ACTA
STOMATOLOGICA
CROATICA
www.ascro.hr

Acta stomatol Croat. 2024;58(2):185-192.
DOI: 10.15644/asc58/2/8

ORIGINAL SCIENTIFIC PAPER
IZVORNI ZNANSTVENI RAD

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Assessment of Tooth Shade Measurement Precision and Consistency with Digital Photography Calibration System

Procjena preciznosti i dosljednosti mjerenja boje zuba sa sustavom kalibracije digitalne fotografije

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Abstract

Objectives: To ascertain the degree of precision and repeatability inherent in the "capture to edit" digital imaging system, namely the ColorChecker Passport Photo (X-Rite, MI, USA), and to juxtapose its performance against spectrophotometric assessments utilizing the Vita Easyshade® (Vita Zahnfabrik, H Rauter GmbH & Co. KG., Bad Sackingen, Germany) for the same set of teeth. **Materials and methods:** Eighty participants aged 19-25 were included in the study; all of them were Croatian students at the School of Dental Medicine, University of Zagreb. Color measurements of the maxillary right central incisors were performed in controlled, standardized laboratory conditions. The measurements were performed on calibrated digital photographs by an experienced clinician three times in a row, and L, a, and b of CIELAB color space values were recorded. The same procedure was performed using the Vita Easyshade 5.0 spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) in "Tooth single" mode. **Results:** The Cronbach's alpha was used as a repeatability measurement, thus revealing high consistency for both methods (α=0.94-1). Correlations were moderate (Pearson r=0.44-0.66 $p<0.05$). Testing confirmed that digital photography is inaccurate as spectrophotometry ($p<0.05$). An analysis of errors of means and their standard deviations revealed consistent discrepancies with minor deviations. **Conclusion:** The "capture to edit" method showed high consistency (Cronbach's α=0.94-0.96), and it exhibits comparability in terms of variability, reliability, and repeatability when compared to spectrophotometric measurement (VitaShade 5, VitaZahnfabrik). Disparities between the methods are evident and anticipated, yet they do not follow a consistently linear pattern. The combination of repeatability and consistency renders the "capture to edit" method a valuable tool for enhanced color mapping, thus facilitating comparisons between digital images.

Received: December 30, 2023
Accepted: May 20, 2024

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MeSH Terms: Tooth; Color; Photography
Author Keywords: Tooth color; Capture to edit; Calibrated digital photography; VitaShade; ColorChecker Passport

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Introduction

Determination of an accurate tooth shade is often considered the most challenging part of producing the natural appearance of teeth and represents the final validation in general smile esthetic (1). An accurate choice of tooth shade allows clinicians and dental technicians to imitate the natural tooth color and fulfil the patient's esthetic expectations (2, 3, 4).

Visual Color matching is considered a subjective procedure (5), and due to interhuman differences in color perception (6), visual shade assessment, as the oldest method of shade selection using commercial shade guide, is unreliable, easily standardized, or repeatable (7). It is also well known that the shade of any restoration is influenced by many ex-

Uvod

Određivanje točne boje zuba često se smatra najvećim izazovom u postizanju prirodnog izgleda zuba i ključna je komponenta u cjelokupnoj estetici osmijeha (1). Odabir odgovarajuće boje zuba omogućuje doktorima dentalne medicine i dentalnim tehničarima da imitiraju njihovu prirodnu boju te ispune estetska očekivanja pacijenta (2, 3, 4).

Vizualno određivanje boje zuba smatra se subjektivnom metodom (5) zbog različitosti u ljudskoj percepciji boje (6). Taj se način, kao najstarija metoda određivanja boje zuba uporabom konvencionalnoga ključa boja, smatra nepouzdanim, nedovoljno standardiziranim ili ponovljivim (7). Također se zna da na boju bilo kojega dentalnoga restaurativnoga rada utječu mnogi vanjski čimbenici, poput okolišnih, zatim ternal factors, such as the environment, the dentist's subjective opinion, surrounding light, and various patient-related causes (7–9).

Numerous efforts have been made to objectively determine and communicate tooth shade using multiple methods. Instrumental color determination methods include different instruments such as spectrophotometers, spectropolarimeters, spectroradiometers, intra-oral scanners, and digital imaging (10–13) to produce quantifiable and reliable outcomes. Spectrophotometer-based devices have shown high reliability and accuracy in previous investigations (2, 14, 15) but they cannot convey information about transparency, opacity, dynamic range, and detailed surface color mapping.

Using calibrated dental photography makes the goal of better detailing color reachable. Efforts to calibrate dental photography have been complicated by different hardware and software systems used to obtain digital images (13, 16) and their inherent inaccuracies. Standardization of hardware and software and measuring environment has been developed (17, 18). However, these and similar systems are demanding regarding their usage and require high proficiency and skill. Using a "capture to edit" solution with any digital imaging system should provide improved accuracy and tooth shade reproduction.

