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ANALYSIS OF COLORIMETRIC PARAMETERS OF INTERNATIONAL COMMISSION ON ILLUMINATION L*A*B* SYSTEM IN THE COLOR OF MAXILLARY CENTRAL INCISORS

*ANALIZA KOLORIMETRIJSKIH PARAMETARA CIEL*A*B* SISTEMA BOJE CENTRALNOG GORNJEG SEKUTIĆA*

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Summary

Introduction. Tooth color can be represented in a three-dimensional color system by applying L* (lightness), a* (red-green color tone) and b* (yellow-blue color tone) coordinates. Clinically significant color difference, Delta-E, can be expressed in units that are correlated with visual perception using the International Commission on Illumination L*a*b* system. The aim of the study was spectrophotometric analysis of the natural maxillary central incisor color, and to establish any gender-related differences in lightness, red-green tone, and yellow-blue tone coordinates. **Material and Methods.** The study included 80 students (40 male and 40 female, with an average age of 22 years). The color of the maxillary right central incisor was determined using an intraoral spectrophotometer and VITAPAN Classical and VITA 3D-Master color shade guides. Lightness, red-green tone, and yellow-blue tone values were recorded for each result. The obtained data were processed by using χ^2 , Student's t-test and Mann-Whitney test. **Results.** Results showed no statistically significant gender-related difference in color according to the VITAPAN Classical and VITA 3D-Master color key. No difference was found in the lightness of the central maxillary incisor between genders, or in terms of red-green tone ($p = 0.860573$). A statistically significant difference was found when observing the sex-related yellow-blue tone of the color of the central maxillary incisor. **Conclusion.** The analysis of colorimetric parameters of the International Commission on Illumination L*a*b* system provides useful information about the tooth color in the examined population, while potentially revealing differences in lightness, red-green tone and yellow-blue tone between genders.

Key words: Color; Tooth; Spectrophotometry; Incisor; Sex Characteristics

Introduction

One of the main goals of restorative dentistry is to achieve optimal morphological, optical and biological forms of restoration, which includes satisfactory reproduction of the color/shade of the natural teeth [1]. In restorative dentistry, tooth color is usually deter-

Sažetak

Uvod. Boja zuba se primenom L* (svetlina), a* (crvenozeleni ton boje) i b* (žutoplavi ton boje) koordinata može predstaviti u trodimenzionalnom sistemu boja. Razlika u boji (ΔE) se primenom *International Commission on Illumination L*a*b** sistema može izraziti u jedinicama koje su kliničke značajne. Cilj rada bio je spektrofotometrijska analiza boje prirodnog centralnog gornjeg sekutića kao i utvrđivanje razlike u vrednostima L*, a* i b* koordinata u zavisnosti od pola ispitanika. **Materijal i metode.** U istraživanju je učestvovalo 80 studenata (40 ispitanika muškog pola i 40 ispitanika ženskog pola, prosečne starosti 22 godine). Boja desnog centralnog gornjeg sekutića određivana je primenom intraoralnog spektrofotometra kroz VITAPAN *Classical* i VITA 3D-master boje. L*, a* i b* vrednosti prikazane su za svaki rezultat određivanja boje. Dobijeni podaci obrađeni su primenom χ^2 , Studentov t-testa i Man-Vit-njevog testa. **Rezultati.** Rezultati pokazuju da nema statistički značajne razlike u boji prema VITAPAN *Classical* i VITA 3D-master ključu boja u zavisnosti pola ispitanika. Nije utvrđena razlika u svetlini centralnog gornjeg sekutića među polovima, kao ni po pitanju crvenozelenog tona ($p = 0.860573$). Statistički značajna razlika uočena je kod posmatranja vrednosti žutoplavog tona boje centralnog gornjeg sekutića. **Zaključak.** Analiza kolorimetrijskih parametara *International Commission on Illumination L*a*b** sistema obezbeđuje korisne informacije o boji zuba ispitivane populacije kao i postojanje razlike u svetlini, crvenozelenom tonu i žutoplavom tonu boje u zavisnosti od pola ispitanika.

Ključne reči: boja; zub; spektrofotometrija; sekutić; razlike u polu ispitanika

mined visually using a shade guide, which is the most widely accepted and most commonly used method [2].

