

The repeatability of an intraoral dental colorimeter

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Statement of problem. Characterizing and reproducing color remain one of the most challenging aspects of dentistry. A relatively new intraoral colorimeter measures the color of natural teeth and metal-ceramic restorations and prints out a color recipe for the Vintage Halo Porcelain System. The reliability of the colorimeter is unknown.

Purpose. The purpose of this study was to evaluate the reliability of a contact dental colorimeter and to correlate the shade registered by the colorimeter with the shade selected by experienced clinicians.

Material and methods. In part I of the study, 2 examiners (A and B) took 2 colorimeter measurements from the maxillary right central incisors of 11 subjects. The examiners were blinded to their own data and those of other investigators. The readings were repeated 3 weeks later with the same protocol. The Cronbach α reliability coefficient was used to analyze the collected data. In part II of the study, 2 experienced clinicians (examiners D and E) selected a shade from the classic Vita Lumin Vacuum shade guide for the maxillary right central incisors of the same 11 subjects. The clinicians were blinded to each other's selections and the colorimeter readings. It should be noted that the manufacturer of the colorimeter uses the terms shade, value, and hue to represent chroma, value, and hue, respectively, as defined in the *Glossary of Prosthodontic Terms* (J Prosthet Dent 1999;81:39-110).

Results. The reliability analysis results for each of the combined trials for shade, value, and hue were all $>.94$. The interexaminer reliability α values were $>.9$ for shade and value and .64 to .74 for hue. The interexaminer α represented the value range of each of 4 measurements. The intraexaminer reliability α values for shade, value, and hue were .99, .95, and .96 for examiner A and .99, .93, and .97 for examiner B, respectively. In part II of the study, the colorimeter agreed with itself 82% of the time, whereas clinicians agreed with each other on the selected shade 73% of the time. Selections made by the colorimeter and the clinicians matched 55% to 64% of the time.

Conclusion. Within the limitations of this study, the colorimeter reliably measured the color of natural teeth. (J Prosthet Dent 2002;88:585-90.)

CLINICAL IMPLICATIONS

This study suggests that a reliable intraoral contact colorimeter is available to the dental profession for natural tooth color measurement. The colorimeter's accuracy remains untested.

The demand for attractive restorations challenges the restorative dentist to produce prostheses that duplicate the form, function, and esthetics of the natural dentition. The esthetics of any restoration depend on outline form, surface form, translucency, and color.¹ Esthetically superior restorations are now possible as a result of improvements in dental materials and fabrication techniques. However, one of the most challenging aspects of esthetic dentistry is color assessment and its reproduction.

The physical production of color requires 3 elements: a light source, an object, and a detector.² The detector can be the eye and brain of the observer or a sensor connected to a computer. Color measurement has been classified and specified in several ways.^{2,3} Two of the most widely used systems for describing color are the Munsell System and the International Commission on Illumination (CIE) color/order system. The Munsell System compares the perceived color of an object with a standardized and orderly arrangement of colored chips.² It describes colors in a 3-dimensional coordinate system of hue, value, and chroma. In this system, hue is represented by 10 different colors. Each color is arranged around the circular horizontal plane of the coordinate axis. Chroma is the strength (or intensity) of the color and is represented by the spokes of a wheel, with the purest color at the periphery. Value refers to the lightness or darkness of a color. The 10 value levels are represented by 9 wheels on the vertical axis.²