This study compares the spectral reflectance factors of the maxillary first centrals from a cohort of 80 participants. These factors were assessed using a spectrophotometer (Vita EasyShade V) and were further compared with digital images acquired through an innovative methodology from the same cohort.

The comparative analysis encompassed key factors such as consistency, repeatability, and inter-method accuracy (19). It is a well-established fact that due to disparities in the measuring methods and resultant outcomes, a direct comparison of accuracy between these two methods is inherently complex. Nevertheless, spectrophotometers maintain a pervasive presence in clinical practice and are commonly upheld as the gold standard (20).

Therefore, we considered it relevant to compare the similarities and disparities between measurements obtained using these methods.

Measurement uncertainties can be classified into two key categories that define the quality of measurements: precision and accuracy. Precision refers to the degree of similarity among multiple test measurements, regardless of their proximity to the actual value, while accuracy relates to how close test measurements are to a reference value (21).

Lack of precision is primarily attributable to random errors, while a lack of accuracy stems from systematic errors, often termed bias errors (21). Repeatability assesses how effectively an instrument can replicate identical measurements without requiring repositioning of the specimen. Reproducibility, similar to repeatability, takes into account changes in measurement conditions, including repositioning the specimen, different operators, and variations in instruments. Enhanced levels of repeatability and reproducibility correlate with increased measurement reliability (8, 21).

subjektivne procjene doktora dentalne medicine, utjecaj svjetla u okruženju te razni drugi uzroci vezani za samog pacijenta (7 – 9).

Objektivna boja zuba pokušava se odrediti i prenijeti mnogim metodama. Instrumentalne metode određivanja boje zuba da bi se postigli kvantitativni i pouzdani rezultati uključuju različite instrumente poput spektrofotometara, spektropolarimetara, spektroradiometara, intraoralnih skenera i digitalnih fotografija (10 – 13). Uređaji temeljeni na spektrofotometriji pokazali su visoku pouzdanost i točnost u dosadašnjim istraživanjima (2, 14, 15), ali ne mogu prenijeti informacije o transparentnosti, opacitetu, dinamičkom rasponu i detaljima površine zuba.

Uporaba kalibrirane dentalne fotografije čini detaljiziranje boje zuba dostižnim. Napori usmjereni na kalibraciju dentalne fotografije bili su komplicirani zbog različitih hardverskih i softverskih sustava korištenih za dobivanje digitalnih fotografija (13, 16) i njihovih inherentnih nepravilnosti. Zato je razvijena standardizacija hardvera i softvera te mjernog okruženja (17, 18). No ti i slični sustavi zahtjevni su tijekom uporabe i iziskuju visoku stručnost i vještinu. Korištenje rješenja *capture to edit* s bilo kojim digitalnim sustavom fotografiranja trebalo bi poboljšati točnost i omogućiti reprodukciju boje zuba.

U ovom istraživanju uspoređeni su spektralni čimbenici refleksije maksilarnih središnjih sjekutića na 80 ispitanika. Procijenjeni su spektrofotometrom (Vita EasyShade V) te su poslije toga uspoređivani s digitalnim fotografijama istih ispitanika dobivenima inovativnom metodologijom.

Komparativnom analizom obuhvaćeni su ključni čimbenici poput konzistencije, ponovljivosti i uzajamne točnosti metoda (19). Poznato je da je zbog razlika u mjernim metodama i dobivenim rezultatima izravna usporedba točnosti između tih dviju metoda inherentno složena. Ipak, spektrofotometri su sveprisutni u kliničkoj praksi i uglavnom se smatraju zlatnim standardom (20). Zato smatramo relevantnim usporediti sličnosti i razlike između mjerenja dobivenih tim metodama.

Nepouzdanosti u mjerenjima mogu se svrstati u dvije ključne kategorije koje definiraju kvalitetu mjerenja – preciznost i točnost. Preciznost se odnosi na stupanj sličnosti između višestrukih testnih mjerenja bez obzira na njihovu blizinu stvarnoj vrijednosti, a točnost na to koliko su testna mjerenja bliska referentnoj vrijednosti (21).

Nedostatak preciznosti ponajprije je posljedica slučajnih pogrešaka, a nedostatak točnosti proizlazi iz sustavnih pogrešaka, često nazvanih pristranim pogreškama (21). Ponovljivost procjenjuje koliko učinkovito instrument može replicirati identična mjerenja bez potrebe za ponovnim pozicioniranjem uzorka. Reproducibilnost, slično ponovljivosti, uzima u obzir promjene u mjernim uvjetima, uključujući ponovno pozicioniranje uzorka, različite ispitivače i varijacije u instrumentariju. Povećane razine ponovljivosti i reproducibilnosti koreliraju s povećanom pouzdanošću mjerenja (8, 21) .

