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Colour of Permanent Teeth: A Prospective Clinical Study

SUMMARY

***Objectives**: To evaluate the colour range and distribution of human teeth* in vivo *among patients of different gender, bleaching history and dietary/oral habits.*

***Material and Methods**: Patients' tooth colour measurements were performed using a Vita-EasyShade Intraoral Spectrophotometer. A total of 1064 vital, non-restored and non-discoloured teeth (maxillary and mandibular right central incisors, canines, first premolars, and first molars) were evaluated in 133 patients of various ethnic groups, gender, bleaching history and dietary/oral habits.*

***Results**: L*, a* and b* mean values for the group of 133 patients were 74.5, -0.4, and 20.9. Female teeth were slightly lighter, less red and less chromatic than male teeth counterparts (ΔE* = 3.0). Bleached teeth were considerably lighter, less red, and less chromatic than teeth of patients who have not bleached their teeth (ΔE* = 4.6). Habits that include smoking caused the most pronounced differences in tooth colour, with smokers' teeth becoming darker, redder and more chromatic (ΔE* = 4.5).*

***Conclusion**: Within the limitations of this study, it was found that colour differences for male versus female teeth, bleached versus non-bleached teeth, and smoking versus non-smoking patients were well above the 50:50% perceptibility threshold of ΔE*=1.0, and above the acceptability threshold of ΔE*=2.7.*

Keywords: Tooth, colour; Aesthetic Dentistry; Shade Guide

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Introduction

Determining the exact shade of human teeth and reproduction of that shade using restorative dental materials has been one of the most challenging aspects in aesthetic dentistry for many years. Work with colour, unlike many other technical aspects of clinical dentistry, is dependent on many variables, some of which are not in the dentist's control. To complicate the problem further, there has been a paucity of adequate shade matching tools available. Tools for visual shade matching are known as dental shade guides or dental colour standards, and they are supposed to represent colour range and distribution of human dentition[1-3].

Different colour notation systems have been used through years to study colour in dentistry. The data generated in this study were derived from the CIE L*a*b* system, with the following colour coordinates: lightness (L*), green-red coordinate (a*), and blue-yellow coordinate (b*). In addition, chroma (C*, pale to strong colour or "the strength of the colour") and hue (h°, the name of the colour) coordinates were calculated from the a* and b* values. Colour difference (ΔE*) reflects the sum of either L*a*b* or L*C*h° colour coordinate differences[4].

Evaluation of so-called "coverage error" is a very useful in determining how well dental shade guide matches colour range and distribution of human teeth. There is always a shade tab that is the best match among all tabs for each particular natural tooth. Coverage error is the mean value of these best matches expressed in ΔE* units[5-8]. Therefore, evaluation of the range and distribution of the colour of human teeth is not only an anthropological issue,

but it is necessary in the development of proper tools and corresponding restorative materials for colour matching and reproduction.

The first study on colour of human teeth was published in 1931. It evaluated 6000 teeth *in vivo* using visual methods[9]. Since then, numerous studies have provided information on tooth colour using either visual or instrument-based techniques, either *in vitro* or *in vivo*[10-15]. Some researchers have used observers to match tooth standards to human teeth *in vivo*, some have taken photographs of human teeth and measured the photos with a spectrophotometer, others have measured extracted teeth using colorimeters or spectrophotometers, and still others have used colorimeters for *in vivo* colour measurement of human teeth[16-19].

The purpose of this study was to evaluate the colour range and distribution of human teeth *in vivo* among patients of different gender, bleaching history and dietary/oral habits. The null hypothesis for the study was that there was no difference in tooth colour based on gender, bleaching history and smoking with different dietary/oral habits.

Material and Methods

Permission was granted by the University of Texas, Houston Health Science Center Committee of Human Subjects to recruit dental patients for this study. Consent forms were signed by all patients prior to inclusion in the study. All recruited patients completed a questionnaire in which gender, ethnicity, bleaching history, oral habits, and age were recorded.

