Scientific Article

In Vivo Evaluation of Color of Primary Teeth

JaiBum Kim, DDS[1] • Rade Paravina, DDS, MS, PhD[2] • Jung-Wei Chen, DDS, MS[3]

Abstract: ***Purpose:*** *The purpose of this study was to evaluate the color of primary teeth.* ***Methods:*** *A Vita Easyshade intraoral spectrophotometer was used to determine the color of primary teeth: (1) maxillary central incisors, canines, and first molars; and (2) mandibular central incisors, canines, and first molars. A total of 604 teeth were measured. Color difference was compared to ΔE*=2.7 (mean=50:50 replacement point). Coverage error (ΔE^*_{cov}) was calculated.* ***Results:*** *Mean L*a*b*C*h° values for primary teeth were 82.5, 0.2, 18.3, 18.4, and 89.4 respectively. The most frequently chosen shades were A1 (46%), A2 (25%), and B2 (11%). Canines had the highest lightness. Maxillary canines had the lowest a* values, whereas mandibular primary incisors had the highest a* values. Molars were the most chromatic (having the highest b* values), followed by canines and primary incisors in decreasing order. Coverage error (ΔE_{cov}*) of Vitapan Classical was 4.2 (±1.9 SD).* ***Conclusions****: Among primary teeth, the widest ranges, in order, were recorded for: (1) lightness; (2) chroma; and (3) hue. Three Vitapan Classical shades were the best match for 82% of primary teeth. Color differences among the same patient's teeth underline the need for an individual approach in color matching and reproduction of primary teeth. (Pediatr Dent 2007;29:383-6) Received August 3, 2006 / Revision Accepted November 27, 2006.*

KEYWORDS: COLOR, PRIMARY TEETH, SPECTROPHOTOMETER

Many dental professionals would agree that "color is unimportant to the physiologic success of a dental restoration, yet it could be the controlling factor in the overall acceptance by the patient."[1] Child patients and their parents alike desire an esthetically pleasant smile. In fact, children as young as 3 years of age are able to distinguish between attractive and unattractive peers.[2] In a study measuring parental satisfaction with bonded resin strip crowns, parents' dissatisfaction was most often related to the restorations' color.[3] Also, in a study conducted in Japan, color analysis revealed that the colors of esthetic anterior primary crowns were substantially different from the colors of the primary anterior teeth of Japanese children.[4] In a study conducted by Woo et al assessing dentists' and parents' perceptions of health, esthetics, and treatment of primary maxillary incisors, all groups (dentists and parents) considered incisor steel crowns esthetically unacceptable and unhealthy,[5] although they have been shown to be effective restorations.[6,7]

Color can be described in terms of: (1) hue, which is the attribute of a color that enables one to distinguish between different families of color (ie, reds, blues, and greens); (2) value, which indicates the lightness of a color, ranging from pure black to pure white; and (3) chroma, which describes the strength, intensity, or vividness of a color.[8]

The Commission Internationale de L'Eclairage (CIE) defined a CIE L*a*b* color notation system, frequently used in color research in dentistry. In this 3-dimensional system L* represents the lightness (perfect black has an L*=0, while perfect white has L*=100). The a* coordinate is a measure of greenness (negative a*) or redness (positive a*), while the b* coordinate is a measure of blueness (negative b*) or yellowness (positive b*). The Euclidean distance ΔE* is a measure of color difference between 2 points in 3-dimensional color space.[9] Coverage error is a useful parameter for evaluation of dental shade guides: it represents the mean color difference between each tooth and the shade tab that is its best match.[10,11]

Although a color range of natural teeth has been reported by several investigators,[12-14] no reliable database of tooth color currently exists for the primary dentition.

The objectives of this study were to determine: (1) color range and distribution of primary teeth; (2) the most frequently chosen shades; (3) differences among tooth types in the same arch; and (4) differences among corresponding teeth in opposing arches. The hypotheses were that there are

[1]*Dr. Kim is ex-resident, Department of Pediatric Dentistry;* [2]*Dr. Paravina is assistant professor, Department of Restorative Dentistry and Biomaterials; and* [3]*Dr. Chen is clinical assistant professor, Department of Pediatric Dentistry, all at the University of Texas Dental Branch at Houston, Houston, Tex.*

Correspond with Dr. Paravina at rade.paravina@uth.tmc.edu

no color variances between primary tooth types of the same arch, and that there were no color variances between corresponding primary tooth types of opposing arches.

