A New, Small-color-difference Equation for Dental Shades

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Traditionally, dental-shade-guide standards are designated in terms of Munsell hue (H), value (V), and chroma (C). However, ΔE color differences proposed as ADA tolerances for shade guides are in the CIE L*a*b* system. The purpose of this study was to evaluate a new color-difference equation,

$$\Delta E_M = \bar{C}\Delta H/5 + 7\Delta V + 4\Delta C \qquad (1)$$

for estimation of small color differences by Munsell parameters. The published values of the Bioform shade-guide tooth colors determined with a Beckman spectrophotometer were used. Color differences among 276 combinations of the 24 Bioform shade-guide colors were calculated with Eq. 1, with use of the Munsell notation, and also with the CIE L*a*b* equation for ΔE. An estimate of the accuracy of Eq. 1 was 0.41 ΔE units when ΔE CIE was below 4.0. The Vita shade-guide colors were determined with a Beckman spectrophotometer. This data set contained 16 samples, and 120 combinations were used for calculation of color difference. An estimate of the accuracy for this set of data was 0.35 ΔE units when ΔE CIE was less than 4.0. The new color-difference equation provides a means for estimation of ΔE CIE L*a*b* color difference between dental shades with Munsell notation. This equation will be useful for estimation of small ΔE CIE L*a*b* values for shade-guide teeth that are designated in terms of Munsell notation.

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Introduction.

The Munsell Color Order System has been generally accepted for describing dental shades in dentistry (Sproull, 1973). The American Dental Association acceptance program for shade guides requires the identification according to Munsell or a similar visual color-order system for each color specimen in the shade guide (Wozniak, 1987). Color differences between shades are also of interest for determination of whether a shade could be used in place of another. For determination of color difference, the ADA proposes the use of a different color system: the CIE L*a*b* color difference, ΔE. The ADA has a limit of a ΔE of 2 as a tolerance on shade guides (Wozniak, 1987). The purpose of this study was to develop an equation so that small ΔE values could be estimated directly from Munsell parameters. This would make possible the determination of whether a Bioform shade could be substituted for a Vita shade or for a shade from another guide.

Materials and methods.

The overall strategy was to derive an equation for calculating ΔE from Munsell notation and to determine its agreement with CIE ΔE calculations. The two shade guides selected for use in the calculations are the widely used Bioform (Dentsply/York Division, Dentsply International, Inc., York, PA) and Vita (Vident, Baldwin Park, CA).

Derivation of equation.—Several equations have been developed for calculation of color differences by Munsell notation (Nickerson, 1936; Balinkin, 1941; Godlove, 1951). However, these color-difference equations do not give numerical values close enough to CIE L*a*b* ΔE; that is, the regression coefficients ranged from 0.32-0.87, with correlation coefficients of 0.89-0.95. An equation giving values closer to CIE ΔE values was obtained by a multiple regression of $\bar{C}\Delta H$, ΔV, and ΔC (Rafferty *et al.,* 1985) so that a one-to-one regression could be obtained.

Munsell notation of shade guides: Bioform shade guide.—The colors of this shade guide were measured and reported in both Munsell and CIE L*a*b* systems (O'Brien *et al.*, 1989).

Vita shade guide.—The colors of a master guide supplied by Vident were measured by means of a dual-beam spectrophotometer (Beckman Model ACTA CIII, Beckman Instruments, Inc., Fullerton, CA). This spectrophotometer was equipped with an integrating sphere attachment (No. 198848, Model ASPH-U, Beckman Instruments, Inc.) and a beam-reducing accessory (No. 199056, Model ASPH-BR, Beckman Instruments, Inc.), which reduced the light beam to a dimension of approximately 1 mm × 8 mm (the sample-holder exposed a 7 mm × 10 mm oval on the tooth surface). A diagram illustrating this geometry is shown in Fig. 1. The procedure has been described in a previous report (O'Brien *et al.,* 1989). The chromaticity coordinates were converted to Munsell notation by means of graphs (Color Research Laboratory, Agri-

