Development of a Model Shade Guide for Primary Teeth

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Abstract

Aim.: Large disparities in colour ranges and distribution between primary and permanent teeth make shade guides for permanent teeth unsuitable for primary teeth applications. The aim of the study was to develop a model shade guide for primary teeth. **Study Design:** The Vita Easyshade intraoral spectrophotometer was used to determine colour at the middle labial/buccal third surface of 612 primary teeth of 102 patients. **Methods:** Model shade guides, containing 1-16 tabs, were designed in CIELAB (ΔE^*) and CIEDE2000 ($\Delta E'$) colour difference formulae using nonlinear optimization. The coverage error (ΔE_{COV}) was calculated as the mean of minimal colour differences between each of primary teeth and the "closest" shade tab. Results were analyzed using descriptive and analytical statistics. **Results:** The coverage error of Vitapan Classical shade guide applied to the primary teeth evaluated was 4.2 (SD ± 1.8). ΔE^*_{COV} and $\Delta E'_{COV}$ values for model shade guides with 16 tabs were 1.8 and 1.3, respectively. The CIELAB coverage error of the model shade guide containing two tabs outperformed ΔE^*_{COV} of Vitapan Classical. **Conclusions:** As compared with Vitapan Classical shade guide, significantly smaller coverage error was obtained in the model shade guide with the same number of tabs, designed via constrained nonlinear optimization.

Introduction

The need or demand for aesthetic dentistry may be broad based and transcends stereotypical perceptions [Odioso et al., 2000]. Clark et al. [1993] found that parents were more critical of their children's tooth colour than were the children. However, it was reported that children at three years of age have the ability to distinguish between attractive and unattractive peers [Citron, 1995]. Among children, dental features were the fourth most common reason for teasing after height, weight and hair [Shaw et al., 1980], while maxillary primary incisors were found to have a key impact on facial aesthetics in young children [Woo et al., 2005].

Colour is a psychophysical sensation provoked in the eye by the visible light and interpreted by the brain [Berns, 2000]. Human teeth are small, curved, polychromatic and multilayered. This, together with factors such as characteristics of light, optical geometry, background, surround and colour of the adjacent tooth (gingiva, lips, skin) influence the overall perception of colour [Johnston and Kao, 1989; Reno et al., 2000; Mayekar, 2001; Paravina and Powers, 2004].

The CIE (Commission Internationale de l'Eclairage, International Commission on Illumination) L*a*b* (CIELAB) colour difference formula [Berns, 2000] is widely used in dental colour research. In this three-dimensional colour space, the L* is a measure of the lightness (L* = 0 for absolute black; L* = 100 for reference white). The a* is a green (negative a*) – red (positive a*) coordinate, while the b* is a blue (negative b*) – yellow (positive b*) coordinate. ΔE^* denotes CIELAB colour difference. A ΔE^* value of 1 is frequently used as the 50:50% perceptibility threshold, i.e., 50 % of the observers would detect a colour difference between the two objects [Kuehni and Marcus, 1979], while a ΔE^* value of 2.7 was reported as the 50:50% acceptability threshold, i.e., 50 % of the observers would replace a dental restoration because of a colour mismatch [Ragain and Johnston, 2000].

An advanced colour difference equation, CIEDE2000 or $\Delta E'$, has been developed and adopted as the new CIE colour difference formula [Luo et al., 2001]. Consequently, it is of great interest to evaluate the performance of this formula in dental colour research and link the new findings with the ones obtained using the conventional CIELAB formula.

An evaluation of the colour of primary tooth for three different ethnic groups in the USA (African-American, Caucasian, and Hispanic) demonstrated that better matches to the Vitapan Classical shade guide (VC, Vident, Brea, CA) were among African-American and Hispanic subjects. However, it was concluded that Vitapan Classical did not match the primary teeth colour well [Clark et al., 1999]. Another study reported that three Vitapan Classical shade tabs/tags on the shade guide were the best matches for 82% of primary teeth, while some tabs were never found to be the best match for evaluated primary teeth [Kim et al., 2007]. These discrepancies, when combined with the success in modeling shade guides for permanent dentition using both hierarchical clustering and combined clustering and optimization [Analoui et al., 2004; Paravina et al., 2007] were the rationale for the development of model shade guides for primary dentition.