Methods

Upon the approval from the Committee for Protection of Human Subjects of the University of Texas Health Science Center at Houston, subjects of both genders and ages 2 to 5 years were recruited. The legal guardian filled out a questionnaire containing information on the subject's: (1) age; (2) gender; (3) ethnicity; (4) oral hygiene; and (5) history of trauma, if any. Patients who possessed the teeth necessary to complete the assessment were recruited. The primary teeth measured were: (1) maxillary right central incisors, canines, and first molars; and (2) mandibular right central incisors, canines, and first molars.

Each tooth's facial surface was cleaned with wet gauze before measurement. The middle labial/buccal third of the tooth, in both cervicoincisal/occlusal and mesiodistal directions, was measured. The probe tip, covered with a disposable infection control polyurethane barrier, was in direct contact with the tooth during measurement. If a tooth was missing from the arch, the corresponding tooth or teeth from the left quadrants were used. Excluded from the study were: (1) patients who lacked the healthy teeth to complete the assessment; (2) restored teeth; (3) teeth near exfoliation; (4) a white-spot lesion in the middle one third of the tooth; (5) teeth discolored due to trauma; and (6) any single tooth that was obviously discolored for any other reason.

Each tooth was measured once by the principal investigator. A total of 101 patients were recruited, and 604 teeth were measured; 2 molars were missing and, therefore, not measured. A Vita Easyshade intraoral spectrophotometer (Vident, Brea, Calif) was used to measure teeth color. The displayed readings were recorded onto a voice recorder and transferred to Microsoft Office Excel 2003 (Microsoft Corp, Redmond, Wash). The readings consisted of:

1. L*, a*, b*, C*, and h° values, the best matches to Vitapan Classical and 3-D Master shade guides (Vita Zahnfabrik, Bad Säckingen, Germany); and
2. respective ΔL*, Δa*, Δb*, ΔC*, and Δh° values.

CIEL*a*b* color difference (ΔE*) was calculated using the following equation:

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

Coverage error (ΔE^*_{cov}) was calculated to determine the mean color difference of the best matches between the measured tooth and the Vitapan Classical tab selected by the color measuring instrument, as follows:

$$\Delta E^*_{cov} = \sum \Delta E^*_{MIN}/n$$

It was found that a ΔE*=2.7 was a 50:50 ΔE replacement point (50% of observers would reject a restoration due to color mismatch),[15] and this threshold was used to interpret color differences and coverage errors recorded in this study.

Data were analyzed using Microsoft Office Excel 2003 (Microsoft, Redmond, Wash) and SPSS 14.0 for Windows (SPSS Inc, Chicago, Ill). Mean values and standard deviations were calculated. Descriptive statistics for L*a*b*C*h° were calculated. The matched pair *t* test was used to compare maxillary vs mandibular teeth. The general linear model repeated measurement test was used to compare incisors vs canines vs molars. A *P* value of <.05 was determined to be statistically significant.

Results

The sample makeup was as follows: (1) average age was 3.1 (±1.1 SD); (2) gender breakdown was 58% females, 42% males; (3) ethnicity breakdown was 3% Asian, 24% African American, 16% Caucasian, and 57% Hispanic; and (5) hygiene was rated as fair (51%) and good (49%).

Mean L*,a*,b*,C*, and h° values for primary teeth are reported in Table 1, while color coordinate ranges and intervals are reported in Table 2. In order, the highest lightness values were found in: (1) mandibular canines; (2) maxillary canines; (3) mandibular molars; (4) maxillary incisors; (5) mandibular incisors; and (6) maxillary molars. Mandibular incisors were found to have the highest a* value, while maxillary canines were found to have to lowest a* value. In order, the most chromatic values (highest b* values), were found in: (1) maxillary molars; (2) mandibular molars; (3) mandibular canines; (4) maxillary canines; (5) maxillary incisors; and (6) mandibular incisors.

