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## Assessment of Color Parameters on Maxillary Right Central Incisors Using Spectrophotometer and RAW Mobile Photos in Different Light Conditions

### Procjena parametara boje gornjih desnih središnjih sjekutića uporabom spektrofotometra i RAW fotografija s mobilnog uređaja u različitim uvjetima osvjetljenja

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#### Abstract

**Objectives:** The aim of the study was to compare three color parameters assessed on the maxillary right central incisors using a spectrophotometer as the gold standard, along with RAW mobile calibrated and non-calibrated photos in different light conditions. **Materials and methods:** A total of 30 dental students participated in the study. CIE L\*a\*b\* values were measured in the middle third of each maxillary right central incisor spectrophotometrically and digitally on RAW mobile dental photos using different light conditions (F-frontal light; L-lateral light; D-lateral light with diffusers; P-polarizing filter on frontal light; H-hybrid filter as combination of frontal light with polarizing filter and lateral lights with diffusers) with LEDs (light emitting diode) in full power, and with gray card calibration. The obtained results were compared. **Results:** Mean a\* and b\* values on calibrated, as well as mean L\* values on non-calibrated RAW mobile photos did not significantly differ in different light conditions (P>0.05). CIE L\*a\*b\* values on non-calibrated polarizing RAW mobile photos completely matched the same values obtained using a spectrophotometer on the subject's maxillary right central incisor (P>0.05). **Conclusions:** Different light conditions and measuring procedures affected CIE L\*a\*b\* values on RAW mobile photos in this study. Within the limitations, non-calibrated RAW mobile photos using a lightening device with polarizing filters on frontal LED light in standardized conditions can be a useful tool for digital dental shade determination.

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#### Key words

Dental Esthetics; Tooth Color; Color Shade; Dental Photography; Cell Phone Use

#### Introduction

For many years, dental professionals have been using dental photography as part of diagnostic and treatment planning processes, as well as documentation, publishing, education, marketing and communication with patients, dental technicians and colleagues (1, 2). More recently, dental photography has become a very important tool for detecting facial pattern changes after orthodontic treatment, maxillofacial surgery, prosthetic oral rehabilitation and digital smile planning (3-5).

Digital Single Lens Reflex (DSLR) cameras are considered to be the "golden standard" cameras used to take high quality dental photographs (6). In the past few years, smartphone cameras have advanced in terms of sensor quality, resolution and lens sophistication, and mobile dental photography is becoming more and more popular among dentists.

#### Uvod

Već godinama stomatolozi se koriste dentalnom fotografijom pri dijagnostici i planiranju stomatoloških zahvata te za dokumentiranje, objavljivanje, edukaciju, oglašavanje i komunikaciju s pacijentima, zubnim tehničarima i kolegama (1, 2). Posljednjih je godina dentalna fotografija postala vrlo važna i u procjeni promjena odnosa parametara lica nakon ortodontske terapije, maksilofacijalnog kirurškog zahvata, u protetičkoj oralnoj rehabilitaciji i pri digitalnom planiraju dizajna osmijeha (3 – 5).

Digitalni fotoaparati s refleksijom jedne leće (engl. Digital single lens reflex – DSLR) smatraju se zlatnim standardom pri izradi dentalnih fotografija visoke kvalitete (6). U proteklih nekoliko godina poboljšane su kamere na mobilnim pametnim uređajima – bolja im je kvaliteta senzora te rezolucija i kvaliteta leće pa je fotografija dobivena tim uređajima

Some new mobile phone cameras have dual and even triple cameras setups that allow them access to features that were formerly limited to DSLR cameras (7). The main advantages of mobile phones compared to the DSLR are their lightweight, low cost and less complicated use (7).

Digital tooth colour determination was developed in order to reduce and overcome the inaccuracies and inconsistencies of traditional methods of tooth shade determination. Some studies have shown that spectrophotometers are among the most accurate instruments for tooth color matching (8, 9). The new VITA Easyshade® V, spectrophotometer has become a reference device for determining tooth color in numerous clinical studies, and it has been used to determine the color of various dental materials (10-15). Numerous studies have confirmed the accuracy and repeatability of color measurements of these devices (16-18).

The purpose of this clinical study was to assess color parameters on maxillary right central incisors using a spectrophotometer and RAW mobile photos in different light conditions. The first null hypothesis was that no differences between RAW mobile photos would be found within different light conditions. The second null hypothesis was that no differences between color parameters assessed using a spectrophotometer and those assessed digitally on RAW mobile photos in different light conditions would be found.

## Material and methods

The design of the study was approved by the Ethics Committee of the School of Dental Medicine, University of Zagreb, Croatia.

### Sample size, inclusion and exclusion criteria

Prior to data collection, the smallest sample size (30 subjects) to detect the effect of the given test at the desired level of significance was established upon calculation of power and probability of Type II Error (Beta) value.

Thirty seven subjects, students (mean age 23 years; 15 men, 22 women) of the 5th and 6th year of School of Dental Medicine in Zagreb, participated in the study. The elementary inclusion criteria of each subject were as follows: existence of completely healthy and intact maxillary right central incisors. Exclusion criteria were as follows: incidence of discolorations, white spots, damaged or worn teeth, composites, veneers, crowns or bridges, endodontic treatments or orthodontic retainers on the examined teeth. The students having periodontal problems or missing maxillary right central incisors and implants placed instead were also excluded from the study. A total of 7 students were excluded upon these criteria, and finally, thirty students participated in this study (11 men, 19 women) (Figure 1).

### Spectrophotometric assessment

Prior to the spectrophotometric assessment, the teeth of each subject were cleaned and polished (Proxyl RDA 83; Ivoclar Vivadent, Liechtenstein), and the subject was placed against the white wall in the research room without the natural light source (no windows), with fluorescent lighting (4

sve popularnija među stomatolozima. Neki najnoviji mobilni uređaji imaju dvije ili čak tri kamere koje omogućuju promjenu nekih postavki koje su dosad bile moguće samo na digitalnim fotoaparatima (7). Glavne prednosti mobilnih uređaja u usporedbi s digitalnim fotoaparatima su manja težina, niža cijena i jednostavnija primjena (7).

Digitalna procjena boje zuba počela se primjenjivati kako bi se smanjile i prevladale netočnosti i nedosljednosti tijekom tradicionalnih postupaka određivanja boje zuba. Znanstvena su istraživanja pokazala da je spektrofotometar jedan od najpreciznijih uređaja za procjenu boje zuba (8, 9). Tako je spektrofotometar VITA Easyshade V postao referentni uređaj za procjenu boje zuba u velikom broju kliničkih istraživanja te se koristi i pri procjeni boje različitih dentalnih materijala (10–15). U mnogobrojnim je istraživanjima potvrđena točnost i ponovljivost mjerenja boje tim uređajem (16–18).