Key words: colour, shade guide, restorative dentistry, primary teeth, spectrophotometer

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The purpose of this study was to design shade guide models using a database of in vivo colour measurements of primary teeth. The performance of model shade guides was evaluated with respect to the number of tabs and colour difference formula, and compared with the performance of Vitapan Classical shade guide. The null hypothesis was that there was no significant difference between coverage error of Vitapan Classical to primary teeth and corresponding model shade guide.

Materials and Methods

Subjects. Male and female subjects aged 2 to 6 years were recruited. The subjects were patients from the University of Texas Dental Branch at Houston, paediatric dentistry graduate program, presenting to the clinic for their regular scheduled appointments. The procedures, possible discomforts or risks, as well as possible benefits were explained fully to each child's legal guardian, and completed informed consent was obtained prior to the investigation. Legal guardians completed a questionnaire providing information regarding subject age, gender, ethnicity, oral hygiene and any history of trauma. Patients who possessed the necessary teeth to complete the assessment were recruited.

The evaluated teeth were maxillary and mandibular primary central incisor, canine and first molar. The facial surface of each tooth to be measured was wiped with wet gauze prior to measurement. The middle labial/buccal third of the tooth was measured by the principal investigator using the Vita Easyshade (Vident, Brea, CA) intraoral spectrophotometer. The Easyshade probe tip was covered with a disposable infection control polyurethane barrier as it was in direct contact with the tooth during measurement. If any of the teeth were missing from the right side of the arch, the corresponding teeth from the left quadrant were used. Any teeth with caries, extensive restorations or clinically apparent discolouration were excluded. The displayed readings were recorded onto a voice recorder and transferred to Microsoft Office Excel 2003 (Microsoft Corp., Redmond, WA). The readings consisted of L*, a*, b*, C* (chroma, colour strength) and h° (hue, colour name) values, and colour difference as compared with the closest tab form Vitapan Classical shade guide.

Colour assessment. CIELAB (CIE L*a*b*) colour difference was calculated as follows:

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

Coverage error (ΔE*COV) was calculated as the colour difference representing the mean value of the minimal colour differences among each tooth and the Vitapan Classical shade guide using data provided by the Vitapan Easyshade spectrophotometer, as follows [O'Brien et al., 1991]:

$$\Delta E_{COV} = \Sigma \Delta E_{MIN} / n \quad (2)$$

For the purpose of this study, a ΔE* = 2.7 was used as the 50:50% acceptability threshold in the interpretation of colour differences and coverage error [Ragain and Johnston, 2000]. In addition, respective CIE L'C'h' colour coordinate values (CIEDE2000) and colour differences (ΔE') were calculated using the following equation:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H'_{ab}}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'_{ab}}{k_C S_C}\right)\left(\frac{\Delta H'_{ab}}{k_H S_H}\right)} \quad (3)$$

where R_T is a function that accounts for the interaction between chroma and hue differences; a' = a*(1+G), where G = $0.5[1-[(\overline{C^*}^7/(\overline{C^*}^7+25^7)]^{1/2}]$ and where C* is the arithmetic mean of the values C* for a pair of specimens; $K_L=K_C=K_H=1$ [Luo et al., 2001].

Data analysis. This was done by using Microsoft Office Excel 2003 and SPSS v 14.0 for windows (SPSS Inc., Chicago, IL). Mean values, standard deviations, and descriptive statistics of L*, a*, b*, C* and h° were calculated.

Shade guide models. These were designed using agglomerative hierarchical clustering and constrained nonlinear optimization (minimization). Numerical calculations were performed in Matlab (MathWorks, Natick, MA), using the same approach described in the study on modeling shade guides for permanent teeth [Paravina et al., 2007]. Cluster colour representatives were calculated using Ward's criterion of minimum variance as it yielded minimum coverage error values relative to other linkage criteria. Constrained nonlinear optimization was used to further reduce the coverage error. Minimization was calculated by the line search method whereas constrains were implemented via Lagrange multipliers [Lange, 2004].