U ovom istraživanju preciznost je definirana kao stupanj bliskosti među mjerenjima bez obzira na točnost. Također se pokušala utvrditi potencijalno sustavna pogreška između tih

In this article, precision was defined as the degree of closeness among measurements, irrespective of accuracy. An endeavor was undertaken to ascertain the potential existence of systematic error between these methods, employing the spectrophotometer as a reference value. Reproducibility for both methods was evaluated through a series of repeated measurements.

Materials and methods

In this study, a cohort of 80 participants was enrolled, comprising 58 females. All participants were Croatian students attending the School of Dental Medicine at the University of Zagreb, Croatia, within the age range of 19 to 25 years. All subjects were provided with written information, and subsequently they signed informed consent forms which were approved by the Ethical Board of the Dental University of Zagreb (Approval number: 05-PA-26-1/2016). The research was conducted during the final week of February and the first two weeks of March in 2021 to minimize the influence of insolation on skin color.

Spectrophotometric Measurements

The study was performed under standardized light conditions in accordance with CIE (Commision Internationale de l'Eclairage) (Just Normlicht, Weilheimder Teck, Germany) in order to obtain standardized clinical conditions. Lightning strength was 6500 K and 100 Lux. No ambient light was present while measurements were obtained.

The color measurements were carried out in a specialized color investigation laboratory situated in the Department of Prosthodontics at the University of Dental Medicine in Zagreb, Croatia. The established protocol involved participants seated in a height-regulated chair, maintaining a natural head position during measurements. The participants also used C-shaped plastic and sterilized mouth retractors (Cotisen, Huanghua Promisee Dental Co., Ltd). To prevent background reflections and enhance exposure during color measurements, a grey background (Walimex foldable background grey, 150x200 cm) was employed.

The teeth selected for color measurements were the right maxillary central incisors, specifically natural teeth without restorations or any prosthetic appliances or pathological discolorations. Prior to measurement, each tooth was prepared by polishing for 30 seconds using a tooth polish brush and paste (Proxyt RDA 83; Ivoclar Vivadent, Schaan, Liechtenstein). The teeth were then moistened with a wetted cotton pallet for 5 seconds (15).

Color recordings were performed by a seasoned clinician using the Vita Easyshade 5.0 spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany). The "Tooth single" program was employed to record shades in the CIE 1976 L* a* b* color space values (CIELAB). Prior to measurements, the spectrophotometric device was calibrated, adhering strictly to the manufacturer's guidelines. Each tooth underwent three measurements, totaling 720 measurements. The measurements were obtained from approximately the same position on the middle third of the labial tooth surface (24).

metoda koristeći se spektrofotometrom kao referentnom vrijednošću. Reproducibilnost za obje metode procijenjena je na temelju serije ponovljenih mjerenja.

Materijali i metode

U ovom istraživanju sudjelovalo je 80 sudionika – 58 je bilo žena. Svi su bili hrvatski studenti Stomatološkog fakulteta Sveučilišta u Zagrebu, u dobi od 19 do 25 godina. Najprije su dobili pisane informacije o istraživanju, a zatim su potpisali informirani pristanak za sudjelovanje u istraživanju koje je odobrilo Etičko povjerenstvo Stomatološkog fakulteta u Zagrebu (broj odobrenja: 05-PA-26-1/2016). Istraživanje je provedeno posljednjeg tjedna veljače i prva dva tjedna u ožujku 2021. godine da bi se minimizirao utjecaj insolacije na boju kože.

Spektrofotometrijska mjerenja

Istraživanje je provedeno u standardiziranim svjetlosnim uvjetima u skladu s CIE-om (Commision Internationale de l'Eclairage) (Just Normlicht Weilheimder Teck, Njemačka) kako bi se dobili standardizirani klinički uvjeti. Snaga osvjetljenja bila je 6500 K i 100 Lux. Nije bilo ambijentalne svjetlosti tijekom mjerenja.

Mjerenja boje provedena su u specijaliziranom laboratoriju za istraživanje boja u Zavodu za protetiku Stomatološkog fakulteta Sveučilišta u Zagrebu. Utvrđeni protokol uključivao je sjedenje ispitanika na stolcu s regulirajućom visinom sjedenja i pritom se tijekom mjerenja održavao prirodni položaj glave. Na ispitanicima su korišteni plastični i sterilni usni retraktori C-oblika (Cotisen Huanghua Promisee Dental Co. Ltd). Kako bi se spriječila refleksija pozadine i poboljšala ekspozicija tijekom mjerenja boje, korištena je siva pozadina (Walimex sklopiva siva pozadina 150 x 200 cm).