For a long time, the VITAPAN Classical shade guide was the gold standard in the tooth color determination. However, it has several disadvantages, such as insufficient range of available colors, distribution of color with respect to two parameters

Abbreviations

CIE L*a*b*	– International Commission on Illumination L*a*b*
ΔE	– Delta-E (color difference)
3D	– three-dimensional
L*	– lightness
a*	– red-green balance
b*	– yellow-blue balance

(lightness and saturation) only, and lack of dispersion of color samples in the three-dimensional (3D) color space [3]. As a result, several more advanced shade guides have been developed.

In 1991, Hall emphasized the need to include all three color parameters (lightness, hue and saturation) in the color determination process [4]. His pioneering work on the subject was the basis for the development of the VITA 3D-Master shade guide in 1998. Thus, VITA 3D-Master is the first three-dimensional commercial color determination and reproduction system based on the colorimetric classification principles. In the selection and organization of samples in the shade guide, all three parameters affecting color perception were taken into account, and the color selection procedure was adapted to the visual perception mechanisms [5]. Owing to its design, wider color range and uniform color distribution, VITA 3D-Master is superior to all classic shade guides [2, 6]. However, for those with less clinical experience or insufficient knowledge related to this system based on lightness-saturation-hue concept, it may be difficult to understand and apply it in practice [7]. As individual aptitude and conditions in which color determination is performed affect the reliability and accuracy of the tooth color determination procedure, the visual method is considered highly unreliable [6, 8].

The instrumental tooth color determination method offers the potential for eliminating all the aforementioned shortcomings. Numerous devices for instrumental determination of tooth color are available today, such as three-stimulus colorimeters, spectroradiometers, digital cameras and spectrophotometers [1, 2, 9–11].

Nonetheless, due to their accuracy, simplicity and ease of application, spectrophotometers remain the most popular devices in clinical practice [12]. When using a spectrophotometer, tooth color is determined by measuring the amount and spectral composition of light reflected from the surface of the observed tooth. In the class of clinical spectrophotometers, the VITA Easyshade Compact stands out due to its superior performance, since the device can determine not only the base color of the whole tooth and its thirds, but verify the color of the restoration [11]. As spectrophotometers are designed for application on smooth surfaces, their use in dentistry is hindered by the convex tooth exterior, which complicates the correct placement of the probe tip. In vivo colorimeter measurements of the color of permanent maxillary teeth show that the middle third segment best represents the overall tooth color and hue [13, 14]. Following the measurement, the color from the VITApan Classical shade guide and the VITA 3D-Master shade guide is displayed along

with the L*C*h* a*b* coordinates in the CIE L*a*b* color space for the measured tooth area [15].

In 1976, the International Commission on Illumination (Commission Internationale de l'Eclairage) (CIE) introduced the CIE L*a*b* system based on opponent process theory of color. In this three-dimensional space, color can be represented by L*, a* and b* coordinates on their respective axes. Coordinate L* (vertical axis) represents the lightness of the color (with L* = 0 denoting pure black and L* = 100 pure white, i.e., a perfect diffuser). On the other hand, coordinate a* represents the chromaticity of the color, i.e., red-green color balance (+a indicates redness and –a greenness), whereas coordinate b* represents the yellow-blue color balance (+b indicates yellowness and –b blueness) [16]. For natural colors, the values of these coordinates are close to 0 and they increase for more intensive (i.e., more chromatic) colors. A clinically significant color difference, Delta-E (ΔE) can be expressed in units that are correlated with visual perception using the CIE L*a*b* system [1, 3, 4, 8, 11, 14]. In experimental conditions, the $\Delta E > 1$ is visible to the naked eye, while in clinical conditions, the difference must exceed 3.7 to be noticeable [2, 5]. As far back as 1900, Munsell wrote about the 3D aspect of color, which can be captured via parameters such as hue, chroma (saturation) and value (lightness) [17].

A vast research on the topic of tooth color is focused on the dentition in the upper jaw, especially the frontal region, i.e., central incisors, lateral incisors, and canines due to their visual exposure and extremely high esthetic requirements [18]. In several studies, only the maxillary incisors [4] or canines [16] were considered.

Age and gender are also important factors in tooth color [14], whereby several studies have shown that women have lighter teeth than men [19–21]. On the other hand, tooth form and shape are not affected by gender [22].

There are many available studies where spectrophotometric analysis of color parameters was used based on the CIE L*a*b* system [23, 24].

There is a paucity of studies focusing on student (and generally younger) population examining tooth color parameters, as majority of such investigations were based on samples aged 30 and older. This results in lack of generalization, given that due to various age-related physiological changes and the development of secondary dentin, the tooth color becomes darker as we get older [24, 25].