Svrha ovoga kliničkog istraživanja bila je procijeniti parametre boje gornjih desnih središnjih sjekutića spektrofotometrom i digitalno na RAW fotografijama snimljenima mobilnim uređajem u različitim svjetlosnim uvjetima. Prva nulta hipoteza bila je da neće biti razlike u RAW fotografijama s mobilnog uređaja pri različitim uvjetima osvjetljenja. Druga nulta hipoteza glasila je da neće biti razlike između parametara boje procijenjenih spektrofotometrom i digitalno na RAW fotografijama s mobilnog uređaja pri različitim uvjetima osvjetljenja.

## Materijal i postupci

Ovo istraživanje odobrilo je Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu, Hrvatska.

### Veličina uzorka, kriteriji uključivanja i isključivanja

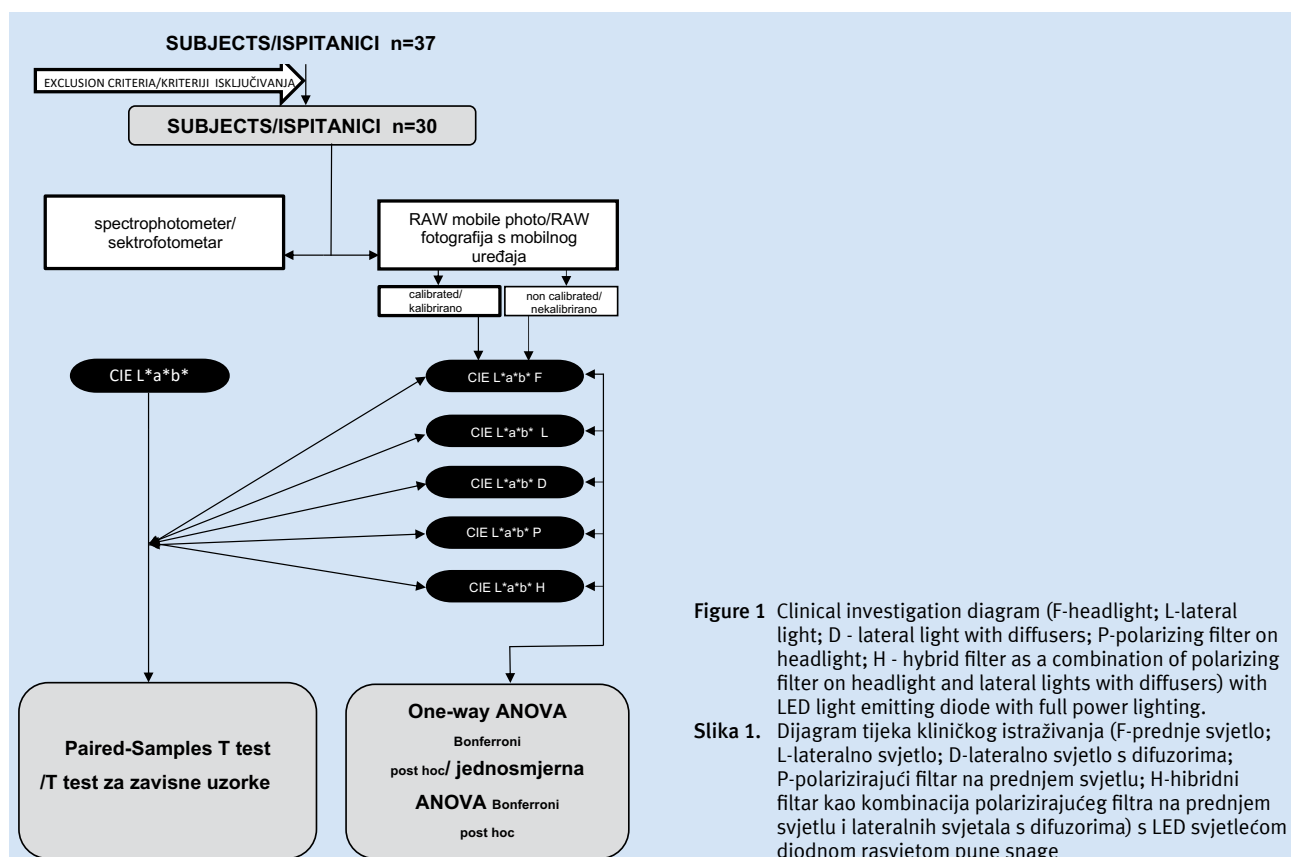
Prije prikupljanja podataka određena je najmanja veličina uzorka (30 ispitanika) pri kojoj je vidljiv utjecaj ispitivanja na željenoj razini značajnosti izračunavanjem snage i vjerojatnosti pojave pogreške tipa II (beta).

Za sudjelovanje u istraživanju prijavilo se 37 ispitanika, studenata (srednja dob 23 godine – 15 muškaraca, 22 žene) 5. i 6. godine studija na Stomatološkom fakultetu u Zagrebu. Osnovni uvjet za sudjelovanje bili su potpuno zdravi i intaktni gornji središnji sjekutići. Kriteriji za isključivanje bili su zubna obojenja, bijele mrlje, oštećeni ili istrošeni zubi, kompozit, ljuske, krunice ili mostovi, endodontski zahvati ili ortodontski aparati na ispitivanim zubima. Studenti s parodontološkim problemima, nedostatkom gornjih desnih središnjih sjekutića ili implantatom ugrađenim na mjestima navedenih zuba isključeni su iz istraživanja.

Na temelju nabrojanih kriterija ukupno je isključeno 7 studenata i u konačnici je njih 30 sudjelovalo u istraživanju (11 muškaraca, 19 žena) (slika 1.).

### Spektrofotometrijska procjena

Prije uporabe spektrofotometra zubi svakog ispitanika očišćeni su i polirani (Proxyl RDA 83; Ivoclar Vivadent, Liechtenštajn), a ispitanik je zatim smješten uz bijeli zid u istraživačkoj sobi bez prirodnog izvora svjetlosti (bez prozora) uz fluorescentno osvjetljenje (4 x 120 cm, 36 W, color 765, Phi-



**Figure 1** Clinical investigation diagram (F-headlight; L-lateral light; D - lateral light with diffusers; P-polarizing filter on headlight; H - hybrid filter as a combination of polarizing filter on headlight and lateral lights with diffusers) with LED light emitting diode with full power lighting.