Zubi odabrani za mjerenje boje bili su desni maksilarni središnji sjekutići, isključivo prirodni zubi bez restaurativnih ili protetičkih radova ili patoloških diskoloracija. Prije mjerenja svaki je zub pripremljen poliranjem tijekom 30 sekunda četkicom za poliranje zuba i pastom (Proxyt RDA 83; Ivoclar Vivadent, Schaan, Lihtenštajn). Zubi su zatim pet sekunda vlaženi mokrom vatom (15).

Mjerenja boje obavio je iskusni kliničar spektrofotometrom Vita Easyshade 5.0 (Vita Zahnfabrik, Bad Säckingen, Njemačka). Program *Tooth single* korišten je za snimanje nijansi u vrijednostima CIE 1976 **L*** **a*** **b*** (CIELAB). Prije mjerenja je spektrofotometrijski uređaj kalibriran strogo prema smjernicama proizvođača. Svaki zub je podvrgnut trima mjerenjima – ukupno 720 mjerenja. Mjerenja su dobivena s otprilike iste pozicije na srednjoj trećini labijalne površine zuba (24).

Digital Image Measurements

The second phase of the investigation involved capturing standardized frontal photographs of the head, face, and teeth, all in a natural head position, immediately after the spectrophotometric measurements. Digital photographs were taken using a Canon EOS 5D Mark II (Canon Inc., Tokyo, Japan) paired with a prime lens with a focal length of 50 mm (Canon EF 50mm; Canon Inc., Tokyo, Japan). Polarization filter (Hoya Cir-pol Pro 1 Digital, 52 mm, Hoya Corporation, Japan) was used to avoid surface gloss.

The ISO speed was set to ISO-100, and the distance between the patient and the camera was 150 cm. A tripod and remote shutter were utilized for each photograph, accompanied by Mecablitz 15 MS-1 (Metz-Werke GmbH&Co, Zirndorf, Germany). During the taking of photography, the patient held a ColorChecker Passport Classic Target (X-Rite Inc., Michigan, USA) under the chin (see Figure 1). The ColorChecker Passport that was used included a gray card and white balance target (22).

Digital photographs were taken and saved as .CR2 files with consistent image compression levels.

Subsequent post-processing was conducted using Adobe Lightroom 6.0 software (Adobe Systems, San Jose, California, USA) and X-Rite's proprietary Lightroom plugin. Throughout this process, a unique camera profile was created in Lightroom for each patient and employed for automated color correction of the image, utilizing the Classic Target color profile from the photograph. Measurements were conducted using the software's "Color Picker" tool, employing a round point size of 100 pixels. Each measurement was repeated three times by the same operator, with recorded L, a, and b values stored in a database.

Mjerenja na digitalnoj fotografiji

Druga faza istraživanja uključivala je snimanje standardiziranih frontalnih fotografija glave, lica i zuba, sve u prirodnom položaju glave, i to odmah poslije spektrofotometrijskih mjerenja. Digitalne fotografije snimljene su Canonom EOS 5D Mark II (Canon Inc., Tokio, Japan) u kombinaciji s primarnim objektivom žarišne duljine od 50 mm (Canon EF 50mm; Canon Inc., Tokio, Japan). Polarizacijski filtar (Hoya Cir-pol Pro 1 Digital 52 mm, Hoya Corporation, Japan) korišten je da bi se izbjegao odsjaj površine.

ISO brzina postavljena je na ISO-100, a udaljenost između pacijenta i kamere bila je 150 cm. Korišteni su stativ i daljinski okidač za svaku fotografiju, uz bljeskalicu Mecablitz 15 MS-1 (Metz-Werke GmbH&Co, Zirndorf, Njemačka). Tijekom fotografiranja pacijent je držao ColorChecker Passport Classic Target (X-Rite Inc., Michigan, SAD) točno ispod brade (slika 1.).

Navedeni korišteni ColorChecker Passport imao je inkorporirane komponente, tzv. sive kartice (*gray card*) i cilj balansa bijele boje (*white balance target*) (22).

Digitalne fotografije snimljene su i spremljene kao .CR2 datoteke s konzistentnim stupnjem kompresije fotografije.

Postobrada je nakon toga obavljena softverom Adobe Lightroom 6.0 (Adobe Systems, San Jose, Kalifornija, SAD) i X-Rite-ovim Lightroom pluginom. Tijekom toga postupka kreiran je jedinstveni profil kamere u Lightroomu za svakog pacijenta i primijenjen za automatsku korekciju boje slike koristeći se Classic Target color profilom iz fotografije. Mjerenja su provedena alatom softvera *Color Picker*, koristeći se okruglom točkom veličine 100 piksela. Svako mjerenje isti je ispitivač ponovio tri puta s evidentiranim vrijednostima **L**, **a** i **b** pohranjenima u bazu podataka.