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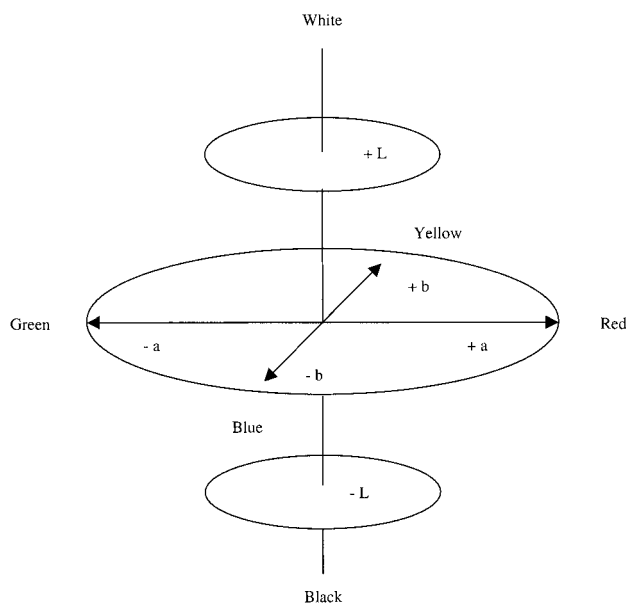


Fig. 1. CIE Lab color space.

The CIE system is the international standard for color measurements.² It incorporates a standard observer and light source. In the CIE concept, all colors can be matched by mixing relative amounts of the 3 primary colors: red (X), green (Y), and blue (Z).² The X , Y , and Z values can be mathematically converted to CIE Lab scales and expressed in the CIE Lab color space as shown in Figure 1.² The L axis represents the darkness and lightness coordinate, with values ranging from 0 (perfect black) to 100 (perfect white). The a axis represents chromaticity coordinates: green signifies negative coordinates and red positive coordinates. The b axis also represents chromaticity coordinates: yellow signifies positive coordinates and blue negative coordinates.

The CIE X , Y , Z color space determines whether 2 colors are the same or different, but it does not determine the appearance of color.^{2,3} O'Brien et al⁴ proposed a color difference equation ($\Delta E_M = \Delta H/5 + 7\Delta V + 4\Delta C$) to assess small color differences between different dental shades or different shade guides.⁴ ΔE_M is an estimation of CIE ΔE based on Munsell parameters, is the average chroma, and ΔH , ΔV , and ΔC are the difference in hue, value, and chroma, respectively, of the 2 colors being compared.

Controlling the color of dental restorations is difficult primarily because the task is completed visually. The process is affected by many factors, such as individual differences in understanding and perceiving color,^{2,3,5} experience of the observer,^{2,5} lighting,^{2,3,6} and surrounding gingival color.⁶ Moreover, visual assessment is often communicated to a laboratory technician through the use of inadequate shade guides.⁷ Shade guides made by the same manufacturer may differ slightly.^{1,7} Most shade guides lack the volume of color space required to

represent the natural dentition,^{7,8} and shades often are not systematically distributed throughout the guide.^{7,9-11} Historically, adjunctive aids such as slides, pictures, and written descriptions have been used to make the color selection process more accurate.^{9,12}

A lack of quality control and standardization in the manufacturing of dental materials further complicates the task of color control.^{10,11} Porcelain powders are not the same color from batch to batch^{10,12} and do not always match the shade guide once they are fused.^{1,10,11} More often than not, shade guide specimens and the porcelain powders are not made of the same material or fabricated in a similar fashion.^{9-11,13}

Instruments such as spectrophotometers and colorimeters have been used in industrial and research settings for the evaluation and specification of color. Spectrophotometers measure the reflectance or transmittance factors of an object 1 wavelength at a time. They have been used to measure the spectral curves of porcelains and extracted teeth.^{1,12,14-16} However, widespread use of spectrophotometers in dental research and clinical settings has been hindered by the fact that the equipment is complex and expensive and, more importantly, that it is difficult to measure the color of teeth in vivo with these machines. Much of the dental research on the color of natural teeth and porcelains, in vivo and in vitro, has been conducted with colorimeters.¹⁷⁻²⁷ These instruments are designed to measure color in X , Y , Z tristimulus terms or in CIE Lab values; color filters approximate the spectral function of the standard observer's eye. Colorimeter measurements have been compared with spectrophotometer readings and deemed reliable and accurate for color difference measurements.^{17,21-28}

The results of investigations of the relationship between color perceived by human observers and color assessed by colorimeters have been inconclusive. Some investigators found a significant correlation between instrumental measurements and human observations²³⁻²⁵; others reported no significant agreement.²⁶⁻²⁸ O'Brien et al²⁸ compared the sensitivity of a clinical electronic colorimeter and a group of human observers with the colored pigments used in commercial dental porcelains. They found that the colorimeter tested was more sensitive to orange pigments in porcelain, whereas the experienced human observers were able to detect lower concentrations of yellow, blue, brown, and gray pigments in the porcelain under controlled lighting.