**Slika 1.** Dijagram tijeka kliničkog istraživanja (F-prednje svjetlo; L-lateralno svjetlo; D-lateralno svjetlo s difuzorima; P-polarizirajući filter na prednjem svjetlu; H-hibridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom pune snage

x 120 cm, 36 W, color 765, Philips, Hamburg, Germany), light temperature of 5080 K and illuminance of 500 lux measured using colorimeter Chroma-2 (Lisun Electronics, Shanghai, China)(19). In order to avoid dehydration of the teeth affecting the results, the subjects were asked to drink water prior to measurements (20).

A lip and cheek retractor was placed in each subject's mouth when standing (Spandex, Hager & Werken, Duisburg, Germany), his/her head leaning against the wall, and white balance reference gray card was placed below and in the same plane with the examined teeth (WhiBal, Michael Tapes De-sign, USA).

At each measurement, the infection control shield was placed over the probe tip when using the Easyshade V spectrophotometer set in "tooth single" mode (VITA Zahnfabrik, Bad Sackingen, Germany). The accuracy and reliability of the device have already been proven (21). The probe tip was positioned on the surface of the central area of the middle third of each right maxillary central incisor and this position was marked using a red waterproof marker to ensure the accurate positioning of the digital probe.

Before each measurement, the device was calibrated, the tip was positioned correctly on the tooth, and measured CIE L\*a\*b\* values were recorded.

#### Mobile dental photographing

While setting the photo shooting, the subject was asked to close the mouth to avoid dehydration, and then the lip and cheek retractor was placed again in the subject's mouth while he/she was standing and leaning the head against the wall.

lips, Hamburg, Njemačka), temperature svjetlosti od 5080 K i iluminaciju od 500 luksa izmjerenih kolorimetrom Chroma-2 (Lisun Electronics, Šangaj, Kina)(19). Da bi se izbjegla dehidracija zuba koja bi mogla utjecati na rezultate, ispitanici su zamoljeni da prije mjerenja popiju vodu (20).

U stojećem stavu ispitanicima je u usta postavljen retraktor usnica i obraza (Spandex, Hager & Werken, Duisburg, Njemačka), glava im je naslonjena na bijeli zid u pozadini, a ispod ispitivanih zuba, a u istoj ravnini, postavljena je siva referentna kartica (WhiBal, Michael Tapes De-sign, SAD).

Za svako mjerenje postavljena je na vršak sonde spektrofotometra zaštitna kapica koja štiti od infekcije, a spektrofotometar Easyshade postavljen je na funkciju mjerenja jednog zuba (VITA Zahnfabrik, Bad Sackingen, Njemačka). Točnost i pouzdanost toga uređaja već je ispitana (21). Vršak mjerne sonde smješten je na središnje područje površine srednje trećine svakoga desnog gornjega središnjeg sjekutića i taj je promjer označen drvenim vodoopornim markerom u svrhu osiguranja kasnijeg pravilnog postavljanja digitalne probe.

Prije svakog mjerenja uređaj je kalibriran, vršak sonde pravilno je postavljen na zub, a izmjerene CIE L\*a\*b\* vrijednosti su zabilježene.

#### Fotografiranje mobilnim uređajem

Pri fotografiranju ispitanik je zamoljen da zatvori usta kako bi se izbjegla dehidracija, zatim mu je, u stojećem stavu, glava naslonjena na zid te u usta postavljen retraktor.

The iPhone 11 Pro smartphone (Apple, Cupertino, CA, USA) was adjusted in the adapter at the back of the Smile Lite MDP device (Smile Line, St-Imier, Switzerland) following the manufacturer's instructions (7). The device was placed on a tripod, with camera 15 cm away and parallel as possible to the vestibular side of the examined tooth in order to avoid distortion of the photo (7). The Yamera application from application store (Apple, Cupertino, CA, USA), was used to adjust back telephoto camera aperture ( $f/2.0$  with 52 mm focal length), white balance (5500 K), sensor sensitivity (100 ISO) and shutter speed (1/125) and to allow to capture RAW format of the pictures. Five photos of each subject were taken in five different light conditions (F-frontal light; L-lateral light; D-lateral light with diffusers; P- filter on frontal light; H-hybrid filter as combination of frontal light with polarizing filter and lateral lights with diffusers) with LEDs (light emitting diode) in full power (7).

### Digital workflow

A total of 150 mobile photos were taken and imported in Adobe Photoshop Lightroom 6 (Adobe, San Jose, CA, USA) in Develop mode. All the photos were measured two times, once with and once without special calibration using gray card on the picture. Measurement aperture size was set on 0.5 x 0.5 mm (Digital colorimeter, Microsoft, Redmond, WA, USA).

For calibration, white balance of each photo had to be carried out using the measurement probe placed on one of four gray segments on the card while adjusting image exposure balance by setting lightness ( $L^*$ ) at 75\*, and  $a^*$  and  $b^*$  values at 0\* on histogram (22, 23). Subsequently, the measurement of CIE  $L^*a^*b^*$  values on the tooth was performed by setting the measurement probe right in the middle of the red circle marked previously on each maxillary right central incisor. When measuring with no calibration, the measurement of CIE  $L^*a^*b^*$  values on the tooth was performed immediately on the tooth, thus avoiding previous calibration of the gray scale.

### Statistical analysis

The measured data were entered into Excel database, statically analyzed and imported into the SPSS 19.0 (SPSS, Chicago, IL, USA) statistical program.

A power analysis to determine the sample size of the study was performed using The Univariate Analysis of Variance.

Clinical study flow chart is presented in Figure 1.

A one-way ANOVA was used to determine whether there were any differences in mean CIE  $L^*a^*b^*$  values of RAW mobile photos at five different light conditions (F-frontal light; L-lateral light; D-lateral light with diffusers; P- filter on frontal light; H-hybrid filter as combination of frontal light with polarizing filter and lateral lights with diffusers) with LEDs (light emitting diode) in full power and Bonferroni corrected post hoc tests (paired t-tests) were used to explore differences in  $L^*a^*b^*$  values within the groups.

