Original Article

Color Relationships of Natural Anterior Teeth: An *In vivo* Study

Sedanur Turgut, Hamiyet Kılınç, Güneş Bulut Eyüpoglu[1], Bora Bağış[2]

Departments of Prosthodontics and [1]Restorative Dentistry, Faculty of Dentistry, Karadeniz Technical University, Trabzon, [2]Department of Prosthodontics, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey

Abstract

Objectives: To investigate the color relationships between the anterior teeth *in vivo*. **Materials and Methods:** A total of 640 volunteers (age: 18–22) participated in the study. The color measurements of left maxillary and mandibular central, lateral, and canine were performed using a colorimeter. Color differences were calculated according to the CIE L*a*b* (ΔE*) and CIEDE2000 (ΔE_{00}*) system. The National Bureau of Standards (NBS) ratings were also evaluated. Statistical analyses were performed using two-way ANOVA and Fisher's exact test ($P < 0.05$). **Results:** Significant differences were found between the L*, a*, b*, and ΔE* values ($P < 0.05$), except for mandibular central and lateral. ΔE* values were found between 1.5 ΔE* (mandibular central–mandibular lateral) and 8.1 ΔE* (maxillary central–maxillary canine). While the highest L* (80.5) and the least b* (15.1) values were obtained for mandibular central, the mean L* (73.6) and the mean b* values (21.3) were obtained for the maxillary canine. a* value was found to be highest for the mandibular lateral (1.1) and the least for the maxillary central (−0.2) teeth. NBS values were between 1.3 and 7.4 units, and only mandibular central and mandibular lateral teeth exhibited "almost the same" color values, while the other teeth exhibited "slightly different," "very different," or "remarkably different" color values. **Conclusion:** Anterior maxillary and mandibular teeth exhibited "different" color values. Only mandibular incisors and mandibular laterals showed "almost the same" color. Canines were more dark/red/yellow for both mandible and maxilla. Centrals were more bright/green/yellow for maxilla and bright/green/blue for mandibular. Clinicians should select the color one by one for each tooth and be aware of their color relations for optimal esthetics.

Keywords: *Color selection, esthetic, tooth*

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Introduction

Color of a tooth is the most prominent factor among optical properties and is influenced by both internal morphology and external texture such as the outline form, size, shape, surface anatomy, and light reflection patterns.[1] Tooth tissues (pulp, dentin, and enamel) have different optical properties, and their natural appearance depends on their thickness, calcification, composition, and translucency, which are ultimately responsible for the polychromatic characteristics of the crown.[2] Enamel has a highly calcified structure and less organic material content, while dentin has less mineral content and higher organic tubular structure. Therefore, enamel displays higher light transmission and is more translucent than dentin. The thickness of dentin and enamel tends to vary according to the different teeth groups and also different parts of the same crown.[3,4] Enamel thickness is lower in the cervical region and increases toward the incisal edge, whereas the dentin distribution shows the opposite pattern. Accordingly, due to the reflection of the underlying dentin, high density in cervical region decreases toward the incisal.[1,5] The red and yellow colors of natural teeth increase, and the translucency

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Address for correspondence: Dr. Bora Bağış, Department of Prosthodontics, Faculty of Dentistry, Izmir Katip Celebi University, Izmir, Turkey.
E-mail: bbagis@yahoo.com

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characteristic decreases toward the cervical portion from the incisal portion of teeth.[1]

Some authors have claimed that the dentin predominately determines tooth color, unlike enamel, which has a minor effect through scattering at wavelengths in the blue range.[6] The volume of the pulp chamber and the vitality of the tooth vary at different stages of the dental development. In general, the pulp chamber is very wide and has greater intensity of red between the ages of 13 and 19 years. With the formation of secondary dentin, the pulp chamber becomes smaller and less red with age.[7]

As the tooth crown is not monochromatic and has various color layers on the crown surface, it seems difficult to replicate these structures using dental materials that have different colors and translucency.[8] For adequate color reproduction, it is valuable to quantify the color distributions of natural teeth accurately, and the color of the restoration should be prepared in accordance with the adjacent and symmetrical teeth.[9]