A total of 32 shade guides were designed, 16 using CIELAB and 16 using CIEDE2000. The first shade guide developed with each formula contained 1 tab, the second contained two tabs, etc., ending with the 16th shade guide that contained 16 tabs. The data were compared with corresponding values for VC. Pearson correlations evaluated the association of the number of shade tabs and coverage error. A regression analysis was used to determine the association between the coverage error of a shade tab when the method of shade tab creation and number of tabs were constant. A p value of < 0.05 was selected to designate results that were considered statistically significant.

Results

Study population. This included 102 patients with the median age of 4 years of age (range 2-6 years). Six teeth per patient were evaluated for a total of 612 teeth. There were 44 males (43%) and 58 females (57%). The study included 32 African Americans (31%), 21 Caucasians (21%), 47 Hispanic Americans (46%), while 2 (2%) patients were deemed to be of other ethnicity.

Coverage error of Vitapan Classical shade guide applied to the evaluated primary teeth was 4.2 (SD ± 1.8), while ΔE*COV among each of the Vitapan Classical tabs selected by the measuring device and corresponding primary teeth ranged from 1.5 to 5.7 (Table 1). Mean L*, C* and h° values for primary teeth were 82.2, 18.4, and 88.1, respectively.

Coverage errors for the present shade guide models using CIELAB and CIEDE2000 formulae are listed in Table 2. It can be seen that the present CIELAB model shade guide with only two tabs outperformed the coverage error of Vitapan Classical shade guide (16 tabs). CIELAB and CIEDE2000 values for model shade guides containing one to five shade tabs are listed in Table 3, while the distribution of primary teeth in percentages for the model shade guide containing five tabs is given in Figure 1.

Statistical analysis. The Pearson correlation ($p<0.001$) revealed a significant negative correlation between the number of shade tabs in a shade guide and the resulting coverage error of the shade guide. The coverage error decreased with the increase of number of tabs. An independent t- test revealed a significant difference between the colour difference equations CIELAB and CIEDE2000 ($p<0.05$). Finally, a regression analysis was used to predict the coverage error when the m the number of tabs was known ($R2=-0.76$).

Table 1. Mean colour differences, ΔE* (SD) among chosen Vitapan Classical shade tabs and corresponding teeth recorded by measuring device.

Shade	ΔE* (SD)
A1	4.1 (1.8)
A2	4.4 (1.8)
A3	3.5 (1.4)
A3.5	2.6 (0.8)
B1	3.8 (1.3)
B2	5.7 (2.0)
B3	3.8 (1.0)
C1	2.6 (1.2)
C2	3.1 (1.9)
C3	3.1 (2.0)
D2	3.7 (0.8)
D3	1.5 (n/a)
Total	4.2 (1.8)

Table 2. Coverage error (SD) for 16 shade guide models obtained using nonlinear constrained optimization, in CIELAB and CIEDE2000 colour difference formulae.

Nos of Tabs in the Shade Guide	ΔE*	ΔE’
1	5.0 (2.5)	3.4 (1.7)
2‡	3.9 (1.9)	2.6 (1.2)
3	3.4 (1.7)	2.4 (1.1)
4	3.0 (1.5)	2.1 (1.0)
5	2.7 (1.4)	2.0 (0.9)
6	2.5 (1.2)	1.9 (0.8)
7	2.4 (1.2)	1.8 (0.8)
8	2.3 (1.1)	1.7 (0.8)
9	2.2 (1.0)	1.6 (0.7)
10	2.1 (1.0)	1.6 (0.7)
11	2.0 (1.0)	1.5 (0.7)
12	2.0 (1.0)	1.5 (0.7)
13	1.9 (0.9)	1.4 (0.7)
14	1.9 (0.9)	1.4 (0.7)
15	1.8 (0.9)	1.4 (0.7)
16	1.8 (0.9)	1.3 (0.6)

‡ Minimal number of tabs in model shade guide that outperformed CIELAB coverage error of Vitapan Classical shade guide with 16 tabs.

