may suffer an edge loss of the light, which may result in errors in colour.[27] Also, the light from the SpectroShade is splinted in order to have each tooth illuminated simultaneously from two sides at 45° angles and directed at 0° observation configuration (MHT Optic Research AG, Switzerland), which will avoid the inaccuracies of edge loss.[28] Spectroshade was the most repeatable device in recording tooth shades clinically and showed a good proportion of complete agreement, higher than that achieved by X-Rite Shadevision colourimeter and Vita Easyshade spectrophotometer.[29]

Colour difference (ΔE*a*b*) quantifies colour difference between any two objects, thus enabling a more precise understanding of the magnitude of the difference in colour. In this study, the mean colour difference (ΔE*a*b*) of actual tooth colour (SpectroShade set in L*a*b* scale) and the SpectroShade readings set in Vita Classical and Vita 3D Master of the corresponding tooth was 2.2, while the colour difference between the chosen shade tabs of Vita Classical for operators 1 and 2 and the actual colour of the corresponding tooth was 2.8 for both operators and 3.3 in the Vita 3D Master system. Paravina *et al*[30] have shown colour differences ranging between 2.4 and 5.2. When the differences they recorded between the best shade matching tabs were compared, the ΔE values ranged from 4.5 to 6.2,[31] and are greater than those obtained in this study. ΔE*a*b* values of tooth / shade tab values were found to be 7.61 for Vita Classical and 3.54 for Vita 3D Master.[24]

There is currently no consensus in the dental literature as to how much colour difference is considered an acceptable colour mismatch and how much of a colour difference is perceptible to the observer.[10] Colour differences of ΔE*a*b* = 1 were detectable by 50% of the observers in-vitro,[32] while Douglas and Brewer[33] found 50% of the prosthodontists rejected a crown mismatch of ΔE*a*b* = 1.7 *in vitro*. Douglas *et al*,[10] showed a higher value of 2.6 ΔE units at which 50% observers could perceive a colour difference (perceptibility tolerance). A colour difference of 5.5 ΔE units was considered in that study as a mismatch *in vivo* but was clinically acceptable (acceptability tolerance). ΔE = 3.3 was considered unacceptable for 50% of observers when comparing composite resin specimens *in vitro*.[34] A colour difference of ΔE = 3.7 units between teeth in the mouth was rated as a match, while ΔE = 6.8 as a mean colour difference was rated as a marginally acceptable mismatch between compared teeth under *in vivo* conditions.[35]

It is important to establish tolerances for both perceptibility and acceptability in terms of colour difference (ΔE units), as research results assessed for statistical significance alone cannot be interpreted for clinical significance.[10] It may seem that a higher tolerance level may be acceptable in *in vivo* conditions.

Therefore, although differences were found in this study between the shade tabs chosen when using the Vita Classical and Vita 3D Master shade guides and the spectrophotometer readings, the actual colour differences may not be readily perceived and/or may be acceptable in the clinical situation.

The strong negative correlation in the L* and a* for both Vita Classical (Pearson's coefficient of correlation, r = -0,817) and Vita Master3D (Pearson's coefficient of correlation, r = -0,852) indicates that as the error in L* increases the error in a* decreases. It may seem that errors in L* i.e. lightness/brightness during shade matching may be an important factor in obtaining correct shade matching.

The Vita Classical shade guide was chosen for comparison because it has been a gold standard in dentistry for decades[30] and is well established in the market, and the Vita 3D Master was supposed to more closely cover the tooth colour space.

This study was designed to evaluate the accuracy of the visual shade matching technique and not to test the reliability of the spectrophotometer. A similar study design can be used to test the reliability of two or more spectrophotometers. This study evaluated each operator of the spectrophotometer separately for it seemed logical to test each operator individually rather than combining the readings as separating the data may give a broader descriptive analysis of any variability that may be present.

CONCLUSION

Within the limitations of this study, the results indicate that although visual assessment using shade guides to determine colour of natural teeth differed from that obtained using a spectrophotometer, the actual colour differences between the chosen visual shade matching tabs and the spectrophotometer fall within clinically acceptable limits.

CLINICAL SIGNIFICANCE

Whenever possible, both the instrumental and visual colour matching method should be used, as they complement each other especially where there may be colour measurement uncertainties from visual matching techniques and the combination can lead to a more predictable aesthetic outcome.