Patients' tooth colour measurements were performed either at the University, or in 1 of 2 private practice dental offices in Houston, Texas. Spectrophotometric colour measurements were taken using a Vita-EasyShade Intraoral Spectrophotometer (Vident, Brea, CA). Colour measurements were performed in the middle third of non-restored, non-discoloured maxillary and mandibular right central incisors, canines, first premolars, and first molars for each patient. The same instrument was used by the same examiner for all patients. A total of 1064 teeth were evaluated in 133 patients. Table 1 shows the frequency and distribution of the database of patients studied.

Table 1. Patient frequency and distribution in percentages

Gender		Bleaching History	
F	M	No	Yes
60.9	39.1	75.2	24.8

Ethnicity				
AA	A	Ca	H	O
12.8	8.3	49.6	26.3	3.0

Tooth brushing/day				
0	1	2	3	3+
1.5	20.3	64.7	11.3	2.3

Habits						
C	CS	CST	CT	ST	T	N
35.3	3.8	7.5	14.3	1.5	10.5	27.1

Legend:
F – Female; M – Male
AA – African American; A – Asian; Ca– Caucasian; H – Hispanic; O – Other
C – Coffee; S – Smoking; T – Tea; N – None

Tooth colour coordinates (D65 illuminant, 2° standard observer) and colour difference metric values between each tooth and the closest tab from Vitapan Classical (VC) shade guide, determined by the measuring device, were recorded.

The CIE L*a*b* color difference (ΔE*) was calculated as follows[4]:

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

Dental literature describes parameters for colour difference thresholds. A colour difference (ΔE*) of 1 is considered to be undetectable to 50% of observers[20], while colour differences of 2.7[21] and 3.3[22] were found to be an acceptability limit for 50% observers. These values were used in the data interpretation.

Means and standard deviations were determined. Correlation coefficients (r) between pairs of coordinates

were calculated. Statistical significance of differences in colour coordinate values was calculated using a t-test, while the Mann-Whitney test was used when the coefficient of variation was > 30% (SPSS 12.0, SPSS Inc, Chicago, IL).

Results

A chroma/hue diagram of evaluated teeth, with the circles painted in corresponding lightness, is given in figure 1. Means and standard deviations (SD), maximum, minimum, and the ranges of CIE L*a*b* colour coordinates of human teeth *in vivo* are shown in table 2.

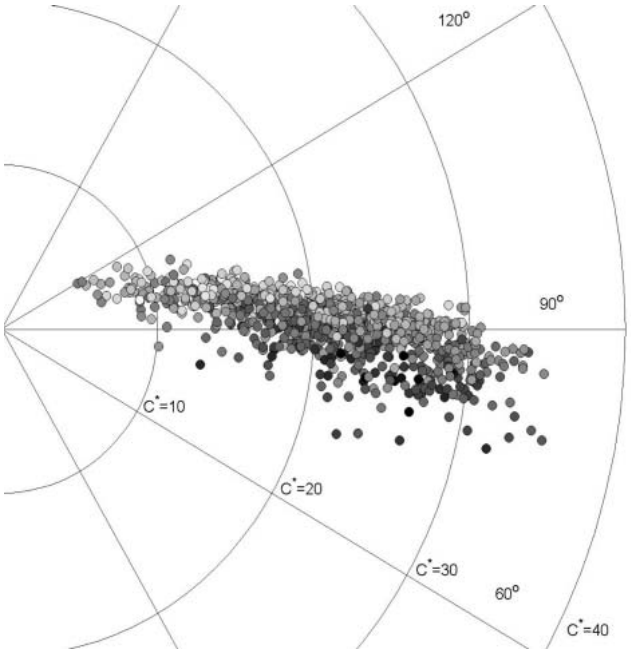

*Figure 1. Colour distribution in C*h space*

*Table 2. CIE L*a*b* colour coordinates of human teeth: Mean, standard deviation (SD), minimal (min) and maximal (max) values, and corresponding ranges*

	L*	a*	b*	C*	h
Mean	74.5	-0.4	20.9	21.0	92.3
SD	6.3	1.7	5.8	5.8	5.8
Max.	89.6	7.3	38.9	39.2	119.2
Min.	55.5	-4.2	3.6	4.2	73.4
Range	34.1	11.5	35.3	35.0	45.8

The colour coordinate differences and total colour differences among groups of subjects of different gender, bleaching history, or non-smoking/smoking criteria are shown in table 3, while statistical analysis is provided in tables 4-6.