Discussion

The Vitapan Classical shade guide has been a widely accepted shade guide and many manufacturers claim to match Classical shades with their restorative materials [Yap et al., 1995; Paravina et al., 2005]. The Vitapan Classical was selected for comparison with the primary tooth colour because it has been used as a ‘gold standard’ in dentistry and has been previously used by many researchers [Seghi at al., 1989; O’Brien et al., 1990; Paravina et al., 2001; Paravina et al., 2002].

The Vitapan Classical (Vident, Brea, CA) shade guide had a coverage error greater than the ΔE*=2.7 threshold. It should be mentioned that conventionally accepted thresholds are to a certain extent arbitrary because equal colour differences did not correspond to equal distances in colour solid or visual thresholds for lightness, chroma and hue. Despite this, the used coverage error thresholds provided a good reference point for performance evaluation. Model shade guides created using optimization in CIELAB formula rendered lower coverage errors than the 16 tab Vitapan Classical shade guide. This supports the assertion that the Vitapan Classical shade guide does not optimally cover primary teeth. The colour differences between mean values for primary teeth recorded in this study and mean values for permanent teeth recorded in the previous study where the same methods and equipment were used, was ΔE*=8.2 [Paravina et al., 2006]. By

Table 3. Shade guide models containing 1 to 5 tabs: CIE L*C*h° values and CIEDE2000 L'C'h' values, all arranged according to decreasing lightness.

Nos of Tabs	Tab	L*	C*	h°	L'	C'	h'
1	A	82.7	18.3	88.4	82.6	18.3	88.7
2	A	85.1	17.9	89.7	85.1	18.1	90.3
	B	79.0	18.8	86.7	79.0	18.7	86.6
3	A	85.3	20.5	89.7	78.5	20.8	86.4
	B	83.6	15.4	88.9	81.3	15.1	87.7
	C	78.5	19.9	86.5	85.5	18.9	90.3
4	A	85.6	16.1	90.4	86.1	16.1	90.7
	B	84.7	20.8	89.4	84.5	20.8	89.4
	C	79.6	15.4	87.0	80.7	15.2	87.4
	D	78.7	21.6	86.3	78.0	20.8	86.1
5	A	86.1	16.2	90.4	86.2	16.1	90.7
	B	84.6	20.6	89.4	84.9	20.7	89.7
	C	81.1	14.8	86.9	80.9	15.1	87.0
	D	79.5	23.2	86.3	80.1	21.7	87.1
	E	77.2	18.3	86.6	75.8	18.7	85.4

comparison with As compared with that study, primary teeth were found to be lighter (ΔL^*=7.7), less chromatic (ΔC^*=–2.5) and redder ($\Delta h°$=–4.2). The large differences in colour and colour ranges between permanent and primary teeth clearly underline the need for "primary" shade guides and the corresponding shades of aesthetic dental materials instead of using products originally designed for permanent teeth.

Coverage error of the Vitapan Classical shade guide applied to primary teeth supported the findings of Kim et al., [2007] who reported the identical value of ΔE^*_{COV}=4.2. In that study, A1, A2, and B2 were the most frequently selected as best matches to primary teeth and accounted for 82% of the selected Vitapan Classical shade tabs, while these three tabs covered 83% of primary teeth in the present study. However, the quality of the method used for designing model shade guides is probably the most important parameter, as confirmed through comparison with the previous study on colour of primary teeth [Kim et al, 2007]. When the present 1-16 tab model shade guides were applied to the independent database from the study of Kim et al., the coverage error increased 5-17% for CIELAB and 7-18% for CIEDE2000. We considered this increase marginal with respect to the increase of 233% in ΔE^*_{COV} of Vitapan Classical (4.2) as compared with to ΔE^*_{COV} of 16-tab CIELAB model shade guide (1.8).