The most frequently chosen shades for the Vitapan Clas-

Table 1. MEAN COLOR COORDINATE VALUES† AND STANDARD DEVIATIONS OF EVALUATED PRIMARY TEETH ††

	L*±(SD)	a*±(SD)	b*±(SD)	C*±(SD)	h°±(SD)
B	79.6±5.5	$0.2^{d,e}$±1.0	20.5±3.3	20.6^{j}±3.2	89.5^{l}±2.8
C	83.5^{a}±3.9	-0.8±0.9	18.5^{i}±3.2	18.6^{k}±3.1	92.7±2.7
E	$82.2^{b,c}$±5.3	$-0.1^{f,g}$±0.8	16.7±2.9	16.7±2.9	$90.5^{m,n}$±2.9
P	81.5^{b}±3.8	2.0±1.6	15.6±3.3	15.9±3.1	83.0±5.2
R	84.9±9.7	$0.0^{d,f,h}$±1.4	18.5^{i}±3.6	18.6^{k}±3.6	$90.0^{l,m,o}$±4.1
S	$83.0^{a,c}$±3.3	$0.0^{e,g,h}$±1.4	19.7±2.9	19.8^{j}±3.0	$90.4^{n,o}$±4.0

† Numbers marked with the same superscripted letter are not statistically different (*P*>.05).

†† B=maxillary right first molar; C=maxillary right canine; E=maxillary right central incisor; P=mandibular right central incisor; R=mandibular right canine; and S=mandibular right first molar.

Table 2. COLOR COORDINATE RANGES OF EVALUATED PRIMARY TEETH,† WITH MINIMUM AND MAXIMUM VALUES LISTED IN PARENTHESES

	L*	a*	b*	C*	h°
B	30.5 (66.7-97.2)	6.0 (-1.4 to 4.6)	14.3 (13.8-28.1)	14.7 (13.8-28.5)	14.5 (80.7-95.2)
C	23.7 (71.1-94.8)	6.2 (-2.9 to 3.3)	18.8 (12.5-31.3)	19 (12.5-31.5)	14.5 (83.9-98.4)
E	26.1 (65.5-91.6)	3.5 (-1.8 to 1.7)	15.1 (11.5-26.6)	15.1 (11.5-26.6)	13.4 (83.4-96.8)
P	18.2 (70.6-88.8)	6.6 (-0.8 to 5.8)	22.2 (4-26.2)	17.6 (9-26.6)	23.2 (69.9-93.1)
R	18.2 (73.7-91.9)	8.6 (-3 to 5.6)	25.3 (11.4-36.7)	25.6 (11.5-37.1)	22.6 (76.8-99.4)
S	22.8 (72-94.8)	8.3 (-2 to 6.3)	15.5 (13.4-28.9)	15.5 (13.4-28.9)	20.1 (76.4-96.5)

† B=maxillary right first molar; C=maxillary right canine; E=maxillary right central incisor; P=mandibular right central incisor; R=mandibular right canine; and S=mandibular right first molar

sical shade guide were: (1) A1; (2) A2; and (3) B2 (Table 3). The coverage error (ΔE_{cov}*) of Vitapan Classical was 4.2 (±1.9 SD). A $\Delta E^* \leq 2.7$ was recorded for 26% of primary teeth.

The greatest color variation among tooth types in the maxillary arch was found, in order, between the primary: (1) incisors and molars (ΔE^*=4.6); (2) incisors and canines (ΔE^*=4.5); and (3) canines and molars (ΔE^*=2.3). The greatest color variation in the mandibular arch was found between the primary: (1) incisors and molars (ΔE^*=4.9); (2) incisors and canines (ΔE^*=4.4); and (3) canines and molars (ΔE^*=1.5). Regarding the opposing arches, the greatest color variation, in order, was between the maxillary and mandibular: (1) molars (ΔE^*=3.5); (2) incisors (ΔE^*=2.5); and (3) canines (ΔE^*=0.9).

The same shade was recorded for maxillary and mandibular incisors 48% of the time, followed by the canines (38%), and molars (27%). In the maxillary arch, the same shade was recorded for 2 of the 3 measured teeth 44% of the time, and all 3 teeth matched in shade 11% of the time. In the mandibular arch, the same shade was recorded for 2 of the 3 measured teeth 57% of the time, and all 3 teeth matched in shade 16% of the time.