One relatively new intraoral contact colorimeter—the Shade Eye-Ex Dental Chroma Meter (Shofu Inc, Kyoto, Japan)—consists of a handheld measuring unit and a desktop DPU-201GS printer and controller. The measuring unit is equipped with a disposable contact tip that measures 2.5 mm in diameter, with an outside diameter of 5.0 mm at the base and 4.0 mm at the top. A holder with a 10-mm base diameter fits over the dispos-

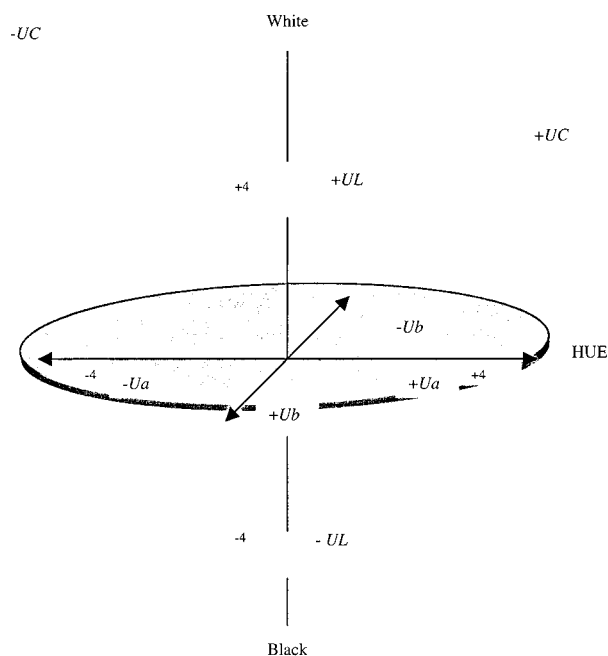


Fig. 2. Colorimeter color space.

able contact tip. The unit uses a pulsating xenon lamp and a 0-degree diffuse configuration to trigger 3 automatic measurements. A maximum of 5 measurements may be recorded if necessary.

The colorimeter is designed to measure the shades of natural teeth (tooth mode) and metal-ceramic restorations (porcelain mode). When the unit is in tooth mode, the following are printed: guide number, shade, value, hue, and the color "recipe" for the Vintage Halo Porcelain System (Shofu Dental Corp, San Marcos, Calif.).²⁹ The mixing ratio printed in the recipe can be referenced to the Shade Eye-Ex/Vintage Halo color mixing chart. The classic Munsell color wheel can be used to interpret the printed data while the colorimeter is in tooth mode. In porcelain mode, the machine measures and prints shade, value, and hue specifications.

The manufacturer of the colorimeter uses the terms shade, value, and hue (Fig. 2) to represent the 3 attributes of color in the Munsell system (Fig. 3). Shade is the x axis, value is the y axis, and hue is the z axis of the color wheel, with yellow and red placed at the opposite end of the spectrum (axis). On the basis of the shade, value, and hue results, the colorimeter selects the nearest Vita Lumin Vacuum (Vita Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) shade tab equivalent and prints it as the guide number. The dentist is encouraged to confirm the tooth shade with the Vita Classic or Vintage Halo (Shofu Inc, Kyoto, Japan) shade guide in conjunction with the gingival mask "GUMY" (Shofu Inc.) supplied by the manufacturer.