1

2

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma_{Y_i}^{2}}{\sigma_X^{2}}\right)$$

a - Cronbach alpha

K - number of measurements

$\sigma_{Y_i}^{2}$ *- variance of ith item*

σ_X^{2} *- variance of the observed total scores*

Figure 1 Example of a calibrated digital image using ColorChecker Passport Classic Target (X-Rite Inc. Michigan, USA)
Slika 1. Primjer kalibrirane digitalne slike s pomoću ColorChecker Passport Classic Target (X-Rite Inc. Michigan, SAD)
Figure 2 Cronbach's alpha formula
Slika 2. Cronbachova alfa formula

Statistical analysis

In the study, each data point was scrutinized to ascertain the mean value alongside the corresponding error percentage. Any data points exhibiting an error margin exceeding 5% were systematically excluded from subsequent analyses. Additionally, instances featuring subpar image quality - characterized by lack of focus, variations in dynamic range, and disparate exposure levels - were discarded from the dataset. This rigorous selection process culminated in a refined dataset encompassing 72 viable cases slated for further analysis.

To evaluate the repeatability of the two methods under investigation, a statistical analysis Cronbach alpha was utilized (Figure 2.)

Concurrently, the accuracy of repeated measurements was assessed through the application of Students' T-tests. Furthermore, a comprehensive analysis of the descriptive data was undertaken to clarify the potential correlations existing between the two methodologies under scrutiny.

The statistical analyses were facilitated utilizing the BlueSky Statistics software, a product of BlueSky Statistics Pty Ltd., situated in Chicago, IL, USA.

Results

The outcomes of this study encompass a comprehensive evaluation of data repeatability across successive measurements employing both analyzed methods. Furthermore, descriptive statistical analysis coupled with inter-method accuracy assessment was utilized to clarify the nuances of the acquired data.

Repeatability

In this investigation, repeatability serves as a critical metric to validate the closeness of outcomes obtained from successive measurements. These outcomes may exhibit variability owing to factors such as alterations in the equipment placement on the tooth, fluctuations in environmental and subject conditions, and discrepancies in recording practices, pertinent to both spectrophotometry and the scrutinized "capture to edit" technique.

The measurements undertaken encompassed the acquisition of L, a, and b CIELAB values. For each component analyzed, three consecutive evaluations were procured utilizing each respective method. The Cronbach's alpha statistical approach was employed to quantify repeatability, which disclosed a substantial and nearly identical level of consistency within the measured data sets, as delineated in Table 1.

Correlations

In the present study, the Pearson correlation coefficient was employed to clarify the magnitude and orientation of the linear association between the variables: spectrophotometry lightness (STCL), a component (STCa), and b component (STCb), in conjunction with digital image lightness (DITCL), a component (DITCa), and b component (DITCb). The analysis revealed moderate correlations for the majority of the scrutinized variable pairs: r(STCL-DITCL)=0.659, r(STCa-DITCa)=0.634, r(STCb-DITCb)=0.440, all of which were statistically significant with p-values less than 0.05.

Statistička analiza

U provedenom istraživanju svaka varijabla pozorno je analizirana te je izračunata prosječna vrijednost uz odgovarajući postotak prosječne pogreške. Svi podatci koji su pokazivali standardiziranu pogrešku veću od 5 % sustavno su isključeni iz daljnjih analiza. Također su iz analiziranoga skupa podataka izbačeni slučajevi sa slabom kvalitetom fotografije – oni s nedostatkom fokusa, varijacijama u dinamičkom rasponu i neodgovarajućim razinama ekspozicije. Takva selekcija rezultirala je pročišćenim skupom podataka koji uključuje 72 valjana slučaja predviđena za daljnju analizu.

Da bi se procijenila ponovljivost dviju uporabljenih metoda, korištena je usporedba Cronbach alpha (slika 2.).

Istodobno je točnost ponovljenih mjerenja procijenjena primjenom Studentova T-testa. Nadalje, obavljena je sveobuhvatna analiza opisnih podataka kako bi se objasnile potencijalne korelacije između dviju uporabljenih metoda.

Statističke analize obavljene su softverom BlueSky Statistics, proizvodom tvrtke BlueSky Statistics Pty Ltd. iz Chicaga, IL, SAD.

Rezultati

Rezultati ovog istraživanja obuhvaćaju sveobuhvatnu procjenu ponovljivosti podataka na temelju sukcesivnih mjerenja koristeći se objema analiziranim metodama. Nadalje, provedena je opisna statistička analiza u kombinaciji s procjenom točnosti metoda da bi se objasnile i male različitosti u dobivenim podatcima.

Ponovljivost

U ovom istraživanju ponovljivost služi kao ključna mjera za validaciju rezultata dobivenih sukcesivnim mjerenjima. Rezultati pokazuju varijabilnost zbog čimbenika poput postavljanja mjernog instrumenta na zub, fluktuacija u okolišnim uvjetima i individualnosti samog subjekta te nesukladnosti u praksama bilježenja relevantnih za spektrofotometrijska i tehnike snimanja *capture to edit*.