Table 3. Colour coordinate differences and total colour differences among groups of subjects

	ΔL*	Δa*	Δb*	ΔE*
F-M	2.3	-0.6	-1.8	3.0
NB-B	-3.4	0.6	3.1	4.6
NS-S	1.7	-0.5	-2.1	2.7

Legend: F - Female; M - Male; NB - No Bleaching; B - Bleaching; NS - No Smoking; S - Smoking

Table 4. Colour coordinates: female/male comparison

Coordinate	Gender	N	Mean	SD	Statistics	95%CI
$\overline{L^*}$	M	52	73.1	4.9	p<0.01	-3.9;-0.7
	F	81	75.4	3.8		
$\overline{C^*}$	M	52	22.1	3.6	p<0.01	0.7;3.1
	F	81	20.2	3.2		
$\overline{h^\circ}$	M	52	91.2	4.1	p<0.01	-3.1;-0.4
	F	81	93.0	3.5		
$\overline{a^*}$	M	52	-0.01	1.3	p=<0.05	
	F	81	-0.6	1.0		
$\overline{b^*}$	M	52	22.0	3.6	p<0.01	0.6;3.1
	F	81	20.2	3.3		

Table 5. Colour coordinates: no bleaching/bleaching comparison

Coordinate	Bleaching history	N	Mean	SD	Statistics	95%CI
$\overline{L^*}$	NB	100	73.7	4.2	p<0.001	-5.1; -1.8
	B	33	77.1	4.0		
$\overline{C^*}$	NB	100	21.7	3.1	p<0.001	1.7; 4.3
	B	33	18.7	3.6		
$\overline{h^\circ}$	NB	100	91.5	3.3	p<0.01	-4.7; -1.3
	B	33	94.5	4.5		
$\overline{a^*}$	NB	100	-.2	1.1	p<0.01	
	B	33	-.8	1.2		
$\overline{b^*}$	NB	100	21.6	3.1	p<0.001	1.8; 4.4
	B	33	18.6	3.6		

Table 6. Colour coordinates: no smoking/smoking comparison

Coordinate	Smoking	N	Mean	SD	Statistics	95%CI
$\overline{L^*}$	NS	117	74.9	4.4	p<0.001	0.8; 5.4
	S	16	71.8	3.8		
$\overline{C^*}$	NS	117	20.8	3.5	n.s.	
	S	16	22.2	3.3		
$\overline{h^\circ}$	NS	117	92.5	3.9	n.s.	
	S	16	90.6	3.3		
$\overline{a^*}$	NS	117	-.4	1.1	n.s.	
	S	16	.1	1.2		
$\overline{b^*}$	NS	117	20.7	3.5	n.s.	
	S	16	22.1	3.3		

Results show that female teeth were slightly lighter, less red and less chromatic than male teeth counterparts. When comparing non-bleached patients with patients who have bleached their teeth in the past, the bleached teeth were considerably lighter, less red, and considerably less chromatic than teeth in patients who have not bleached their teeth. Oral habits that include smoking caused the most pronounced differences in tooth colour, with smokers' teeth becoming darker, redder and more chromatic. It was recorded that as L* values increased, a* values decreased (moves towards green) with a correlation coefficient (r) of 0.58. The correlation between L* and b* was less pronounced (r = 0.25) – as L* increased, b* became less yellow. The correlation between a* and b* coordinates was the most significant (r = 0.67), showing that as a* increased, b* also increased, which means that the teeth became redder and more yellow simultaneously. As far as L*C*h° comparisons were concerned, with the decrease of L*, C* increased (r = 0.25); with the decrease of L*, h° decreased (r = 0.53); and, with the increase in C*, h° decreased (r = 0.76).