A testing device should be both accurate and precise. This study evaluated the reliability of the Shade Eye-Ex

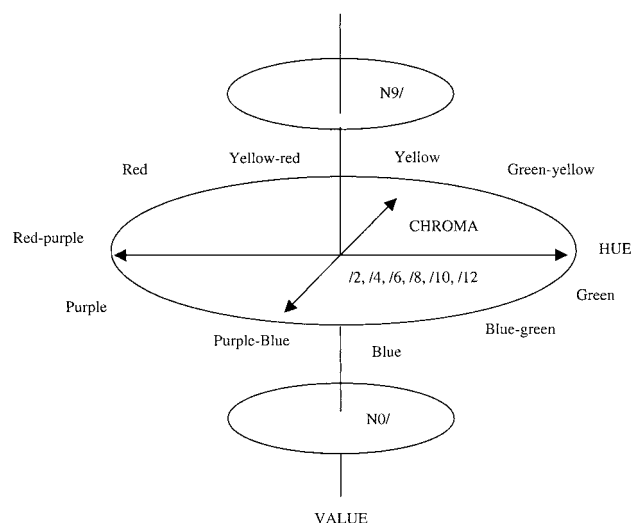


Fig. 3. Munsell color/order system.

Dental Chroma Meter and assessed measurement validity by comparing the shade registered by the colorimeter with the shade selected by experienced clinicians.

MATERIAL AND METHODS

In vivo testing was performed on 11 subjects (2 women and 9 men). The inclusion criteria were as follows: natural maxillary right central incisor present, no history of any restorative procedure performed on the tooth, no history of orthodontic therapy, no history of tooth bleaching, no carious lesions present, and no history of gingivitis or periodontitis. Exclusion criteria were as follows: history of endodontic therapy or significant restorative and/or prosthodontic therapy on maxillary right central incisor, absence of natural maxillary right central incisor, subject undergoing active periodontal and/or orthodontic therapy, subject not able to attend both data recording sessions, and subject using tooth-whitening dentrifice.

In part I of the study, the Shade Eye-Ex Dental Chroma Meter was used to take measurements from the maxillary right central incisor, 0.5 to 1.0 mm from the free gingival margin on the middle gingival third area. Two examiners (A and B) participated in placement of the measuring unit onto the teeth. They were blinded from their own data and those of other investigators. A third person (examiner C) calibrated and maintained the unit according to the manufacturer's instructions for each study session. He also formatted, collected, and recorded the printed data.

In the first trial, each subject was seated in a well-lit area of the clinic with his or her head and back against a partition wall. A disposable tongue blade was used to retract the maxillary lip. The light-emitting diode display faced away from examiner A; only examiner C could observe the panel. Once examiner A was satisfied with

Table I. Reliability coefficients for machine-registered shade, value, and hue

	Day 1		Day 2		Day 1		Day 2	
	Run 1 (exam 1 and 2)	Run 2 (exam 1 and 2)	Run 1 (exam 1 and 2)	Run 2 (exam 1 and 2)	Exam A (run 1 and 2)	Exam B (run 1 and 2)	Exam A (run 1 and 2)	Exam B (run 1 and 2)
Shade	.99	.98	1.00	.99	.97	.99	.97	.97
Value	1.00	.94	1.00	.89	.90	.85	.90	.80
Hue	.90	.96	1.00	.89	.85	.94	1.00	.89

exam = Examiner.

the position of the contact tip, he informed examiner C to initiate 3 to 5 automatic measurements. The measurement tip then was removed from the tooth surface, and examiner C collected the data from the printer. Two readings from the same spot were obtained in this manner (runs 1 and 2), with a lapse of no more than 1 minute between them. Examiner B repeated the same sequence of tasks. In the second trial, measurements were made on the same subjects in the same manner 3 weeks later.