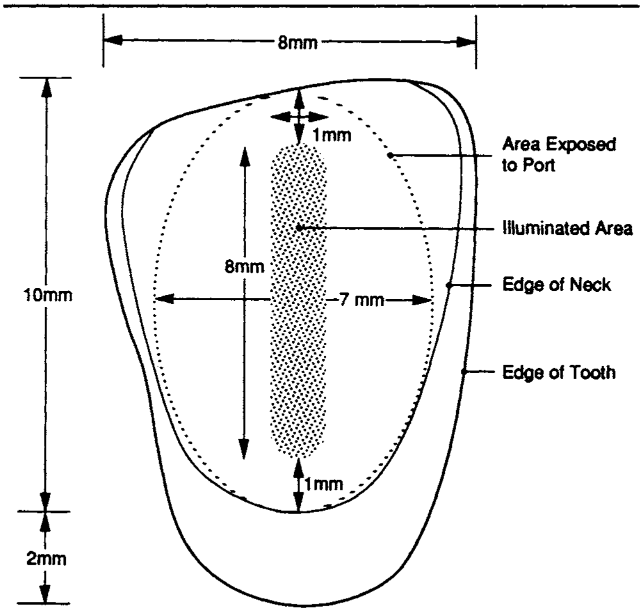

Fig. 1—Area of the shade-guide tooth where color measurements were made.

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cultural Marketing Service, USDA, 1964) and the method described by ASTM standard D 1535-80 (1984).

When translucent samples are measured, the background must be controlled so that uniform results between different spectrophotometers can be obtained. For a consistent background to be provided, the shade-guide teeth were coated with white barium sulfate ('Baker Analyzed' Reagent, J.T. Baker Chemical Co., Phillipsburg, NJ) on the lingual surfaces. All the samples measured had the same dimensions, and the measurements were made vertically along a 1-mm-wide area in the middle third of the tooth (Fig. 1). This provided an average color for the tooth that minimized the influence of variations in thickness of each tooth along its length.

Calculation and comparison of color differences.—CIE L*a*b* color differences were calculated between Bioform shades, Vita shades, and between Bioform and Vita shades by means of the CIE L*a*b* color-difference equation (CIE, 1978):

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^{*2})]^{1/2} \qquad (2)$$

Color differences between the same pairs of shade-guide colors were also calculated by the Munsell notation with Eq. 1. The results were then compared for determination of the degree of agreement between the two methods for calculation of ΔE.

Results.

Derivation of equation.—The new proposed equation is as follows:

$$\Delta E_M = \bar{C}\Delta H/5 + 7\Delta V + 4\Delta C \qquad (1)$$

where ΔE_M is an estimation of CIE ΔE based upon Munsell parameters, $\bar{C}$ is the average chroma, and ΔH, ΔV, and ΔC are the difference in hue, value, and chroma of the two colors being compared.

Vita shade guide.—The measured CIE L*a*b* values and Munsell notation are given in Table 1.

Comparison of ΔE CIE and ΔE_M.—The color differences calculated by the proposed equation (Eq. 1) when Munsell notation was used, ΔE_M, were plotted against the values of ΔE calculated with use of the CIE ΔE equation (Eq. 2) in Figs. 2-4. The average difference in the estimation of ΔE values by the proposed equation and the CIE L*a*b* equations increased as a function of ΔE, as shown in Table 2.