The Paired-Samples T test was used to compare CIE  $L^*a^*b^*$  values of the same maxillary right central incisor as-

U adapter na stražnjoj strani uređaja Smile Lite MDP (Smile Line, St-Imier, Švicarska) postavljen je pametni mobilni uređaj iPhone 11 Pro (Apple, Cupertino, CA, SAD) prema uputama proizvođača (7). Tako pripremljen uređaj postavljen je na stativ za slikanje s kamerom mobilnog uređaja postavljeno na 15 cm udaljenosti te paralelnom s vestibularnom stijenkom ispitivanog zuba kako bi se izbjegla moguća distorzija slike (7). Za prilagodbu otvora blende stražnje telefotokamere mobilnog uređaja ( $f/2.0$  with 52 mm focal length), balansa bijele boje (5500 K), osjetljivosti senzora (100 ISO), brzine okidača (1/125) te podešavanja RAW formata fotografije, korištena je mobilna aplikacija Yamera (Apple, Cupertino, CA, SAD). Svakom ispitaniku izrađeno je pet fotografija koristeći se različitim uvjetima osvjetljenja (F – prednje svjetlo; L – lateralno svjetlo; D – lateralno svjetlo s difuzorima; P – polarizirajući filter na prednjem svjetlu; H – hibridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom pune snage (7).

### Digitalni tijek mjerenja

Ukupno je snimljeno 150 fotografija i sve su unesene u program Adobe Photoshop Lightroom 6 (Adobe, San Jose, CA, SAD) u «Develop mode». Sve su fotografije mjerene dva puta – jedanput bez specijalne kalibracije uz pomoć sive kartice na fotografiji i drugi put. Promjer mjerne probe iznosio je 0,5 x 0,5 mm (Digital colorimeter, Microsoft, Redmond, WA, SAD).

Za kalibraciju balansa bijele boje bilo je potrebno mjerne probu postaviti u jedan od sivo označenih segmenata na kartici i prilagoditi ekspoziciju postavljajući ručno svjetlinu ( $L^*$ ) na 75\*, a  $a^*$  i  $b^*$  vrijednosti na 0\* u prikazanom histogramu (22, 23).

Mjerenje CIE  $L^*a^*b^*$  vrijednosti zuba obavljeno je postavljanjem mjerne probe u sredinu crvenoga kruga označenog na svakom gornjem desnom središnjem sjekutiću. Pri postupku bez kalibracije mjerenje je provedeno samo na zubu, bez kalibracije sive ljestvice.

### Statistička analiza

Izmjereni podaci uneseni su u Excelovu bazu podataka, statistički analizirani i zatim uneseni u statistički program SPSS 19.0 (SPSS, Chicago, IL, SAD).

Analiza snage testa za određivanje veličine uzorka u ovom istraživanju provedena je univarijantnom analizom varijance.

Klinički tijek istraživanja prikazan je na slici 1.

Za procjenu razlike u srednjim CIE  $L^*a^*b^*$  vrijednostima RAW fotografija s mobilnog uređaja, ovisno o vrsti svjetlosnih uvjeta, korišten je jednosmjerni ANOVA test i Bonferronijeva post hoc korekcija (t-test za zavisne uzorke) kako bi se ispitala razlika u  $L^*a^*b^*$  vrijednostima unutar pet skupina (F – prednje svjetlo; L – lateralno svjetlo; D – lateralno svjetlo s difuzorima; P – polarizirajući filter na prednjem svjetlu; H – hibridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima s LED svjetlećom diodnom rasvjetom pune snage).

sessed using a spectrophotometer, and digitally measured on RAW mobile photos taken in five different light conditions.

The level of significance was set to 0.05 (5%).

## Results

The Univariate Analysis of Variance in this study revealed that using the sample size of 30, P value of 0.00 and effect size of 0.143 there was a 98.5% chance of detecting the difference that was really there, and therefore, the above mentioned sample size was determined.

Mean CIE L\*a\*b\* values (x) and standard deviations (SD) measured both spectrophotometrically and digitally on calibrated and non-calibrated RAW mobile photos using different light conditions are shown in Figure 2.

Mean a\* and b\* values on calibrated, as well as mean L\* values on non-calibrated RAW mobile photos did not significantly differ in different light conditions (Figure 2, Table 1;  $P > 0.05$ ). On calibrated RAW mobile photos, mean L\* values significantly differed, with the lowest values on polarizing filter photos and the highest values using lateral lights (Figure 2; Table 1;  $P < 0.05$ ). On non-calibrated RAW mobile photos,

T-test za zavisne uzorke korišten je za usporedbu CIE L\*a\*b\* vrijednosti na istom gornjem desnom središnjem sjekutiću izmjerenih spektrofotometrom i digitalno na RAW fotografiji s mobilnog uređaja u pet različitim svjetlosnih uvjeta.

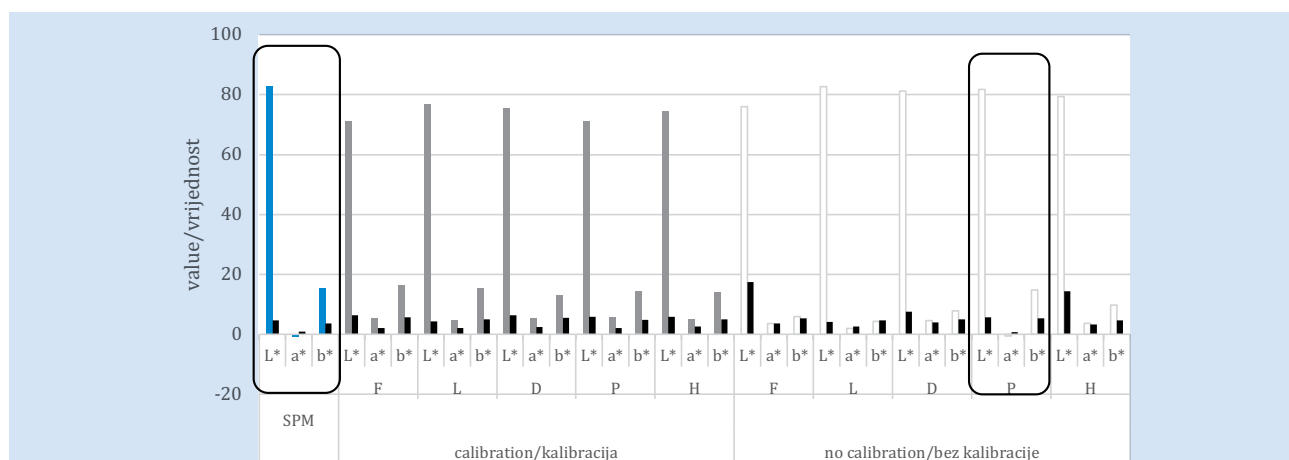
Razina značajnosti postavljena je na 0,05 (5 %).

## Rezultati

Univarijatna analiza varijance potvrdila je da kod uzorka od 30 ispitanika P vrijednosti od 0,00 te veličine efekta od 0,143, postoji 98,5 % vjerojatnosti otkrivanja razlike koja stvarno postoji te je stoga prethodno spomenuta veličina uzorka i primijenjena.