Mjerenja obuhvaćaju bilježenje **L**, **a** i **b** CIELAB vrijednosti. Za svaku analiziranu komponentu provedena je serija od triju uzastopnih mjerenja koristeći se svakom metodom. Statistički test Cronbach alpha korišten je za kvantificiranje ponovljivosti. Pronađena je statistički značajna i gotovo identična razina konzistentnosti unutar skupova izmjerenih podataka (tablica 1.).

Korelacije

U ovom istraživanju upotrijebljen je Pearsonov koeficijent korelacije da bi se opisalo veličinu i smjer linearne povezanosti između varijabli: spektrofotometrijska svjetlina (STCL), komponenta **a** (STCa) i komponenta **b** (STCb), u kombinaciji sa svjetlinom (DITCL), komponentom **a** (DITCa) i komponentom **b** (DITCb) digitalne slike. Analiza je otkrila umjerene korelacije za većinu ispitanih parova varijabli: r(STCL-DITCL) = 0,659, r(STCa-DITCa) = 0,634, r(STCb-DITCb,) = 0,440, sve su statistički značajne s p-vrijednostima manjima od 0,05.

Table 1 Repeatability results for three repeated measurements for both employed methods - spectrophotometry on vital teeth using VitaShade 5, and digital photography calibrated with X-Rite ColorChecker 2

Tablica 1. Rezultati ponovljivosti za tri ponovljena mjerenja za obje korištene metode - spektrofotometrija na vitalnim zubima s pomoću VitaShade 5 i digitalna fotografija kalibrirana s X-Rite ColorChecker 2

Method	Cronbach's Alpha (L)	Cronbach's Alpha (a)	Cronbach's Alpha (b)
VitaShade 5	1	0.99	0.99
X-Rite ColorChecker	0.94	0.96	0.94

Table 2 Descriptive values for variables spectrophotometry lightness STCL, a component - STCa, and b component STCb, and digital image lightness DITCL, a component DITCa, and b component DITCb -measured in CIELabcolor space

Tablica 2. Opisne vrijednosti za varijable spektrofotometrijska svjetlina STCL, a komponenta - STCa, i b komponenta STCb, i svjetlina digitalne slike DITCL, a komponenta DITCa i b komponenta DITCb -mjereno u CIELabcolor prostoru

	STCL	STCa	STCb	DITCL	DITCa	DITCb	dEL	dEa	dEb
Mean	90.58	1.41	6.63	82.56	-1.47	16.46	8.02	2.88	-9.85
SD	8.22	2,36	4.71	4.91	1.04	3.04	1.75	0.38	0.78
min	63.77	-10.73	-4.93	66.94	-4.40	9.53	6.23	3.21	-8.11
max	98.10	7.37	22.17	94.87	1.93	24.23	10.27	2.11	-10.14

Mean errors and accuracy

Measurement deviations were determined by subtracting the values obtained from spectrophotometry measurements from those ascertained through digital imaging measurements. Subsequently, the consistency of these discrepancies was scrutinized and analyzed, as delineated in Table 2.

The accuracy of the methods was assessed through the execution of paired samples T-tests. The statistical analysis indicated significant differences across all variable pairs: STCL-DITCL with t=8.79, degrees of freedom (df) =71, p<0.05; STCa-DITCa with t=10.73, df=71, p<0.05; and STCb-DITCb with t=-16.44, df=71, p<0.05.

Discussion

The challenge of color and shade matching remains a prominent issue within the field of dentistry (1–5). Visual determination, primarily reliant on commercial shade guides, is the prevailing method for tooth shade determination (6). However, it is widely regarded as highly unreliable and inconsistent (7). Improvements aimed at objectivity and by enhancing the quality of color information the patient satisfaction could also be enhanced (1,3). While spectrophotometers are recognized as standard clinical tools (2, 14, 15), they possess limitations concerning transparency, color dynamics, and fine detail, areas where digital imaging offers superior capabilities (10, 11, 12, 13).

In this study, the Vita Easyshade Advance 5.0 spectrophotometer was employed to ascertain CIELAB L, a, and b values within the CIELAB color space. The results were compared in terms of reproducibility, repeatability, and variance with those obtained through the calibration of digital images using the X-Rite ColorChecker Passport Classic Target color reference and software calibration. Each method underwent three measurements, with outliers promptly excluded to ensure greater data consistency for subsequent analysis.

Given the significant influence of a patient's age on tooth shade color, the selected age group in this study ranged from 19 to 25 years to maintain consistency. Nevertheless, it is essential to acknowledge that in more advanced age groups

Srednje pogreške i točnost

Odstupanja u mjerenjima utvrđena su oduzimanjem vrijednosti dobivenih spektrofotometrijskim mjerenjima od onih dobivenih mjerenjima digitalne slike. Poslije toga analizirana je i procijenjena konzistentnost tih odstupanja kako je prikazano u tablici 2.