The color distributions of teeth have been evaluated before either visually or using spectrophotometers, colorimeters, or digital cameras.[1,9,10] The color distributions were reported in the CIE L*a*b* system. The system enabled the evaluation of the degree of color change (ΔE*) based on three coordinates. L* color coordinate represents lightness or brightness, a* represents greenness (positive) and redness (negative), and b* represents yellowness (positive) and blueness (negative).[9,11,12] Numeric description of color permits precise definition of the magnitude of the color difference between objects. The critical level of ΔE* values can be quantified by the National Bureau of Standards (NBS) rates, which is the way that a color change is evaluated by the human eye.[13] The CIEDE2000 color difference (ΔE_{00}*) was found considerably more sophisticated and computationally involved than the equations for CIE L*a*b* difference.[14,15] Perceptibility threshold (PT) and acceptability threshold (AT) have been introduced as two major thresholds for assessing color differences and serve as a control to evaluate the dental structures clinical success and interpret visual and instrumental findings.[15] The ΔE_{00}*values were compared with 50:50% PT and 50:50% AT values reported in the previous studies.[15,16] Several studies[15-18] determined that 50:50% PT ranged from 0.80 to 1.30 ΔE_{00}* units and that 50:50% AT ranged from 1.80 to 2.25 ΔE_{00}*. Paravina *et al*.[16] found that 50:50% PT and ATs were significantly different. CIEDE2000 50:50% PT was 0.8 ΔE_{00}*, whereas 50:50% AT was 1.8 ΔE_{00}*.

The factors affecting the color of a tooth have been examined earlier;[19] however, searching the literature, there was no adequate knowledge of the color relationship between the anterior teeth. As the age of the patient and the morphology and thickness of both enamel and dentin of teeth differ, the color values of teeth may also differ. If the color values for anterior teeth are different, the shade of the restoration should not be selected based on the existing neighbor teeth, and clinicians should select the color for each tooth individually, especially when two or more teeth are absent. The purpose of this study was to investigate the color relationship between both the maxillary and mandibular central, and the lateral and canine teeth *in vivo*. By doing this, it would be possible to predict the proper color of the missing anterior tooth from the color of another existing tooth in the anterior region.

The hypothesis of the present study was that there would be differences between the color values of anterior teeth.

Materials and Methods

A total of 640 volunteer dentistry students (320 females and 320 males) with ages between 18 and 22 years (average age = 20.8) participated in this study. Written information was obtained from all participants and they signed informed consent form which was approved by the Ethical Board of the Karadeniz Technical University (no: 2015/58). The criteria of the evaluated participants are given in Table 1. Participants were clinically examined, and only the teeth that met the inclusion criteria were included for the study, while others were excluded from the study. A single operator performed the color measurements in the same time period (at 11:00–12:00 noon hours) and at the same dental unit.

Before the color measurements, each tooth (left maxillary and mandibular central, lateral, and canine) was cleaned using a soft polishing brush and polishing paste by one clinician. After the cleaning procedure, the teeth surfaces were wiped with clean paper for saliva and moisture, and the color values were immediately measured. Before the measurements, the colorimeter (ShadeEye NCC, Shofu, Japan) was calibrated with its own special calibration tool and positioned in the center side (middle third) of the facial surface of the teeth. The measurements were carried out according to the CIE L*a*b* system three times for each tooth, and the average was recorded.

Color differences (ΔE*) between the teeth of the same individual were calculated using the following formula:
$\Delta E\ (L^*a^*b) = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$

ΔL*: The difference between the L* values

Δa*: The difference between the a* values

Δb*: The difference between the b* values

ΔE* values of the evaluated teeth were multiplied by a factor of 0.92 to obtain the NBS values. NBS ratings of

how a color change is evaluated by the human eye are given in Table 2.

The ΔE_{00}* values were also calculated from the CIE L*a*b* color space. Given a pair of color values in CIE L*a*b* color space, L_0*, a_0*, b_0* and L_1*, a_1*, b_1* and color differences were calculated with the following formula;

$$\Delta E^*_{00} = \sqrt{\left(\frac{\ddot{A}L'}{kLSL}\right)^2 + \left(\frac{\ddot{A}C'}{kCSC}\right)^2 + \left(\frac{\ddot{A}H'}{kHSH}\right)^2 + RT\left(\frac{\ddot{A}C'}{kCSC}\right)^2\left(\frac{\ddot{A}H'}{kHSH}\right)^2}$$

ΔC' and ΔH' are the differences in chroma and hue for a pair of specimens. S_L, S_C, and S_H are the weighting functions for the lightness, chroma, and hue, respectively, and k_L, k_C, and k_H are the parametric weighting factors for variations in experimental conditions. RT, a rotation function, is applied to account for the interaction between chroma and hue differences in the blue region.[20,21] The parametric factors were set to 1.[21] The ΔE^*_{00} values were then compared with 50:50% PT and 50:50% AT values.

Statistical analyses were performed with two-way ANOVA and Fisher's exact test to evaluate the mean values of the L*, a*, b*, and ΔE* values of anterior teeth for both maxilla and mandible with a significance level of 5%.