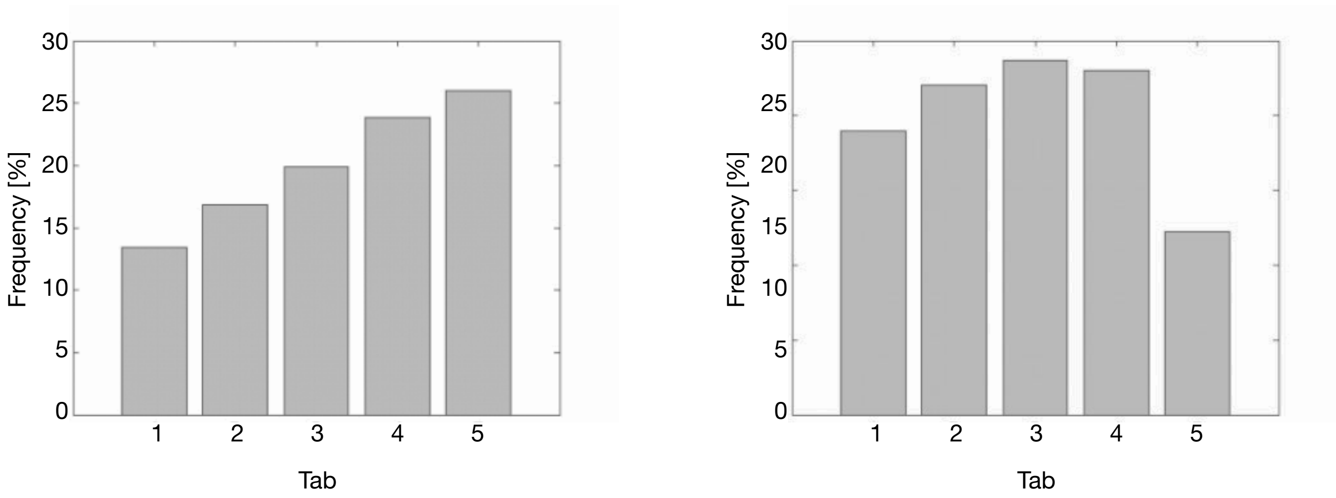
Analoui et al. [2004] established a method of designing shade guides for a target average ΔE and described a correlation between the ΔE_{COV} and number of shade tabs. Significant negative Pearson correlation between coverage error and the number of shade tabs registered in this study is in accordance with these findings. An increase in the ΔE_{COV} corresponded to the decrease in the number of shade tabs. In another study, optimization outperformed clustering and was the method of choice for representation of tooth colour and designing dental shade guides [Paravina et al., 2007]. As compared with clustering, optimization rendered lower coverage error in all cases (number of tabs and colour difference formulation) and provided more uniform distribution of natural teeth within the shade guide.

The CIEDE2000 formula is an improvement upon the CIELAB formula and has been adopted as the new CIE colour difference formula. However, the vast majority of published data regarding the colour of dental materials was obtained using the CIELAB formula. Therefore, both CIELAB- and CIEDE2000-based model shade guides were designed in this study. The CIELAB and CIEDE2000 cannot be compared directly but no very strong correlation existed between them in the evaluation of colour in dentistry indicating a favourable probability for accurate conversion of values between these two formulae [Paravina et al., 2005].

A five-tab model shade guide designed using maximum use of the optimization in the CIELAB had a coverage error equal to the 50:50% acceptability threshold. This can be considered as an appropriate number of shades for primary teeth, especially for resin composites that exhibit blending effect (chameleon effect) and colour shift towards surrounding hard dental tissues due to physical translucency. Tab distribution of primary teeth in percentages is given in Figure 1. The lower

Figure 1. Percentage of primary teeth covered by each shade guide tab in 5-tab model using: a) CIELAB (5.1); and b) CIEDE2000 (SD ± =4.7).

a. **b.**



value of standard deviation of the CIEDE2000 model shade guide as compared with the CIELAB model (4.7 vs. 5.1) indicates better performance of the new formulation.

A scientific approach in designing and developing of a guide for "primary" shades can result in enhanced aesthetic outcome. Future research challenges include creation of a physical "primary" shade guide and development of corresponding shades of resin composites and prefabricated crowns.