Srednje CIE L\*a\*b\* vrijednosti (x) i standardne devijacije (SD) mjerene spektrofotometrom i digitalno na kalibriranim i nekalibriranim RAW fotografijama s mobilnog uređaja u pet različitim uvjeta osvjetljenja prikazane su na slici 2.

Srednje a\* i b\* vrijednosti na kalibriranim te srednje L\* vrijednosti na nekalibriranim RAW fotografijama s mobilnog uređaja nisu se značajno razlikovale u različitim svjetlosnim uvjetima (slika 2., tablica 1.;  $P > 0,05$ ). Na kalibriranim RAW fotografijama s mobilnog uređaja srednje L\* vrijednosti značajno su se razlikovale ovisno o svjetlosnim uvjetima,



**Figure 2** Mean CIE L\*a\*b\* values (x) and standard deviations (SD) measured using spectrophotometer (SPM ■) and digitally on calibrated (■) and non-calibrated (□) RAW mobile photos using different light conditions (F-frontal light; L-lateral light; D-lateral light with diffusers; P- filter on frontal light; H-hybrid filter as combination of frontal light with polarizing filter and lateral lights with diffusers) with LEDs (light emitting diode) in full power. Best matching values were marked ( $P > 0.05$ ).

**Slika 2.** Srednje CIE L\*a\*b\* vrijednosti (x) i standardne devijacije (SD) izmjerene spektrofotometrom (SPM ■) i digitalno na kalibriranim (■) i nekalibriranim (□) RAW fotografijama s mobilnog uređaja u pet različitim uvjeta osvjetljenja (F-prednje svjetlo; L-lateralno svjetlo; D-lateralno svjetlo s difuzorima; P-polarizirajući filter na prednjem svjetlu; H-hipridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom pune snage. Najbolje podudaranje je označeno na fotografiji ( $P > 0.05$ ).

**Table 1** Statistically significant difference in CIE L\*a\*b\* values digitally measured on RAW mobile photos in different light conditions (df – degree of freedom; F – F value; p – level of significance)

**Tablica 1.** Statistička značajnost razlike CIE L\*a\*b\* vrijednosti digitalno izmjerenih na RAW fotografijama s mobilnog uređaja u pet različitim svjetlosnih uvjeta (df – stupanj slobode; F – F vrijednost; p – razina značajnosti)

		df	F	p
Calibration • Kalibracija	L*	4	6,07	0,00
	a*	4	0,98	0,42 NS
	b*	4	2,06	0,09 NS
No calibration • Bez kalibracije	L*	4	1,69	0,16 NS
	a*	4	12,21	0,00
	b*	4	14,91	0,00

**Table 2** Statistically significant difference in CIE L\*a\*b\* value pairs measured using spectrophotometer and digitally on RAW mobile photos in different light conditions (F-frontal light; L-lateral light; D-lateral light with diffusers; P- filter on frontal light; H-hybrid filter as combination of frontal light with polarizing filter and lateral lights with diffusers) with LEDs (light emitting diode) in full power. Best matching pair was marked in bold ( $P > 0.05$ ), (df – degree of freedom; t – t value; p – level of significance)

**Tablica 2.** Statistička značajnost razlike u CIE L\*a\*b\* vrijednosti parova spektrofotometrijskih i digitalnih mjerenja na RAW fotografijama s mobilnog uređaja u pet različitim svjetlosnih uvjeta (F-prednje svjetlo; L-lateralno svjetlo; D-lateralno svjetlo s difuzorima; P-polarizirajući filter na prednjem svjetlu; H-hibridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom pune snage. Najbolje podudaranje označeno je u tablici masnim brojevima ( $P > 0.05$ ), (df – stupanj slobode; t – t vrijednost; p – razina značajnosti)

			t	df	p
Calibration • Kalibracija	F	L*	8.84	3	0.00
		a*	-16.24	29	0.00
		b*	-0.96	29	0.35 NS
	L	L*	5.29	29	0.00
		a*	-13.56	29	0.00
		b*	-0.10	29	0.92 NS
	D	L*	6.03	29	0.00
		a*	-13.15	29	0.00
		b*	2.44	29	0.02
	P	L*	11.52	29	0.00
		a*	-14.54	29	0.00
		b*	1.35	29	0.19 NS
	H	L*	8.49	29	0.00
		a*	-12.49	29	0.00
		b*	1.30	29	0.21 NS
No calibration • Bez kalibracije	F	L*	2.17	29	0.04
		a*	-6.74	29	0.00
		b*	8.56	29	0.00
	L	L*	-0.02	29	0.99 NS
		a*	-5.94	29	0.00
		b*	10.92	29	0.00
	D	L*	1.10	29	0.28 NS
		a*	-7.60	29	0.00
		b*	6.85	29	0.00
	P	<b>L*</b>	<b>0.95</b>	<b>29</b>	<b>0.35 NS</b>
		<b>a*</b>	<b>-1.92</b>	<b>29</b>	<b>0.06 NS</b>
		<b>b*</b>	<b>0.64</b>	<b>29</b>	<b>0.53NS</b>
	H	L*	1.25	29	0.22 NS
		a*	-12.49	29	0.00
		b*	5.39	29	0.22 NS

both mean  $a^*$  and  $b^*$  values significantly differed, with the lowest  $a^*$  values on photos using lateral lights and the highest  $a^*$  values on polarizing filter photos, the lowest  $b^*$  values using diffusers and the highest  $b^*$  values on frontal photos (Figure 1; Table 1;  $P < 0.05$ ).

A comparison of CIE L\*a\*b\* values was made using a spectrophotometer, and those values, measured digitally with or without calibration in different light conditions, revealed that only non-calibrated polarizing filter photos completely matched in all three color characteristics (Figure 2; Table 2;  $P > 0.05$ ).

s najnižim vrijednostima kod onih s polarizirajućim filtrom i najviših kod onih s lateralnim svjetlima (slika 2.; tablica 1.;  $P < 0,5$ ). Na nekalibriranim RAW fotografijama s mobilnog uređaja srednje  $a^*$  i  $b^*$  vrijednosti značajno su se razlikovale, s najnižim  $a^*$  vrijednostima kod onih s lateralnim svjetlom i najvišim  $a^*$  vrijednostima kod onih s polarizirajućim filtrom, te najnižim  $b^*$  vrijednostima kod onih s difuzorima i najvišima kod onih s prednjim svjetlom (slika 2., tablica 1.;  $P < 0,05$ ).