Results

The data obtained from the variables L*, a*, b*, and ΔE* were analyzed to predict the color relations for both maxillary and mandibular anterior teeth. The mean values of the L*, a*, and b* values are given in Table 3.

Evaluating the L* values, significant differences were found between all the maxillary anterior teeth ($P < 0.05$); the mandibular central and lateral teeth, on the other hand, exhibited no significant differences ($P = 0.25$).

Evaluating the a* values, significant differences were found for all anterior maxillary teeth ($P < 0.05$). No significant difference was found between the maxillary lateral, mandibular central, and mandibular lateral ($P > 0.05$). There were also no significant differences between the maxillary canine and mandibular canine ($P = 0.553$).

Evaluating b* values, significant differences were found between all the anterior teeth ($P < 0.05$). The mandibular central and mandibular lateral teeth exhibited no significant difference ($P = 0.63$).

While the highest L* (80.5) and the least b* (15.1) values were obtained with the mandibular central, the Mean L* (73.6) and the Mean b* values (21.3) were obtained with the maxillary canine. a* value was found to be the highest for the mandibular lateral (1.1) and was found to be the least for the maxillary central (−0.2) teeth.

The color change values of the evaluated teeth and their relations are given in Table 4. ΔE* values were found between the 1.5 ΔE* unit (mandibular

Table 1: Analysis of participant selection

Analysis of participant selection (*n*)	Inclusion criteria (*n*)	Exclusion criteria (*n*)	Other (*n*)
Sample (3840)	18-22 age	Anterior teeth with caries and restoration (37)	Did not meet inclusion criteria (76)
Assessed for compliance (723)	Lack of anterior tooth loss	Nonvital teeth (6)	Refused to participate (0)
Volunteers (640)		That staining of the teeth (11)	Other reasons (0)
		Measurements will be obstacles to obscure dentition (4)	
		Bleaching history (2)	
		Smokers (19)	
		Active periodontal/orthodontic treatment history (4)	

n=Number of participants

Table 2: National Bureau of Standards units and their critical remarks of color differences

NBS unit	Critical remarks of color differences
0.0-0.5	Almost the same
0.5-1.5	Slightly different
1.5-3.0	Perceivably different
3.0-6.0	Remarkably different
6.0-12.0	Extremely marked different
12.0 or more	Different color

NBS=National Bureau of Standards

Table 3: Mean values of L*, a*, and b* for anterior maxillary and mandibular teeth

	L*	a*	b*
Maxillary central	80.5±5.1[a]	−0.2±0.4[a]	17.1±3.1[a]
Maxillary lateral	76.5±4.4[b]	0.8±0.3[b]	15.3±2.8[b]
Maxillary canine	73.6±4.2[c]	1.1±0.4[c]	21.3±3.3[c]
Mandibular central	78.8±4.4[d]	0.7±0.3[b]	16.3±3.1[a,b]
Mandibular lateral	77.9±5.2[d]	0.9±0.4[b]	17.5±3.0[a]
Mandibular canine	74.8±4.2[e]	1±0.4[c]	21.9±4.4[c]

Vertically, means with same superscript uppercase letters were not statistically significant (P>0.05)

Table 4: Color differences of anterior maxillary and mandibular teeth

	ΔE*	Color relations
Maxillary central/maxillary lateral	4.4±0.8[a]	Maxillary central is more bright/green/yellow than maxillary lateral Maxillary lateral is more dark/red/blue than maxillary central
Maxillary central/maxillary canine	8.1±1.6[b]	Maxillary central is more bright/green/blue than maxillary canine Maxillary canine is more dark/red/yellow than maxillary central
Maxillary lateral/maxillary canine	6.9±1.4[b]	Maxillary lateral is more bright/green/blue than maxillary canine Maxillary canine is more dark/red/yellow than maxillary lateral
Mandibular central/mandibular lateral	1.5±0.5[c]	Mandibular central is more bright/green/blue than mandibular lateral Mandibular lateral is more dark/red/yellow than mandibular central
Mandibular central/mandibular canine	7.8±1.5[b]	Mandibular central is more bright/green/blue than mandibular canine Mandibular canine is more dark/red/yellow than mandibular central
Mandibular lateral/mandibular canine	6.3±1.1[b,a]	Mandibular lateral is more bright/green/blue than mandibular canine Mandibular canine is more dark/red/yellow than mandibular lateral
Maxillary central/mandibular central	1.9±0.4[c,d]	Maxillary central is more bright/green/yellow than mandibular central Mandibular central is more dark/red/blue than maxillary central
Maxillary lateral/mandibular lateral	2.6±0.5[d,a]	Maxillary lateral is more dark/green/blue than mandibular lateral Mandibular lateral is more bright/red/yellow than maxillary lateral
Maxillary canine/mandibular canine	2.0±0.6[d]	Maxillary canine is more dark/red/blue than mandibular canine Mandibular canine is more bright/green/yellow than mandibular canine