Therefore, the aim of our study was to determine if there are any gender-related differences in the natural maxillary central incisor color in the student population by conducting spectrophotometric analysis of relevant color parameters using the CIE L*a*b* system.

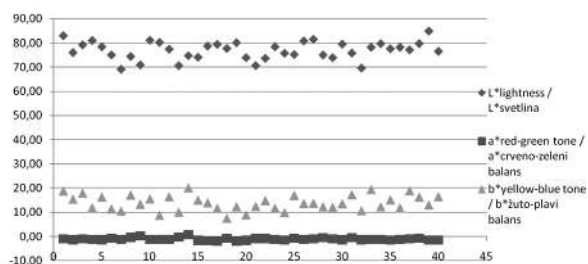
Material and Methods

This prospective study included 80 dental students (40 males and 40 females, aged 20 - 24 years) attending the Faculty of Medicine of the University of Novi Sad. Students meeting any of the following criteria were

excluded from the study: tooth discoloration due to smoking or certain medications, presence of direct or indirect restorations of the natural maxillary central incisors, and previous endodontic treatments involving these teeth. The color of maxillary right central incisor was determined using VITA Easyshade Compact intraoral spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany). At the start of the study, all participants received a professional dental cleaning. Prior to selecting the color, the spectrophotometer was subjected to manual calibration involving the application of protective foil, followed by choosing the appropriate function from the menu in order to assess the overall tooth color. When performing the measurements, the probe tip was set vertically at an equal distance from the surface of the tooth, no less than 2 mm away from both the incisal and the gingival edge, in the middle segment of the maxillary central incisor, as the most representative of the natural tooth color. Each measurement by VITAPAN Classical and VITA 3D-Master color provided L^* , a^* and b^* values to be recorded. The obtained results were processed using χ^2 , Student's t-test and Mann-Whitney test.

Results

According to the values obtained by intraoral spectrophotometer, in the male subsample, the bright-



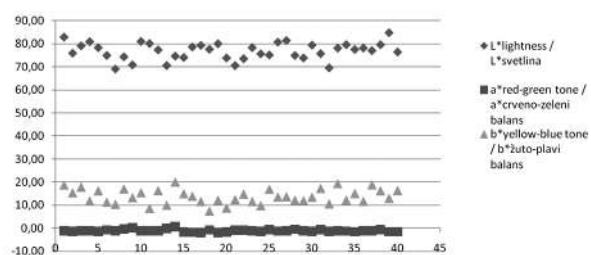
Graph 1. Distribution of colorimetric parameters (L^* - lightness, a^* - red-green tone, and b^* - yellow-blue tone) of maxillary central incisor color values in male participants
Grafikon 1. Distribucija kolorimetrijskih parametara (L^* - svetlina, a^* - crvenozeleni balans, i b^* - žuto-plavi balans boje) centralnog gornjeg sekutića kod ispitanika muškog pola

ness parameter (L^*) ranged from 70.2 to 83.7, with an average of 76.67 (**Graph 1**), while values in the female subjects ranged from 69.0 to 84.8, with an average of 76.81 (**Graph 2**). The difference between values obtained in male and female subjects was not statistically significant, as shown in **Table 1**.

In 36 of 40 male participants, the red-green tone (a^* coordinate) tended toward the red (negative) part of the scale (ranging from -0.1 to -2.3), while the remaining four participants had positive values (ranging from 0.0 to 0.3), as shown in **Graph 1**. Similar red-green tone distribution was noted in female students, with negative values in 37 cases (ranging from -0.2 to -2.0), as shown in **Graph 2**. Once again, the difference between obtained values in males and females was not statistically significant (**Table 1**).

In the male subsample, the value of the yellow-blue tone (b^* coordinate) was strictly positive (8.4 - 21.9), indicating predominance of yellow color tone (**Graph 1**). Similarly, only positive values were recorded in the female participants, ranging from 7.4 to 20.1 (**Graph 2**). However, the difference between genders was statistically significant ($p = 0.036402$, **Table 1**).