References

1. Dancy WK, Yaman P, Dennison JB, O'Brein WJ, Razzoog ME. Colour measurements as quality criteria for clinical shade matching of porcelain crowns, J Esthet Restor Dent 2003;15(2):114-22.
2. Ishikawa-Nagai S, Yoshida A , Da Silva JD, Miller L. Spectrophotometric analysis of tooth colour reproduction on anterior all-ceramic crowns: Part 1: analysis and interpretation of tooth colour. J Esthet Restor Dent 2010;22:42–52.
3. Brewer JD, Wee A, Seghi R. Advances in colour matching. Dent Clin North Am 2004;48:341–58.
4. Joiner A. Tooth colour: a review of the literature. J Dent 2004;32:3-12.
5. O'Brien W J. A new, small-colour-difference equation for dental shades. J Dent Res 1990;69:1762-4.
6. Culpepper WD. A comparative study of shade-matching procedures. J Prosthet Dent 1970;24:166-73.
7. Corcodel N, Helling S, Rammelsberg P, Hassel AJ. Metameric effect between natural teeth and the shade tabs of a shade guide. Eur J Oral Sci 2010;118:311–6.
8. Baharin SA, Dong TY, Jing TW. Anterior tooth shade selection procedure: influence of light sources and patient's position. Sains Malaysiana 2013;42(1):7–11.
9. Odaira C, Itoh S, Ishibashi K. Clinical evaluation of a dental colour analysis system: The Crystaleye Spectrophotometer. J Prosthodont Res 2011;55:199–205.
10. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007;97:200-8.
11. CIELAB 1978. Commission Internationale de l'Eclarirage (CIELAB 1978).
12. Todorovic A, Todorovic, Gostovic AS, Lazic V, Milic B, Djurišic S. Reliability of conventional shade guides in teeth colour determination. Vojnosanit Pregl 2013;70(10):929–34.
13. Analoui M, Papkosta E, Cochran M, Matis B. Designing visually optimal shade guides. J Prosthet Dent 2004;92:371-6.
14. Klaff D. Achieving the predictable composite resin restoration: the nature of colour. International Dentistry 2010;SA12(2).
15. Ahn JS, Lee YK. Colour distribution of a shade guide in the value, chroma, and hue scale. J Prosthet Dent 2008;100:18-28.
16. Zenthoefer A, Cabrera T, Corcodel N, Hassel A, Rammelsberg Repeatability, Reliability and Accuracy of Two Clinically Applicable Spectrophotometers. IADR General Session 2013.
17. Lehmann KM, Devigus A, Igiel C, Wentaschek S, Azar MS, Scheller H. Repeatability of colour-measuring devices. Eur J Esthet Dent 2011;6(4):428-35.
18. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent 2009;01(3):193-9.
19. Bayindir F, Gozalo-Diaz D, Kim Pusateri S, Wee AG. Incisal translucency of vital natural unrestored teeth: A clinical study. J Esthet and Restor Dent 2012;24(5):335–43.
20. Won-Suk Oh, Woong-Koh, Brien WJ. Estimation of visual shade matching errors with two shade guides. Quintessence Int 2009;40:833-66.
21. Naik AV, Jurel SK, Pai RC. Inter-operator variability in shade matching for restoration with two shade guides. Int J Contemp Dent 2011;(2)1:30-4.
22. Paul S, Peter A, Pietrobon N, Hämmerle CHF. Visual and spectrophotometric shade analysis of human teeth. J Dent Res. 2002;81(8):578-82.
23. Park JH, Lee YK, Lim BS. Influence of illuminants on the colour distribution of shade guides. J Prosthet Dent 2006;96:402-11.
24. Li Q, Yu H, Wang YN. *In vivo* spectroradiometric evaluation of colour matching errors among five shade guides. J Oral Rehab 2009;36:65–70.
25. Meireles SS, Demarco FF, Santos IS, Dumith SC, Della Bona A. Validation and reliability of visual assessment with a shade guide for tooth-colour classification. Oper Dent 2008;33(2):121-6.
26. Chu SJ, Trushkowsky RD, Paravina RD. Dental colour matching instruments and systems. Review of clinical and research aspects. J Dent 2010;38s e2-e16.
27. Bolt RA, ten Bosch JJ, Coops JC. Influence of window size in small-window colour measurement, particularly of teeth. Phys. Med. Biol. 1994;39:1133-42.
28. Ten Bosch, JJ.Coops JC. Tooth colour and reflectance as related to light scattering and enamel hardness. J Dent Res 1995; 74:1 374-80.
29. Khurana R, Tredwin CJ, Weisbloom M, Moles DR. A clinical evaluation of the individual repeatability of three commercially available colour measuring devices. Brit Dent J 2007;203(12):675-80.
30. Paravina RD, Majkic G, Imai FH, Powers JM. Optimization of tooth colour and shade guide design. Int J Prosthodont 2007;16:269-76.
31. Paravina RD. Performance assessment of dental shade guides. J Dent 2009;37s:15-20.
32. Kuehni RG, Marcus RT. An experiment in visual scaling of small colour differences. Colour Research and Application 1979;4:83-91.
33. Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. J Prosthet Dent 1998;79:254-60.
34. Ruyter IE, Nilner K, Moller B. Colour stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987;3:246-51.
35. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colourimetry. J Dent Res 1989;68:819-22.