Točnost metoda procijenjena je provedbom T-testova za uparene uzorke. Statistička analiza pokazala je značajne razlike među svim parovima varijabli: STCL-DITCL s t = 8,79, stupnjevi slobode (df) = 71, p < 0,05; STCa-DITCa s t = 10,73, df = 71, p < 0,05; i STCb-DITCb s t = -16,44, df = 71, p < 0,05.

Rasprava

Izazov usklađivanja boja i nijansi u zubnim nizovima ostaje važno pitanje u stomatologiji (1 – 5). Vizualno određivanje koje se oslanja na ključeve boja najčešća je metoda za određivanje boje zuba (6), ali smatra se vrlo nepouzdanom i nekonzistentnom (7). Poboljšanja usmjerena na objektivnost i kvalitetnije informacije o boji mogu povećati zadovoljstvo pacijenata (1, 3). Dok se spektrofotometri prepoznaju kao standardni klinički alati (2, 14), ograničeni su u transparentnosti, dinamici boja i finih detalja u područjima u kojima je digitalno snimanje superiorno (10, 11, 12, 13).

U ovom istraživanju korišten je spektrofotometar Vita Easyshade Advance 5.0 za određivanje CIELAB **L, a** i **b** vrijednosti unutar CIELAB prostora boja. Rezultati su uspoređeni u reproducibilnosti, ponovljivosti i varijancama s onima dobivenima kroz kalibraciju digitalnih slika koristeći se X-Rite ColorChecker Passport Classic Target referencijom boja i softverskom kalibracijom. Svakom metodom obavljena su tri mjerenja, pri čemu su znatna odstupanja odmah eliminirana da bi se osigurala bolja konzistentnost podataka za daljnju analizu.

S obzirom na znatan utjecaj dobi pacijenta na boju nijanse zuba, odabrana dobna skupina u ovom istraživanju bila je od 19 do 25 godina kako bi se održala konzistentnost. Ipak, važno je priznati da se u starijim dobnim skupinama, sa širim spektrom boja, korisnost obiju metoda može značajno razlikovati.

with a wider spectrum of colors, the utility of both methods may vary significantly.

Our findings demonstrate a high level of repeatability for measurements using both methods, as indicated by Cronbach's Alpha values ranging from 0.99 to 1.0 for Vita EasyShade and 0.94 to 0.96 for X-Rite ColorChecker across all components of the measured color space. This consistency aligns with previous research on spectrophotometric measurements and is comparable to data acquired using digital 3D scanners (11). It also supports recent data for digital image calibration references (23). Correlations between the two methods exhibited a moderate level of agreement, with each component of the CIELAB color space displaying variations in accuracy. Specifically, L exhibited an offset of 8.02 +/- 1.75, a exhibited an offset of 2.88 +/- 0.38, and b exhibited an offset of -9.85 +/- 0.78. While substantial offsets were observed for each component, a low average standard deviation and minimal standard error suggest a specific relationship with accurate values. However, this relationship does not appear to follow a linear pattern. Nevertheless, their exceptional repeatability renders them suitable for intra- and inter-image comparisons.

Similar systems that incorporate CIELab principles to determine ceramic shade have already found practical applications (18). This reinforces our conclusion that, while not precisely accurate, the results remain usable in practical conditions. Determining the specific shade is just one facet essential for faithfully reproducing the authentic appearance of a living structure. The "Capture to edit" method holds the potential to provide a more precise and repeatable color description and reproduction, particularly when combined with other shade determination techniques.

Conclusion

While it is challenging to assert that the "capture to edit" photographic method is accurate, it is undeniably characterized by a high degree of consistency, as reflected in Cronbach's Alpha values ranging from 0.94 to 0.96. Moreover, it exhibits comparability in terms of variability, reliability, and repeatability when compared to spectrophotometric measurement (VitaShade 5, VitaZahnfabrik). Noteworthy disparities between the methods are evident and anticipated, yet they do not follow a consistently linear pattern. The combination of repeatability and consistency renders the "capture to edit" method a valuable tool for enhanced color mapping, thus facilitating comparisons between digital images.

Conflict of interest: None declared.

Authors contributions: **BDO** – have conducted the research; **BDO, DI**- have contributed to the concept and design of the study and to the acquisition of data; wrote the manuscript; **DB, MŽ** – revision of the first draft, has contributed in writing of the study; **MŠ** – revised the manuscript critically for important intellectual content.