Discussion

Although a color range of permanent human teeth has been reported by several investigators,[12-14] no reliable database of tooth color currently exists for the primary dentition. The higher L* values of primary canines compared to other evaluated tooth types was an unexpected finding in the present study. According to Goodkind and Schwabacher,[13] permanent canines were darker than central or lateral incisors, and central incisors had the highest lightness.

ΔE^* values for the canines and incisors in the opposing arches were below the ΔE^*=2.7 threshold. In the maxillary arch, only the canine/molar pair exhibited a color difference below this threshold. Also, in the mandibular arch, only the canine/molar pair exhibited a color difference below the 50:50% replacement point.

The coverage error of Vitapan Classical is evidence that the Vitapan Classical shade guide does not optimally match the color of primary teeth. Although the 3 most frequently chosen shades were A1, A2, and B2 (Table 3), significant color differences were recorded compared to the measured teeth. The color difference among primary teeth and their best match in Vitapan Classical was at or below the limit of visual perception, ΔE^*=1,16 in only 2%. A total of 74% of primary teeth exhibited ΔE^* beyond the 50:50% replacement point compared with the best match form Vitapan Classical. This finding is very similar to that for permanent teeth, where 75% were beyond the 50:50% replacement point compared with the best match form Vitapan Classical. This apparent similarity, however, might be misleading. A ΔE^* between mean L*a*b* values for primary and permanent teeth was 8.2, with primary teeth one being: (1) lighter; (2) redder; and (3) less chromatic. The coverage errors for the Vitapan Classical shade guide reported in the literature were: (a) 3.0 (±2.3)[10]; (b) 3.1(±1.7)[17]; and (c) 4.1 (±1.8).[11] Corresponding values for Vitapan 3D Master were: (a) 2.3 (±1.5)[18]; and (b) 2.6 (±1.2).[17]

Since the L*a*b* ranges of Vitapan Classical covered the corresponding ranges of primary teeth—with 61%, 51%, and 49%, respectively—manufacturers might consider producing new shade guides and respective materials for primary teeth. Clinical guidelines should be developed to include proper shade matching for the esthetic treatment of the primary dentition.

Vita Easyshade is a hand-held spectrophotometer. It consists of a handpiece and a base unit.[19] Vita Easyshade uses a pseudocircular 0/0 measuring geometry. Potential concerns might be associated with the: (1) size of primary teeth; (2) edge-loss error; and (3) freehand positioning of the measuring tip. Primary teeth are smaller than permanent teeth and the inner ring of the probe diameter is 5 mm. Tooth color, however, is measured by 2 spectrometers placed within the inner ring of the probe, with a diameter that does not exceed 3 mm. The outer ring consists of 12 fiber bundles used to illuminate the measurement area.[20] Due to the edge-loss er-

Table 3. PERCENTAGE OF VITAPAN CLASSICAL SHADE TABS THAT BEST MATCHED EVALUATED PRIMARY TEETH (1 SHADE TAB PER TOOTH)

SHADE TAB	%
A1	46
A2	25
A3	5
A3.5	<1
A4	<1
B1	5
B2	11
B3	<1
B4	<1
C1	4
C2	1
C3	<1
C4	0
D2	1
D3	<1
D4	0

ror, recorded L* values are reduced, thus corresponding to a darker appearance. Appropriate measurement modes (tooth, crown, or shade tab) of Vita Easyshade should be used to correct the edge-loss error. Freehand positioning is controlled by 3 fibers in the probe's inner ring that prevent measurements if steadiness and perpendicular position of the probe are not achieved.[20]

Conclusions

Based on this study's results, the following conclusions can be made:

1. Among color coordinates, the widest ranges, in order, were recorded for: (a) lightness; (b) chroma; and (c) hue. Data on color range and distribution of primary teeth can be used for development of improved shades of esthetic materials and dental shade guides for primary teeth.
2. Three Vitapan Classical shades were the best match for 82% of primary teeth. The coverage error of Vitapan Classical showed that this shade guide did not optimally match the primary tooth shade.
3. Color variations among different tooth types and corresponding tooth types in opposing arches underline the need for an individual, tooth-by-tooth approach in color matching and reproduction of primary teeth.

Acknowledgments

The authors wish to thank Dr. Jack Stalker, resident at the Department of Pediatric Dentistry, University of Texas Dental Branch at Houston, for his invaluable help in data collection.

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