Based on the analysis of the information presented in **Table 2** and the p-value of 0.0000178, it can be concluded that the tooth color of dental students established using VITAPAN Classical shade guide is not evenly distributed, as D color ($p =$



Graph 2. Distribution of colorimetric parameters (L^* - lightness, a^* - red-green tone, and b^* - yellow-blue tone) of maxillary central incisor color values in female participants
Grafikon 2. Distribucija kolorimetrijskih parametara (L^* - svetlina, a^* - crvenozeleni balans, i b^* - žuto-plavi balans boje) centralnog gornjeg sekutića kod ispitanika ženskog pola

Table 1. Analysis of the colorimetric parameters related to the maxillary central incisor (L^* - lightness, a^* - red-green tone, and b^* - yellow-blue tone) with respect to gender

Tabela 1. Analiza kolorimetrijskih parametara centralnog gornjeg sekutića (L^* - svetlina, a^* - crvenozeleni balans, i b^* - žuto-plavi balans boje) u zavisnosti od pola ispitanika

Group 1 M//Grupa 1 M vs. Group 2 F/Grupa 2 Ž	Mean Srednja	Mean Srednja	t-value t-vrednost	df df	P P	Valid N Validan broj	Valid N Validan broj
Lightness M/Svetlina M vs. Lightness F/Svetlina Ž	76.67	76.81	-0.176226	78	0.860573	40	40
Red-green M/Crvenozelena M vs. Red-green F/Crvenozelena Ž	-0.9	-1.1075	1.564895	78	0.121656	40	40
Yellow-blue M/Žutoplava M vs. Yellow-blue F/Žutoplava Ž	15.365	13.8325	2.129084	78	0.036402	40	40

M/M - Male/Muški pol, F/Ž - Female/Ženski pol

Table 2. Z-test (VITAPAN Classical shade guide) and Mann-Whitney test (VITA 3D-Master shade guide)
Tabela 2. Z-test (VITAPAN klasični ključ boja) i Man-Vitnijev test (VITA 3D-Master ključ boja)

Sample Proportion/Proporcija uzorka	N/Broj ispitanika	Z	p-value/p vrednost
VITAPAN Classical/VITAPAN klasični	80	2.721443	0.00325
Vita 3D/Vita 3D	80	0.620652	0.534829

0.00325) is prevalent in more than 25% of the sample, as shown in **Table 2** and **Graph 3**.

Using the 3D-Master shade guide, lightness group 3 was identified in more than 20% of participants, as shown in **Table 2** and **Graph 4**.

Among the male students, A1 (i.e., 2M1) color had the highest lightness value (83.7) while C3 (i.e., 3.5M) color had the lowest (70.2), as shown in **Table 1**. As shown in **Table 2**, among the female students, C2 (i.e., 3M1) and A1 (i.e., 1.5M1) color had the lowest (69.0) and the highest (84.8) lightness value, respectively.

Discussion

As part of this investigation, precise tooth color measurements were performed using the VITA Easyshade Compact optoelectronic device, which enables quick and accurate measuring and provides results that are completely independent of the conditions under which color selection is made or the person performing the procedure [5, 9, 26, 27]. The VITA Easyshade Compact device is considered the most reliable in both in vitro and in vivo settings [28] and is thus typically used as a reference for tooth color determination [29]. Available evidence indicates that, in comparison with the visual method, its color correspondence is 93.3%, with an increase in accuracy by 33% [30].

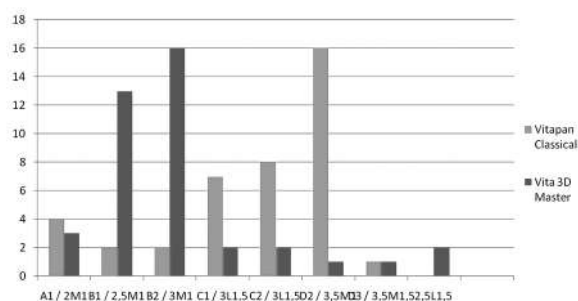
VITA Easyshade Compact is easy to use and it enables visualizing the L*C*h*a*b* coordinates for the measured tooth area in the CIE L*a*b* color space, while providing other useful information about the shade, such as the difference between the color of

a measured tooth area and approximate VITAPAN Classical A1-D4 shade in the 3D color space [5].

Moreover, as age has been shown to affect the color of natural teeth, to eliminate any age-related variations, the present study focused on individuals aged 20 – 24 years [31]. This is in line with other studies, given that older participants are rarely considered for this type of research [16]. Evidence reported in related literature indicates that teeth become darker with age [32].