Usporedba CIE L\*a\*b\* vrijednosti izmjerenih spektrofotometrom i digitalno s kalibracijom i bez kalibracije u različitim svjetlosnim uvjetima pokazala je da se jedino nekalibrirane fotografije s mobilnog uređaja s polarizirajućim filtrom potpuno podudaraju sa svim trima parametrima boje zuba (slika 2.; tablica 2.;  $P > 0,05$ ).

## Discussion

The aim of this study was to determine if CIE L\*a\*b\* values in any of the investigated RAW mobile photos with different light conditions matched the same values measured directly in the mouth of the patient using a spectrophotometer.

Our first null hypothesis was partially rejected because the results revealed that in calibrated RAW mobile photos mean a\* and b\* values were matched in all five different light conditions, while in non-calibrated only mean L\* values were matched (Figure 2; Table 1;  $P > 0.05$ ).

This result was expected as the distance between the camera and the object was only 15 cm and the light used for each photo, set on the highest LED power, fell at different angles and produced different appearances. Only frontal light (F) and polarizing filter (P) provided correct direction of light, perpendicular to the maxillary right central incisor, while the other angles were lower than 90°.

In this study, we wanted to investigate into the impact of different light conditions, not only the possibility of making and analyzing RAW polarizing mobile photo, on CIE L\*a\*b\* values obtained with and without calibration in standardized conditions we produced. The reason we have decided to explore both calibrated (standard procedure for DSLRs) and non-calibrated photos can be explained by the fact that smartphones produce their images in a completely different way than DSLRs. On the image processing side, the Apple's Deep Fusion technology uses the chipset's neural engine and advanced machine learning to perform pixel-by-pixel optimization for better textures, lower noise, and a wider dynamic range, making non-calibrated pictures as accurate as possible to the real world (24). Therefore, an additional calibration in this proprietary technology might make calibrated pictures differ from the real world, and we aimed to investigate it.

The second null hypothesis was, also, partially accepted because we found only one type of RAW mobile photo matching the CIE L\*a\*b\* values measured using a spectrophotometer, and that was for non-calibrated RAW polarizing photo (P) (Figure 2; Table 2;  $P > 0.05$ ). In other cases we found statistically significant differences in CIE L\*a\*b\* values between measurement (Figure 2; Table 2;  $P < 0.05$ ). Our results are in line with some studies, thus proving the accuracy of dental shade matching using cross-polarized digital photography (25-27). Dental shade evaluation on dental photos obtained from DSLR usually use recommended cross-polarization filters because they mitigate specular reflections; therefore, they eliminate the superficial value impact (enamel) achieving hyper saturated chromatic shade of the tooth (22, 23, 28). Furthermore, calibrating for colour accuracy of this type of photos is strongly recommended in order to achieve realistic colors.

This result was expected because there is one very important link between these two measurements as both methods measure the actual color of dentin, not enamel, thus avoiding the influence of reflections coming from the superficial part of the tooth. Additionally, we have also proved that a non-calibrated version of polarizing RAW mobile photo was more precise in color accuracy compared to the calibrated one.

## Rasprava

Svrha ovog istraživanja bila je ispitati podudaraju li se CIE L\*a\*b\* vrijednosti ijedne RAW fotografije s mobilnog telefona slikane u pet različitih svjetlosnih uvjeta s istim vrijednostima izmjerjenima izravno u ustima pacijenta korištenjem spektrofotometra.

Prva nulta hipoteza djelomično je odbačena jer su rezultati pokazali da se na kalibriranim RAW fotografijama srednje a\* i b\* vrijednosti podudaraju u svim svjetlosnim uvjetima, a na nekalibriranim samo srednje L\* vrijednosti (slika 2.; tablica 1.;  $P > 0,05$ ).

Taj je rezultat bio očekivan jer je udaljenost od kamere i slikanog objekta iznosila 15 cm i svjetlo korišteno za svaku vrstu fotografije, postavljeno na najjaču diodnu snagu, padalo je iz različitih kutova i izazivalo razlike u izgledu objekta. Samo su prednje svjetlo (F) i polarizirajući filter (P) osigurali pravilan smjer svjetlosti okomit na gornji desni središnji sjekutić, a oni kod ostalih fotografija bili su manji od 90°.

U ovom istraživanju želio se ispitati utjecaj različitih svjetlosnih uvjeta, a ne samo mogućnost izrade i analize RAW mobilne fotografije s polarizirajućim filtrom, na CIE L\*a\*b\* vrijednosti izmjerene kalibracijom i bez nje u standardiziranim uvjetima slikanja.

Razlog da smo odlučili ispitati i kalibrirane (standardni protokol za fotografiju s digitalnog fotoaparata) objašnjava se činjenicom da mobilni uređaji produciraju fotografiju potpuno drukčije od digitalnog fotoaparata. Pri obradi fotografije Appleovom Deep Fusion tehnologijom koristi se set elektroničkih komponenti neuralne mreže i napredno računalno učenje za postizanje najbolje pikselne optimizacije u svrhu boljih tekstura, izbjegavanja šumova te širega dinamičkog spektra na slici, što nekalibriranu fotografiju čini najtočnijom u usporedbi sa stvarnim svijetom (24). Prema tome, dodatno kalibriranje tako dobivenih fotografija može kalibriranu sliku učiniti još različitijom od stvarnoga svijeta, a to se željelo ispitati u ovom istraživanju.

Druga nulta hipoteza djelomično je prihvaćena jer je pronađen samo jedan tip RAW fotografije s mobilnog uređaja čije su CIE L\*a\*b\* vrijednosti bile podudarne s istim vrijednostima izmjerjenima spektrofotometrom, a to je bila nekalibrirana RAW fotografija s polarizacijskim filtrom (P) (slika 2.; tablica 2.;  $P > 0,05$ ). U svim ostalim slučajevima između mjerenja je pronađena statistički značajna razlika u CIE L\*a\*b\* vrijednostima (slika 2.; tablica 2.;  $P < 0,05$ ). Naši rezultati podudaraju se s ostalim istraživanjima koja su potvrdila točnost u podudaranju boje zuba uporabom digitalne fotografije s polarizacijskim filtrom (25 – 27). Za procjenu boje zuba na dentalnim fotografijama izrađenima digitalnim fotoaparatom uporaba polarizacijskog filtra obično se preporučuje jer ublažava zrcalnu refleksiju i eliminira utjecaj površinskih struktura (cakline) koje izazivaju prezasićenu kromatiziranu boju (22, 23, 28). Uz to, za postizanje što realnijih boja za tu se vrstu fotografija preporučuje i kalibracija.