Naši nalazi pokazuju visoku razinu ponovljivosti za mjerenja korištenjem obiju metoda, kako je indicirano vrijednostima Cronbach's Alpha od 0,99 do 1,0 za Vita EasyShade i 0,94 do 0,96 za X-Rite ColorChecker u svim komponentama izmjerenoga prostora boja. Ta konzistentnost u skladu je s dosadašnjim istraživanjima o spektrofotometrijskim mjerenjima i usporediva je s podatcima dobivenima korištenjem digitalnih 3D skenera (11). Također podržava nedavne podatke za referentne kalibracije digitalnih slika (23). Korelacije između dviju metoda pokazale su umjerenu razinu slaganja, s time da svaka komponenta CIELAB prostora boja pokazuje varijacije u točnosti. Konkretno, **L** je pokazao odstupanje od 8,02 +/- 1,75, **a** je imao odstupanje od 2,88 +/- 0,38, a **b** od -9,85 +/- 0,78. Iako su zabilježena značajna odstupanja za svaku komponentu, niska prosječna standardna devijacija i minimalna standardna pogreška sugeriraju specifičnu povezanost s točnim vrijednostima. No ta povezanost ne slijedi linearni trend, ali njihova izrazita ponovljivost čini ih prikladnima za intra i interslikovne usporedbe.

Slični sustavi koji uključuju CIELab čimbenike za određivanje boje keramike pronašli su praktične primjene (18). Naš je zaključak da su rezultati konzistentni i korisni u praksi, iako nisu potpuno egzaktni. Određivanje specifične boje samo je jedan od čimbenika potrebnih za vjerno reproduciranje autentičnog izgleda živoga tkiva. Metoda *capture to edit* može pružiti precizniji i ponovljiviji opis boje i jasniju reprodukciju, posebno kada se kombinira s drugim tehnikama određivanja boje.

Zaključak

Iako nije moguće tvrditi da je fotografska metoda *capture to edit* egzaktna zabilježba boje zuba, nesporno je da je karakterizira visok stupanj konzistentnosti, kao što je prikazano u vrijednostima Cronbachove Alphe koje se kreću od 0,94 do 0,96. Nadalje, ta metoda pokazuje usporedivost u smislu konzistentne varijabilnosti, visoke pouzdanosti i ponovljivosti usporedive sa spektrofotometrijskim mjerenjem (VitaShade 5, VitaZahnfabrik). Značajne razlike između ispitivanih metoda očite su i očekivane, no ne slijede linearni obrazac. Kombinacija ponovljivosti i konzistentnosti čini metodu *capture to edit* vrijednim alatom za poboljšano mapiranje boja i olakšavanje usporedbe digitalnih fotozabilježbi.

Sukob interesa: Nije bilo sukoba interesa.

Doprinosi autora: **B.D.O.** – proveo istraživanje; **B.D.O., D.I.** pridonijeli su konceptu i dizajnu studije i prikupljanju podataka; napisao rukopis; **D.B., M.Ž.** – revizija prvog nacrta, pridonio pisanju studije; **M.Š.** – kritički je revidirao rukopis zbog važnih intelektualnih sadržaja.

Sažetak

Svrha: Utvrditi stupanj preciznosti i ponovljivosti sustava digitalne fotografije *capture to edit*, tj. sustava ColorChecker Passport Photo (X-Rite, MI, SAD) te usporediti rezultate s onima dobivenima mjerenjem spektrofotometrom Vita Easyshade® (Vita Zahnfabrik, H Rauter GmbH & Co. KG, Bad Sackingen, Njemačka) na istim ispitivanim zubima. **Materijali i metode:** U istraživanju je sudjelovalo 80 ispitanika u dobi od 19 do 25 godina, svi studenti Stomatološkog fakulteta Sveučilišta u Zagrebu. Sva mjerenja boje maksilarnoga desnoga središnjeg sjekutića provedena su u standardiziranim i kontroliranim laboratorijskim uvjetima. Na kalibriranim digitalnim fotografijama iskusni je kliničar obavio tri uzastopna mjerenja i zabilježio **L**, **a** i **b** vrijednosti CIELAB prostora boja. Isto to izmjereno je i spektrofotometrom Vita Easyshade 5.0 spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) u programu *Tooth single*. **Svrha:** Svrha ovog istraživanja bila je utvrditi stupanj preciznosti i ponovljivosti sustava digitalne fotografije *capture to edit*, odnosno sustava ColorChecker Passport Photo (X-Rite, MI, SAD), te usporediti rezultate s onima dobivenima mjerenjem spektrofotometrom Vita Easyshade® (Vita Zahnfabrik, H Rauter GmbH & Co. KG, Bad Sackingen, Njemačka) na istim ispitivanim zubima.

Zaprimljen: 30. prosinca 2023.
Prihvaćen: 20. svibnja 2024.

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Autorske ključne riječi: Boja zuba; Snimite za uređivanje; Kalibrirana digitalna fotografija; VitaShade; ColorChecker putovnica

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