Conclusion

Within the limitations of this study and as compared with to Vitapan Classical shade guide, significantly smaller coverage error with the same number of tabs was obtained with the present model shade guide designed using clustering and optimization.

Aknowledgements

An approval from the Committee for Protection of Human Subjects was obtained prior to data collection (HSC-DB-05-0083).

References

Analoui M, Papkosta E, Cochran M, Matis B. Designing visually optimal shade guides. J Prosthet Dent 2004; 92:371-376.

Berns R. Billmeyer and Saltzman's principles of color technology. New York, John Wiley and Sons, 2000.

Citron C. Esthetics in pediatric dentistry. NY State Dent J 1995; 61:30-31.

Clark D, Hann H, Williamson M, Berkowitz JJ. Aesthetic concerns of children and parents in relation to different classifications of the tooth surface index of fluorosis. Community Dent Oral Epidemiol 1993; 21:360-364.

Clark P, Powers JM, Seybold S, Fay R, Johnson, R. Primary teeth color in African-American, Caucasian and Hispanic patients. J Dent Res 1999; 78:231.

Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989; 68: 819-822.

Kim J, Paravina RD, Chen JW. In Vivo Evaluation of Color of Primary Teeth. Pediatric Dent 2007;29:209-212.

Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. Color Res Appl 1979; 4:83-91.

Lange K: Optimization. New York, Springer, 2004.

Luo MR, Cui G, Rigg B. The development of the CIE 2000 color-difference formula: CIEDE2000. Color Res Appl 2001;26:340-350.

Mayekar S. Shades of a color: illusion or reality? Dent Clin North Am 2001; 45:155-172.

O'Brien W, Boenke K, Groh C. Coverage errors of two shade guides. Int J Prosthodont 1991; 4:45-50.

O'Brien W, Groh C, Boenke K. A new, small-color-difference equation for dental shades. J Dent Res 1990; 69:1762-1764.

Odioso L, Gibb R, Gerlach R. Impact of demographic, behavioral, and dental care utilization parameters on tooth color and personal satisfaction. Compend Contin Educ Dent Suppl 2000; 29: S35-S41.

Paravina R, Kimura M, Powers J. Evaluation of polymerization-dependent changes in color and translucency of resin composites using two formulae. Odontology 2005; 93: 46-51.

Paravina R, Powers J, Fay R. Dental color standards: shade tab arrangement. J Esthet Restor Dent 2001; 13:254-263.

Paravina R, Powers J, Fay RM. Color comparison of two shade guides. Int J Prosthodont 2002; 15:73-78.

Paravina RD, Majkic G, Imai FH, Powers JM. Optimization of Tooth Color and Shade Guide Design. J Prosthodont 2007; 16:269-276.

Paravina RD, O'Keefe KL, Kuljic BL. Color of permanent teeth: A prospective clinical study. BaSS J. See http://www.ebass.org. 2006; 10:93-97.

Paravina RD, Powers JM. Esthetic Color Training in Dentistry. St. Louis, Elsevier-Mosby, 2004.

Ragain J, Johnston W. Color acceptance of direct dental restorative materials by human observers. Col Res Appl 2000; 25:278-285.

Reno E, Sundberg R, Block R, Bush R. The influence of lip/gum color on subject perception of tooth color. J Dent Res 2000; 79:381.

Seghi R, Hewlett E, Kim J. Visual and instrumental colorimeteric assessments of small color differences on translucent dental porcelain. J Dent Res 1989; 68:1760-1764.

Shaw WC, Meek SC, Jones DS. Nicknames, teasing, harassment, and the salience of dental features among school children. Br J Orthod 1980; 7:75-80.

Woo D, Sheller B, Williams B, Mancl L, Grembowski D. Dentists' and parents' perceptions of health, esthetics, and treatment of maxillary primary incisors. Pediatr Dent 2005, 27:19-23.

Yap AU, Bhole S, Tan KB. Shade match of tooth-colored restorative materials based on a commercial shade guide. Quintessence Int 1995; 26:697-702.