Ovaj je rezultat bio očekivan zato što postoji jedna vrlo važna poveznica između principa mjerenja u objema metoda jer mjere zapravo boju dentina, a ne cakline, izbjegavajući tako utjecaj refleksija koje se pojavljuju na površini zuba. Uz

Using different tools in determining accurate tooth color in dentistry has been part of interest for many years. To date it has already been proven that digital spectrophotometers exhibit significantly better reliability compared with visual shade selection (29). Repeatability, reliability and accuracy of this device have already been tested, and they have been proven to be extremely high (30-32).

Measured digitally using software, CIE L\*a\*b\* values of maxillary central incisors in subjects, mean age 34.4 years, in Dozić et al. study, revealed tooth color to be darker, more greenish and yellowish compared with the same values of subjects whose mean chronological age was 23 years in our study (33). These results are consistent with the results of those researchers who claim that age affects tooth color (34).

Except for spectrophotometers, using a dental photography in determining tooth color has become part of interest in recent studies. However, a variety of methods for assessing color have been shown to exist (35, 36). One of the protocols which have been well established in this field is eLabor\_aid, using cross-polarized light photography, gray card calibration and digital software (22, 23).

More recently, smartphones producing high-quality pictures have also been introduced into dentistry (7). To the best of our knowledge, there are still no scientific papers published on the topic of their application in the field of color determination. Therefore we have decided to test the smartphone that has currently been most frequently used in different light conditions. In the course of our research, we tried to meet the protocol used for DSLR color determination. Since the smartphone used in this study does not have the ability to manually adjust the camera, we decided to use a special application in order to achieve the same conditions considering white balance, ISO, shutter speed and aperture, as well as RAW picture format. The only feature which makes the DSLR more developed than a smartphone camera is the focal length (for dental photos it is usually set on  $f/22$ ). Therefore, in this study, we decided to use a telephoto camera and the 12MP 1/3.4" sensor on smartphone which provides real 2x optical zoom, with its 52 mm equivalent  $f/2.0$ -aperture lens being great for portrait shots, and getting closer to subjects without physically moving (a patient's head was leaning against the wall) and ensured tripod for camera to avoid any movements. A standard DSLR distance based on the camera lens/sensor size (which is usually 24-45 cm) was adapted for the smartphone, and it was set to 15 cm, according to the manufacturer's instructions (7, 23).

For the same reason, we have decided to measure only the right maxillary central incisor placed to be parallel to the camera and then manually focused. The application was also used to obtain RAW images that could not usually be gained. The RAW format is recommended because it captures all image data recorded by the sensor when taking a photo without compression or reduction (37).

To obtain the same position of the tip probe in repeated spectrophotometric measurements, investigators usually use positioning jigs or splints (30). In our case it was not acceptable to use any type of jig because it would influence the final color assessed digitally. In order to achieve the same spot of

to, u ovom je istraživanju dokazano da je nekalibrirana verzija RAW fotografije s mobilnim uređajem točnija u prikazu boje od one kalibrirane.

Već godinama postoji zanimanje za korištenje različitih alata za najtočniju procjenu boje zuba u stomatologiji. Do danas je već dokazano da su digitalni spektrofotometri znatno pouzdaniji od vizualnih tehnika procjene (29). Ponovljivost, pouzdanost i točnost toga uređaja već je testirana i dokazano je vrlo visoka (30 – 32).

CIE L\*a\*b\* vrijednosti ispitanika prosječne dobi od 34,4 godine mjerene digitalno u kompjutorskom programu u istraživanju Dožića i suradnika pokazale su da su im gornji središnji sjekutići bili tamnije boje, zeleniji i žući od istih vrijednosti izmjerenih spektrofotometrom u našem istraživanju u kojemu su ispitanici bili mlađi (prosječna dob 23 godine). (33). Takav se nalaz poklapa s rezultatima onih istraživanja u kojima autori tvrde da se boja zuba mijenja s godinama (34).

Uz spektrofotometar, predmet istraživanja u mnogim studijama postala je posljednjih godina i dentalna fotografija na kojoj se određuje boja zuba, ali za procjenu boje na njoj koriste se različite metode (35, 36). Jedna od najčešće korištenih svakako je eLabor\_aid koji se koristi fotografijom s polarizacijskim filtrom, kalibracijom sivom karticom i kompjutorskim programom (22, 23).

Posljednjih godina pametni mobilni telefoni mogu izraditi fotografije visoke kvalitete i sve se češće koriste i u stomatologiji (7). Prema našim saznanjima još nema znanstvenih radova o temi primjene tih fotografija za procjenu boje i to je bio razlog da smo u ovom istraživanju za testiranje izabrali jedan od danas najčešće korištenih mobilnih uređaja u različitim svjetlosnim uvjetima.

U istraživanju je odlučeno provoditi protokol za određivanje boje jednak onomu za digitalni fotoaparatus. S obzirom na to da mobilni uređaj korišten u ovom istraživanju ne omogućuje individualnu prilagodbu kamere, odlučeno je koristiti se posebnom aplikacijom koja je omogućila postizanje jednakih uvjeta pri balansu bijele boje, otvoru blende, brzini okidača te opciju RAW formata fotografije kao kod digitalnog fotoaparata.

Jedino što je kod digitalnog aparata bolje od kamere mobilnog uređaja jest dubinska oština (koja se za dentalnu fotografiju obično postavlja na  $f/22$ ). Zato je u ovom istraživanju korištena telefotokamera i 12MP 1/3.4" senzor na mobilnom uređaju koji osigurava 2 x optičko povećanje s 52 mm, što je ekvivalent  $f/2.0$  otvora leće za portretno fotografiranje i približavanje objektu bez fizičkoga primicanja (glava ispitanika bila je naslonjena na zid), uz postavljanje kamere na stativ da se izbjegnu bilo kakva podrhtavanja.

Standardna udaljenost digitalnog fotoaparata koja ovisi o veličini senzora i leće (obično je to 24 – 45 cm) prilagođena je u ovom istraživanju na 15 cm prema uputama proizvođača (7, 23).