Vertically, means with same superscript uppercase letters were not statistically significant (P>0.05)

Table 5: Perception of color differences according to National Bureau of Standards

	NBS unit	Human perception
Maxillary central/maxillary lateral	4.0±0.8	Remarkably different
Maxillary central/maxillary canine	7.4±1.1	Very different
Maxillary lateral/maxillary canine	6.3±0.8	Very different
Mandibular central/mandibular lateral	1.3±0.3	Almost the same
Mandibular central/mandibular canine	7.1±1.0	Very different
Mandibular lateral/mandibular canine	5.7±0.7	Remarkably different
Maxillary central/mandibular central	1.7±0.4	Slightly different
Maxillary lateral/mandibular lateral	2.3±0.4	Slightly different
Maxillary canine/mandibular canine	1.8±0.5	Slightly different

NBS=National Bureau of Standards

central– mandibular lateral) and the 8.1 ΔE* unit (maxillary central–maxillary canine) for the anterior teeth. Perception of color differences according to NBS is also given in Table 5. Only the mandibular central and the mandibular lateral teeth showed "almost the same" color in terms of human perception. According to CIEDE2000 system, all of the color differences between the evaluated teeth were above the 50:50% PT. The highest ΔE_{00}* was found between maxillary central and mandibular canine (ΔE_{00}* = 5.4); it was above 50:50% AT. The color difference thresholds according to ΔE_{00}* values are given in Table 6.

Table 6: Color difference thresholds according to CIEDE2000 system

	ΔE_{00}*	Color difference thresholds
Maxillary central/maxillary lateral	2.9±0.8	50:50% AT
Maxillary central/maxillary canine	5.4±1.1	50:50% AT
Maxillary lateral/maxillary canine	4.6±0.7	50:50% AT
Mandibular central/mandibular lateral	1.0±0.3	50:50% PT
Mandibular central/mandibular canine	5.2±1.1	50:50% AT
Mandibular lateral/mandibular canine	4.2±0.8	50:50% AT
Maxillary central/mandibular central	1.3±0.4	50:50% PT
Maxillary lateral/mandibular lateral	1.7±0.4	50:50% PT
Maxillary canine/mandibular canine	1.3±0.5	50:50% PT

PT=Perceptibility threshold; AT=Acceptability threshold

Discussion

The hypothesis of the present study that there would be color value differences between anterior teeth was partially accepted. Significant color differences were found between the teeth except for the mandibular central and mandibular lateral teeth at three CIE L*a*b coordinates. Evaluating the L*, a*, and b* values of maxillary teeth, the central, lateral, and canine teeth exhibited significantly different colors. For mandibular anterior teeth, the canine exhibited significantly different color values at the L*, a*, and b* coordinates compared to the central and lateral, as the canine was darker, redder, and yellower.

In the present study, color variation values were between 1.5 and 8.1 ΔE* units. As the variations perceived by the human eye are limited to a certain degree,[22,23] the acceptability and PTs of color differences have been the subject of debate in the dental literature. Several authors have determined that the clinical PTs ranged from ΔE* = 1.0–3.7.[24] The NBS ratings, which are quantified by ΔE* values, are commonly used to evaluate color changes according to the human eye.[25] According to NBS, only mandibular central and mandibular lateral teeth exhibited "almost the same" color values, while the other teeth exhibited "slightly different," "very different," or "remarkably different" color values. Currently, the CIEDE2000 system was considered as a better indicator of human perceptibility and acceptability of color differences between tooth colors.[16,21] The ΔE_{00}* values were between 1.0 and 5.4 units for the present study. According to the Paravina *et al*.,[16] evaluating the present study findings, maxillary central/maxillary lateral, maxillary central/maxillary canine, maxillary lateral/maxillary canine, mandibular central/mandibular canine, and mandibular lateral/mandibular canine showed 50:50% AT; whereas, the other comparisons were 50:50% PT. Previous studies[4,9] have shown that the amount of reflected and absorbed light through the tooth depends on the thickness and translucency of the dentin and enamel. The authors have reported that the exact thickness of the enamel and dentin in all tooth types differs. Oguro *et al*.[25] reported that the enamel thickness of the human anterior tooth affected the color and that it was a statistically significant predictor of tooth color change. In that study, Δb* changes were widely distributed in the range of 6.6–9.15 with a decrease in enamel thickness, whereas Δa* hardly showed any changes as the enamel thinned. These results indicate that tooth color change with a decrease in enamel thickness was most dependent on changes in b* values.[8] Different color values obtained in the present study may be attributed to the different enamel or dentin thickness of each tooth. Mandibular central and lateral teeth are known to be the smallest human adult teeth,[26] and possessing approximately the same enamel and dentin thickness could be the reason for the fact that their color values were found to be "almost the same."