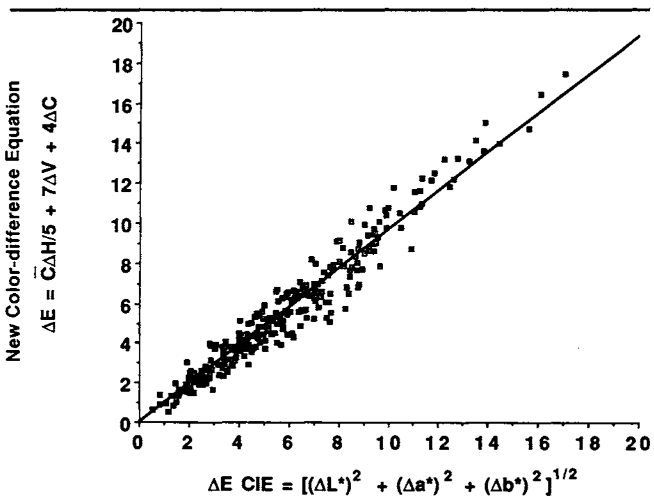

Fig. 2—The new color difference (ΔE_M) *vs.* ΔE CIE L*a*b* for the Bioform Shade Tabs (n = 276). The equation for the regression line is ΔE_M = 0.971 ΔE CIE, and the correlation coefficient is 0.972.

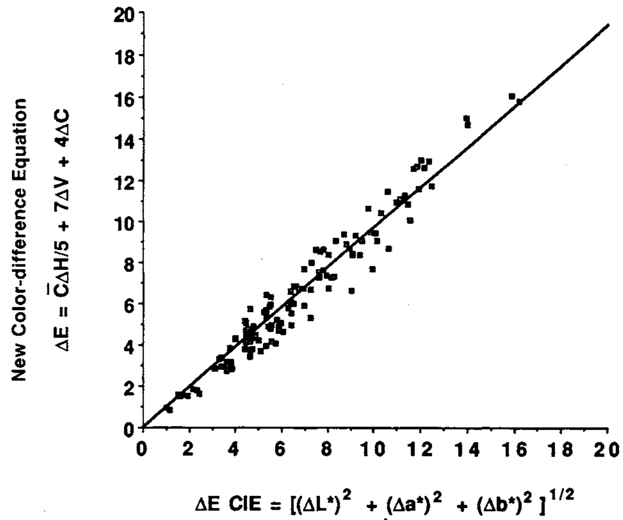

Fig. 3—The new color difference (ΔE_M) *vs.* ΔE CIE L*a*b* for the Vita Shade Tabs (n = 120). The equation for the regression line is ΔE_M = 0.973 ΔE CIE, and the correlation coefficient is 0.974.

The cumulative frequency distribution of ΔE_M - ΔE CIE is shown in Table 3. Only a small percentage of samples (1.7-3.1%) had an average difference in the estimation of ΔE values greater than 2.0. For all those samples, the ΔE_M underestimated ΔE CIE. The range of ΔE CIE was 6.53-12.32; that is, for samples with ΔE CIE < 6.53, the difference in the estimation of ΔE values was less than 2.0.

For all three data sets, the equation for the regression line was ΔE_M = 0.97 ΔE CIE; that is, there is approximately a one-to-one relationship between the ΔE_M calculated with use of Eq. 1 and the ΔE calculated with use of Eq. 2. The correlation coefficient (r) was 0.97 for all groups. The coefficient of determination (r^2) was 0.94 for the Bioform and the combined Bioform and Vita data sets and 0.95 for the Vita data set.

Discussion.

The new equation (Eq. 1) for calculation of color differences between the combined shade-guide teeth showed an average

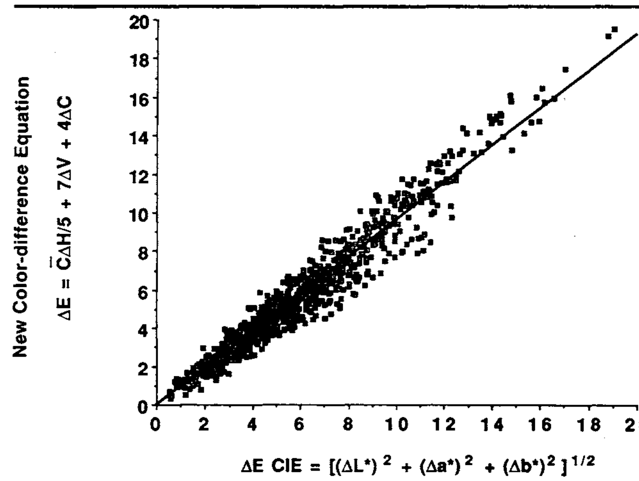

Fig. 4—The new color difference (ΔE_M) *vs.* ΔE CIE L*a*b* for the combined Bioform and Vita Shade Tabs (n = 780). The equation for the regression line is ΔE_M = 0.967 ΔE CIE, and the correlation coefficient is 0.971.