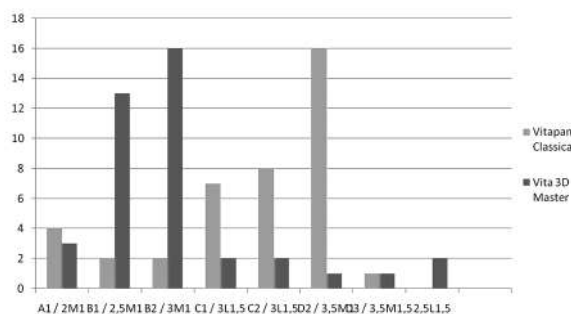
In the CIE L*a*b* system, which is recognized as a universal system for color specification, both the light source and the observer are standardized. With this system, each color can be represented as a point in a spherical space and its position is determined by the distance between the point and each of the three (L*, a* and b*) axes. Therefore, knowledge about this system and its usage is recommended [1, 33]. Within the color space diagram, the color range of natural teeth occupies a small segment of a specific shape (akin to a vertically placed banana), located in the upper third of the diagram (representing the yellow-orange part of spectrum), and in the area of moderate saturation (related to lightness). Consequently, the lightest shades (which have lower saturation) are the closest to the vertical axis [34]. Still, it is worth noting that the distribution of natural tooth color in a Sudanese sample formed a parallelogram shape, while in American and German population it showed elongated oval and circular shape, respectively [19].

The average lightness values in our male (76.67) and female (76.81) subsamples are in accordance with the published results (77.1) [16]. However, the analysis of the L* coordinate values (i.e., the lightness of the



Graph 3. Maxillary central incisor color values in male participants according to the VITAPAN Classical and VITA 3D-Master shade guides

Grafikon 3. Boja centralnog gornjeg sekutića kod ispitanika muškog pola u skladu sa VITAPAN klasičnim i VITA 3D-Master ključem boja



Graph 4. Maxillary central incisor color values in female participants according to the VITAPAN Classical and VITA 3D-Master shade guides

Grafikon 4. Boja centralnog gornjeg sekutića kod ispitanika ženskog pola u skladu sa VITAPAN klasičnim i VITA 3D-Master ključem boja

maxillary central incisor) revealed no statistically significant difference between genders, opposite to the observations of other authors that women tend to have brighter teeth [19, 31]. In addition, in some studies, colorimetric measurements have shown that, even though maxillary teeth are more yellow compared to mandibular teeth, maxillary incisors are lighter than mandibular incisors [16]. The mean red-green tone value in our male and female subsample was -0.9 and -1.1075, respectively. For most participants, irrespective of gender, this parameter had a negative value and no statistically significant gender-related differences were found. As the literature search failed to reveal any studies in which analysis of the red-green or blue-yellow parameter was conducted, no comparison with the available data is possible. Yellow-blue tone was strictly positive and peaked at 15.365 and 13.8325 in males and females, respectively. Overall, the maxillary central incisors of female students exhibited less visible yellow tone.

The results yielded by this study have shown that, regardless of gender, the predominant tooth color corresponded to D2 in the VITAPAN Classical shade guide (i.e., 3M1 in the VITA 3D-Master shade guide). In the current study sample, colors from groups A and B according to the VITAPAN Classical shade guide were less represented in regard to those in the color groups C and D. In particular, using the intraoral spectrophotometer in accordance with the VITAPAN Classical shade guide, A3 and B1 colors were not detected in the male subsample and A2 was absent in the female group. In a study of tooth color in the Sudanese population aged 15

– 72, the most common color was A3, followed by A1. In the same study, 3M1 color according to the 3D-Master shade guide was determined in just over 5% of participants, while 1M2 was found in more than 30% of the sample [19]. In our study, the dominant color according to the 3D-Master shade guide was 3M1, which is in line with the results reported by Gómez-Polo, who analyzed tooth color in the Spanish population [35]. Thus, it can be presumed that tooth color is likely dependent on the ethnicity of the population being examined.

Conclusion

In restorative dentistry, in order to accurately determine the tooth color and reliably interpret the results of analysis, it is essential to master the basic principles of color science. In particular, the colorimetric parameters of the International Commission on Illumination L*a*b* system provide ample information about the tooth color in the examined population, while potentially revealing any differences in lightness, red-green tone and yellow-blue tone between genders.

Owing to the limitations of the present study, no statistically significant differences in the maxillary central incisor lightness and red-green color tone were noted between genders. However, yellow color tone was more prominent among male students. Within the VITAPAN Classical and 3D-Master shade guide, D2 and 3M1 color, respectively, was most prevalent in the studied sample. Moreover, A1 from the VITAPAN Classical shade guide has the highest and C1 the lowest lightness values irrespective of gender.

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