The Cronbach α reliability coefficient was established between the measurements made 3 weeks apart (trials 1 and 2), between the examiners, and between runs 1 and 2. The α value ranges from 0 to 1. An α value greater than .9 indicates that the reliability of the measurement is very high; an α value of 0 indicates no correlation. A negative α value is possible when the instrument measurements are not positively correlated and the reliability model is violated. Part II of the study involved the same 11 subjects and examiner C, but 2 different clinicians—both experienced prosthodontists—made shade selections (examiners D and E). Subjects were seated in the same clinic area used in part I of the study. The examiners (who were blinded to each other's decisions) selected a shade from the Vita Lumin Vacuum shade guide for the maxillary right central incisor of each subject. Examiner C recorded the shade tab selections. The tab names were later converted for an estimation of ΔE . The following equation was used for color difference calculations⁴: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. A “match” was considered to be present when 10 shade selections across the row were the same. When there was a shade match between examiners A and B and a shade match between examiners D and E, but a shade difference between them, the 2 nominal shades were converted to CIE Lab values individually. The numeric shade value was evaluated with the use of the ΔE equation. When ΔE was less than or equal to 1, then the 2 different shades were considered a “near match.”

RESULTS

The results of the reliability analysis for means of the combined trials for shade, value, and hue were .99, .96, and .94, respectively. Table I lists the individual α values. The overall reliability coefficients for the colorimeter and examiner A were .99 (shade), .95 (value), and .96

Table II. Interexaminer reliability for analysis of shade, value, and hue by examiners A and B on days 1 and 2

	Day 1		Day 2	
	Run 1	Run 2	Run 1	Run 2
Shade	.99	.99	.98	.98
Value	.90	.90	.90	.91
Hue	.74	.68	.66	.64

(hue). The overall reliability coefficients for the colorimeter and examiner B were .99 (shade), .93 (value), and .97 (hue). Interexaminer reliability analyses on days 1 and 2 are shown in Table II. Lower interexaminer reliability was found for hue than for shade and value.

Table III demonstrates the shades registered by the colorimeter (operated by examiners A and B) and the shades selected by examiners D and E (the 2 experienced prosthodontists). The colorimeter agreed with its own shade selections across trials and runs 82% of the time. Examiners D and E made the same shade selection 73% of the time. Agreement between the colorimeter and examiners D and E was 64% when a near match was considered to be a match and 55% when near matches were excluded.

DISCUSSION

The overall α values of .99 for shade, .96 for value, and .94 for hue suggest that the colorimeter was reliable. There was a notable discrepancy between the overall hue value and the interexaminer reliability for hue (.64-.74). The intraexaminer reliability for hue was .96 for examiner A and .97 for examiner B, which accounts for the higher overall value for hue. One examiner had a larger standard deviation for hue measurement.

Variations in color readings can be attributed to many factors, including the fact that teeth are not the same color throughout. Plaque and saliva play a role in color inconsistency: saliva can change the reflective index of the underlying surface, and plaque has color characteristics of its own that may interfere with tooth surface gloss. Measurement procedures can introduce variation as well. The pressure with which the contact tip is applied and the angle at which it is held are both important factors. Finally, tooth surface characteristics influence

Table III. Machine- and clinician-selected tooth shades

Specimen	A				B				D	E
	Day 1		Day 2		Day 1		Day 2			
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2		
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2		
1	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
2	A2	A2	A2	A2	A1	A1	A1	A1	A1	C1
3	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
4	A2	A2	A2	A2	A2	A2	A2	A2	A3	A3
5	C4	C4	C4	C4	C4	C4	C4	C4	C4	C4
6	A2	A2	A2	A2	A1	A2	A2	A2	D2	C1
7	D2	D3	A3	A3	C1	C1	D2	D2	D2	D2
8	D2	D2	D2	D2	D2	D2	D2	C1	D2	D2
9	A3.5	A3.5	A3.5	A3.5	A3.5	A3.5	A3.5	A3.5	A3	A3.5
10	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
11	A1	A1	A1	A1	A1	A1	A1	A1	B1	D2

Examiners A and B took the colorimeter readings; examiners D and E used the Classic Vita- Lumin shade guide.

measurement. Although the colorimeter manufacturer recommends a flat contact surface for better results, this ideal surface is often missing in vivo. There are a limited number of teeth with a flat surface large enough to accommodate the 4.0-mm measurement tip.