Color could also differ among various types of teeth, locations, and ages. In general, teeth in older people appear darker and yellower, as the enamel hydroxyapatite crystals become larger.[7] It was demonstrated that teeth composed of large enamel hydroxyapatite crystals appeared to be darker than teeth composed of smaller crystals.[23] Increase in the mean size of these crystals might be one of the reasons for tooth shade darkening in older individuals.[19,23] Furthermore, it has already been shown that concerns about dental esthetics are increasing in priority in younger patients (<35 years of age).[27] As the different age groups could have affected the color distributions, only individuals aged between 18 and 22 years participated in the present study. In this way, the age-dependent changes, which could affect the optical properties of teeth, were avoided.

In this study, a colorimeter was used to analyze the color values of the vital teeth. These devices have become popular because they offer accuracy, standardization, and numerical expression.[28] As shade selection and color matching of restorations with natural dentition continue

to be most confusing problems in esthetic dentistry, both instrumental and visual color matching methods should be used whenever possible so that predictable esthetic outcomes can be achieved. Several studies have evaluated the proper choice of colors using various shade-matching devices in the literature, and these were found to be successful.[9,11,29]

Some authors suggested that color values were different at the cervical, middle, and incisal tooth segments.[1,5] These results are important as the existing tooth segment provides the possibility to predict the color of the missing tooth segment. The authors also investigated the relationship between the thickness of dentin and enamel and the color distributions along the tooth. In one study,[1] the relation in color of maxillary incisors and canines for each segment (cervical, middle, and incisal) was evaluated, and the researchers found a stronger relation with the cervical than with the middle and incisal segments. As the knowledge of tooth color distributions is critical in replicating pleasing anterior restorations, knowing the color relations among anterior teeth would be useful for clinicians. If the missing natural teeth are to be reproduced with dental materials, differences between ages, quadrants, sex, and locations, in terms of shade and pattern of translucency, should be taken into consideration.[30,31] The present study demonstrated all anterior teeth color value relations [Table 4]. As giving a patient a natural esthetic appearance with the dental restorations is very important, it can be said that clinicians should select the color for each individual tooth related to the results present in the study.

Dental clinicians generally select only one shade for full-mouth restorations, and the technicians perform color variations. Therefore, the fabricated restoration appearances are usually associated with the dental technicians' talents and performances; however, if relation of the color values of anterior teeth would be known theoretically, the results of the present study might be useful for both dentists and technicians for giving natural esthetics to the patients. Evaluating the color difference thresholds, all the comparisons (except mandibular central/mandibular lateral) showed %50:50 AT with the neighbor teeth; while the comparisons of the same teeth with maxillary and mandibular showed %50:50 PT. Hence, it seems more sensible to select the color of a tooth from the same type of tooth from the opposite denture instead of the neighbor, if exists.

Among the other optical properties, translucency can also affect the esthetics of a restoration. In this study, this was not investigated because the measurements were made with a colorimeter under *in vivo* conditions. The other limitation of the study was when measuring the inclined surface of a dental structure with the colorimeter, some problems may occur due to the curved facial surfaces of the teeth. The probe tip of the instrument cannot be in direct contact with these surfaces, which cause edge-loss errors, leading to reduced L* values recorded for these types of teeth.[22] Several previous studies reported that edge-loss appears when translucent materials such as tooth structures are measured.[24] Another limitation of this study concerns just comparing the middle third buccal surfaces of anterior teeth. Lower and upper buccal surfaces might also be compared for all anterior teeth in further studies. Further evaluations of color and translucency in different human populations of different ages may provide more useful information and comparisons that can be made with the results of the present study.

Conclusion

Within the limitations of this study, it was concluded that both maxillary and mandibular anterior teeth exhibited different color values. Only mandibular incisors and mandibular laterals showed "almost the same" color. Canines were more dark/red/yellow for both mandible and maxilla. Maxillary centrals were more bright/green/yellow and mandibular centrals were more bright/green/blue. As the color relationships were different for each anterior tooth, clinicians should select the color one by one for each tooth carefully for the color harmony for optimal esthetics.

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Conflicts of interest

There are no conflicts of interest.

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