TABLE 1
CIE L*a*b* AND MUNSELL NOTATION FOR VITA MASTER SHADE GUIDE

Sample	L*	a*	b*	Hue	Value	Chroma
A1	79.57	−1.61	13.05	4.5 Y	7.80	1.7
A2	76.04	−0.08	16.73	2.4 Y	7.45	2.3
A3	75.36	1.36	19.61	1.3 Y	7.40	2.9
A3.5	72.31	1.48	21.81	1.6 Y	7.05	3.2
A4	68.56	1.58	21.00	1.6 Y	6.70	3.1
B1	78.90	−1.76	12.33	5.1 Y	7.75	1.6
B2	76.66	−1.62	16.62	4.3 Y	7.50	2.2
B3	74.13	0.47	22.34	2.3 Y	7.25	3.2
B4	71.81	0.50	22.15	2.4 Y	7.00	3.2
C1	74.29	−1.26	12.56	4.3 Y	7.30	1.6
C2	70.95	−0.22	16.72	2.8 Y	6.95	2.3
C3	68.83	−0.01	16.68	2.6 Y	6.70	2.3
C4	64.78	1.59	18.66	1.6 Y	6.30	2.7
D2	75.27	−0.54	13.47	3.0 Y	7.35	1.8
D3	72.55	0.62	16.14	1.8 Y	7.10	2.3
D4	71.86	−1.03	17.77	3.7 Y	7.05	2.4

TABLE 2
ΔE_M-ΔE CIE AS A FUNCTION OF ΔE CIE

ΔE CIE	Bioform Shade Tabs	Vita Shade Tabs	Bioform + Vita Shade Tabs
<1.00	0.24 n=3	0.05 n=1	0.23 n=10
<2.00	0.30 n=20	0.16 n=6	0.27 n=50
<3.00	0.38 n=53	0.28 n=10	0.36 n=119
<4.00	0.41 n=80	0.35 n=21	0.41 n=202
<5.00	0.43 n=123	0.43 n=41	0.43 n=314
<6.00	0.47 n=163	0.55 n=59	0.48 n=418
<7.00	0.49 n=186	0.56 n=72	0.51 n=499
<8.00	0.54 n=212	0.58 n=84	0.55 n=574
<9.00	0.58 n=232	0.58 n=90	0.58 n=626
Overall 0-19	0.58 n=276	0.63 n=120	0.63 n=780

TABLE 3
CUMULATIVE FREQUENCY DISTRIBUTION OF ΔE_M-ΔE CIE

ΔE_M-ΔE CIE	Bioform Shade Tabs	Vita Shade Tabs	Bioform + Vita Shade Tabs
<0.5	47.5%	51.8%	50.1%
<1.0	82.5%	84.4%	80.7%
<1.5	95.8%	93.1%	92.2%
<2.0	98.3%	98.2%	96.9%
<2.5	100.0%	99.3%	99.0%
<3.0		100.0%	99.8%
<3.5			100.0%
Count with ΔE_M-ΔE CIE>2.0	2	5	23

disagreement of 0.41 ΔE units, when compared with CIE L*a*b* calculations for ΔE values below 4. This disagreement is relatively low and compares well with a precision of 0.50 ΔE units in the measurement of the colors of shade-guide teeth with an advanced spectrophotometer (O'Brien *et al.*, 1989).

The proposed equation is useful in estimation of small color differences between dental shades and an objective verification of an observed close match or mismatch that will be in the range of 2-4 ΔE units. A ΔE of less than 1 is excellent. If two shades are within 2 ΔE units, the match is clinically acceptable, perhaps with minor staining. A ΔE value of greater than around 3.7 indicates a poor match based upon clinical observations (Johnston and Kao, 1989) and can easily be seen.

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