Discussion

It has been shown in many studies that the range of natural human teeth is not adequately reflected in today's shade guides. Not only do they miss the ideal colour space of natural teeth as measured by researchers in the past, but many shade guides are not arranged in a logical sequence and are very complicated to use. Also, even if the guides are used correctly, there are many other human variables involved that can hamper perceived tooth colour, such as the light source, the metamerism phenomenon, inconsistencies in the shade matching environment, and possible colour deficiencies in the eyes of the observer. Obtaining an accurate database of the range and distribution of human teeth is the starting point to an improvement in colour matching standards for dentistry. In addition, the colour of bleached teeth, which is a critical component in today's colour standards, has not been evaluated in previous studies.

The results from the present study can be compared to colour measurement results of previous studies. In a study by O'Brien et al[16], 95 recently extracted teeth were measured by a spectrophotometer. Measurements were taken at the incisal, middle and gingival thirds of the tooth. The middle third mean L*, a*, b* values for their study were 72.4, 1.2, and 16.2, respectively. Corresponding L*, a*, b* ranges were 55.9 to 83.0, -0.7 to 4.6, and 4.4 to 27.0, respectively.

In a study of 2830 human teeth *in vivo* using a colorimeter, the measurements were made in H, V and C units[19]. For the middle third, H ranged from 4.5YR to 2.6Y, V ranged from 5.7 to 8.5, and C ranged from 1.1 to 5. CIE L*a*b* values for means were 75.8, 2.1, and 19.1, respectively.

In a study of 100 recently extracted teeth, measurements using a spectrophotometer and a Chromascan were compared[15]. X, Y and Z values of the middle third ranged from 32.4 to 64.9, 31.7 to 65.7, and 23.2 to 64.6, respectively. Calculations to obtain mean CIE L*a*b* values for this data result in 76.6, 1.8, and 19.9, respectively.

The a* and b* ranges recorded in the present study were wider: this could be due to their use of extracted teeth, or their use of strictly anterior teeth, versus the inclusion of first molar measurements and bleached teeth in this study. In general, comparison of results of different studies can be misleading because different devices were used to obtain the results, with different units being produced. Therefore, comparisons of results and conversion of units should be taken with caution.

Lack of adequate devices for intraoral shade evaluation was the main obstacle for *in vivo* instrumental measurement. Currently, there are several intraoral shade matching devices available, ranging from colorimeters, to digital colour analyzers, to spectrophotometers, as well as instruments that combine these technologies[3]. Vita Easyshade is a handheld intraoral spectrophotometer. Its design took into consideration 2 major inaccuracies associated with contact-type hand-held devices: edge-loss error (incorrect colour readings because a considerable fraction of the light entering the tooth is lost) and free-hand positioning[8]. The instrument contains a 5-mm fiberoptic tip, with 19 1-mm diameter fiberoptic fibres. The light source is a halogen-stabilized tungsten lamp located in the base unit, delivered by fiberoptic bundles to the handpiece. Multiple spectrometers are used to monitor the light source, and to measure scattered light at 2 different distances from the tooth surface. These readings are combined to produce a "principal" spectrum for the tooth[23]. The instrument prints out data which includes

colour coordinates of the tooth, the closest Vita-Lumin shade match, and the closest Vita 3D Master shade match.

Conclusions

Within the limitations of this study, it was found that colour differences for male versus female teeth, bleached versus non-bleached teeth, and patients who smoke were well above the 50:50% perceptibility threshold of $\Delta E^*=1.0$, and above the acceptability threshold of $\Delta E^*=2.7$. Accordingly, these differences should be taken into consideration by both dental manufacturers and dental professionals. Information on colour range and distribution of human teeth is the starting point for designing future dental shade guides and corresponding aesthetic restorative materials.

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