Special equations were used to accommodate the partitioning of the dental color space in the computer algorithm.²⁹ The partition equations provided 300 possible loci within the dental color space. Because the Vita Lumin Vacuum shade guide has only 16 shade tabs, it seems that some of the loci were not used or multiple loci referred to the same shade tab. It is also possible that both strategies were used.

The spectral reflectance of a contoured surface cannot be duplicated unless the same spot on that surface is measured.²¹ It is therefore proper to expect some variation in the results. Findings from this study cannot be compared with those of investigations of different colorimeters because their reference color filters may have had different wavelengths. Without identical color filters, metamerism is a possibility.

One of the clinical experts involved in part II of the study did not undergo testing for color vision deficiencies; the other had normal test results. They agreed with each other 72% of the time, whereas the colorimeter agreed with itself 82% of the time. These results are better than those reported Okubo et al.²⁶ It is unclear whether the Vita shade tab used by Okubo et al was made of porcelain. The CIE Lab values of the 2 Vita shade guides used in their study are quite different from those reported by O'Brien et al.²⁸

A ΔE value of less than 1 is considered excellent.⁴ If the color difference is $1 \leq \Delta E \leq 2$, the match is clinically acceptable with minor surface colorant as a modifier. If the color difference is greater than 2, the match is considered clinically unacceptable. In this study, when the Vita shade tab names were converted into CIE Lab values, color differences in the values for A1 and B1 and in

the values for D2 and C1 were so close as to be clinically indistinguishable.

The tested colorimeter can be used in the clinical setting to determine the shades of natural teeth prior to restorative treatment and to monitor the progress of patients undergoing bleaching procedures. Berns et al² referred to 4 basic principles in color technology, one of which is that during every aspect of production from input raw materials to the final product, colored products must be evaluated at each phase of the process. In everyday fabrication and insertion of a fixed partial denture prosthesis in dentistry, the final esthetic judgment is always made visually by the dentist and the patient. It is imperative that color measurement of restorations made by following the porcelain recipe match that of human visual assessment.

This study was designed to test the reliability of a single colorimeter, not the accuracy of the system in general. The same study design could be used to test reliability between 2 colorimeters manufactured by the same company. The result of such a study would disclose the quality control of the manufacturing process. To test the accuracy of any colorimeter intended for use in the intraoral environment, an intraoral gold standard must be established. There currently is no such standard.

CONCLUSIONS

Within the limitations of this study, the intraoral contact dental colorimeter tested reliably measured the color of natural teeth.

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Noteworthy Abstracts of the Current Literature

The use of shimstock to assess occlusal contacts: a laboratory study

Harper KA, Setchell DJ. *Int J Prosthodont* 2002;15:347-52.

Purpose. This study analyzed the force necessary to pull shimstock inserted between occlusal contacts of a tooth and restorative material specimen at 0-8 μm gaps. These simulations were completed on a developed experimental apparatus.

Material and Methods. The developed apparatus measured different occlusal forces between specimens at 0-20 μm gaps. The apparatus consistently pulled the inserted shimstock at 5 mm/second and measured the pulling force. The opposing specimens were a maxillary unworn first molar cusp and a polished amalgam restoration. The force necessary to remove the shimstock from between the specimens was measured at 9 occlusal loads: 0, 50, 100, 150, 200, 250, 300, 350, and 400 g. Measurements were recorded when the specimens were in contact and also when they were separated by gaps of 2, 4, 6, and 8 μm before shimstock placement.

Results. A linear increase in shimstock removal forces was observed at the 0-, 2-, 4-, and 6- μm gap settings. No significant difference in removal force was observed with the 0-, 2-, and 4- μm gaps.

Conclusion. An increase in occlusal force increased the shimstock removal force. This removal force was highest with the smaller gaps studied (0-4 μm). Zero-, 2-, and 4- μm contacts could not be differentiated using 8- μm shimstock. Gaps up to 6 μm may be designated as holding contacts because the shimstock was still held in place between the contacting surfaces. An 8- μm gap was designated as a light contact. 18 references.—DL Dixon