Iz istog razloga odlučeno je u ovom istraživanju mjeriti samo gornji desni središnji sjekutić koji je postavljen tako da bude paralelan s kamerom mobilnog uređaja i ručno je fokusiran. Aplikacija je iskorištena i za izradu RAW fotografija koje se također ne mogu dobiti u standardnim postavkama. Taj se format preporučuje zato što uzima u obzir sve podatke ko-



measurement on the tooth and on the screen during digital measurement, we have decided to mark a red circle around the probe in the mouth using a waterproof marker. It made it possible for the patient to even close the mouth between the measurements to avoid dehydration of the teeth (20). Each time the patient opened the mouth, the teeth were dried in the same manner. When measuring the CIE  $L^*a^*b^*$  values digitally, we used the region of interest (ROI) with the aperture size set on 0.5 x 0.5 mm, which corresponds exactly to the diameter of the figure measuring the remitted light on the Easyshade V spectrophotometer. The spectrophotometer was placed right in the center of each marked circle during the digital assessment of color parameters on mobile photos.

The limitation of this study is the use of only one condition considering white balance; hence ISO, shutter speed and aperture on the mobile phone and different shooting conditions are suggested. In our further study we will introduce more smartphones, and, also, investigate the differences in CIE  $L^*a^*b^*$  values.

## Conclusions

Within the limits of this study, the following can be concluded: CIE  $L^*a^*b^*$  values in RAW mobile photos differ based on the lighting conditions. They differ because of different light direction angles ( $P < 0.05$ ). CIE  $L^*a^*b^*$  values in non-calibrated RAW mobile photo using lightening device with polarizing filter on frontal LED light in standardized conditions matched the same values measured directly in the mouth of the patient using a spectrophotometer ( $P > 0.05$ ), and, therefore, could be used in digital dental shade determination.

## Conflict of interest

None declared

## Author's contribution

**M.S.** – developed the idea for this research, wrote the article and carried out research; **D.I.** - did the statistics and helped writing the results; **R.Č.** - gave the equipment for the research; **D.K.Z.** – created the idea for this research, helped with statistical analysis

je pri fotografiranju registrira senzor, izbjegavajući bilo kakvu kompresiju i redukciju podataka (37).

Za osiguranje položaja mjerne probe spektrofotometra u ponovljivim mjerjenjima obično se koriste razni držači i udlage (30). U ovom istraživanju to nije bilo prihvatljivo jer je moglo utjecati na rezultat mjerenja. Zato je kao osiguranje položaja na zubu i na ekranu tijekom digitalnog mjerenja odlučeno crvenim vodootpornim markerom označiti krug koji predstavlja probu spektrofotometra. Na taj smo način osigurali i mogućnost ispitanika da zatvori usta između mjerenja te izbjegne dehidraciju zuba (20). Svaki put kad je ispitanik otvorio usta, zub je osušen na isti način. Pri digitalnom mjerenju CIE  $L^*a^*b^*$  vrijednosti korišteno je mjerno područje dimenzija 0,5 x 0,5 koje točno odgovara dijametru optičkog vlakna koje mjeri boju u probi spektrofotometra Easyshade V, a tijekom digitalnog mjerenja parametara boje na fotografijama s mobilnog uređaja mjerna je proba postavljena točno u središte označenog kruga.

Ograničenje ovog istraživanja bilo bi korištenje samo jedne opcije balansa bijele boje, ISO osjetljivosti senzora, brzine okidača i otvora blende na mobilnom uređaju i zato se predlaže koristiti se i drugim opcijama. Ovo istraživanje proširit će se i na druge vrste mobilnih uređaja na kojima će se također ispitati razlike u CIE  $L^*a^*b^*$  vrijednostima između njih.

## Zaključci

S obzirom na ograničenja u ovom istraživanju može se zaključiti sljedeće: CIE  $L^*a^*b^*$  vrijednosti RAW fotografija s mobilnog uređaja razlikuju se ovisno o svjetlosnim uvjetima zbog razlike u smjeru svjetlosti ( $P < 0,05$ ). CIE  $L^*a^*b^*$  vrijednosti nekalibrirane RAW fotografije s mobilnog uređaja, uz korištenje osvjetlivača i polarizirajućeg filtra na prednjem diodnom svjetlu u standardiziranim uvjetima, podudarale su se s istim vrijednostima izmjerjenima u ustima pacijenta ( $P > 0,05$ ) i zato bi se takva fotografija mogla koristiti pri digitalnom određivanju boje zuba.

## Sukob interesa

Autori nisu bili u sukobu interesa.

## Doprinos autora

**M. S.** – ideja za istraživanje, obavio istraživanje, napisao članak; **D. I.** – pomogao napraviti statistiku i rezultate istraživanja; **R. Č.** – dao opremu za istraživanje; **D. K. Z.** – ideja za istraživanje, pomoć pri statističkoj obradi podataka

### Sažetak

**Svrha istraživanja:** Svrha istraživanja bila je usporediti tri parametra boje gornjih desnih središnjih sjekutića spektrofotometrom kao zlatnim standardom te kalibriranim i nekalibriranim RAW fotografijama s nimalnim mobilnim uređajima u različitim uvjetima osvjetljenja. **Materijal i postupci:** U istraživanju je sudjelovalo ukupno 30 studenata dentalne medicine. CIE L\*a\*b\* vrijednosti na središnjoj trećini gornjih desnih središnjih sjekutića izmjerene su spektrofotometrom i digitalno na RAW fotografijama s mobilnog uređaja u različitim uvjetima osvjetljenja (F – prednje svjetlo; L – lateralno svjetlo; D – lateralno svjetlo s difuzorima; P – polarizirajući filter na prednjem svjetlu; H – hibridni filter kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom pune snage te sivom kalibrirajućom karticom. Dobiveni rezultati su uspoređeni. **Rezultati:** Srednje a\* i b\* vrijednosti na kalibriranim i srednje L\* vrijednosti na nekalibriranim RAW fotografijama s mobilnog uređaja nisu se u različitim svjetlosnim uvjetima značajno razlikovale ( $P > 0,05$ ). CIE L\*a\*b\* vrijednosti na nekalibriranim RAW fotografijama s mobilnog uređaja, uz uporabu polarizacijskog filtra, potpuno su se poklapale s istim vrijednostima izmjerenima spektrofotometrom na gornjem desnom središnjem incizivu ispitanika ( $P > 0,05$ ). **Zaključci:** Različiti uvjeti osvjetljenja i postupci mjerenja u ovom su istraživanju utjecali na CIE L\*a\*b\* vrijednosti na RAW fotografijama s mobilnog uređaja. Uz ograničenja ovog istraživanja može se zaključiti da bi se nekalibrirana RAW fotografija s mobilnog uređaja, uz uporabu osvjetlivača s polarizirajućim filtrom na prednjem diodnom svjetlu u standardiziranim uvjetima, mogla koristiti pri digitalnom određivanju boje zuba.

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### Ključne riječi

dentalna estetika; boja zuba; nijanse boja; dentalna fotografija; upotreba mobilnog telefona

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