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

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 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.

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 planiranju digitalnog 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 patometnim uređajima – bolja 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 Easyscale® 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 discolored, white spots, damaged or worn teeth, composites, veneers, crowns or bridges, endodontic treatments or orthodontic retainers on the examined teeth. The students having 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 (Proxyt 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 stomatologima. Najkrajnijoj mobilnoj 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 fotoaparatom su manja težina, niža cijena i jednostavnija primjena (7).

Digitalna procjena boje zuba počela se primjenjivati kako bi se smanjile i prevladale netočnosti i nedosljedenosti 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 Easyscale 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).

Svrača 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 mobilnim uređajem pri različitim uvjetima osjetljenja. 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 osjetljenja.

Material 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 željeno 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 naborjenih 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 (Proxryt RDA 83; Ivoclar Vivadent, Liechtenstein), a ispitanik je zatim smješten uži bijeli zid bez prirodnog izvora svjetlosti (bez prozora) uz fluorescentno osjetljenje (4 x 120 cm, 36 W, color 765, Pho-
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, Shangai, 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 Design, 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.

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

Fotografiranje mobilnim uredajem

Pri fotografinju 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, statistically 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, Švica) 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 postavljenom na 15 cm udaljenosti te paralelnom s vestibularnom stijenkom ispitivanog zuba kako bi se izbjegla moguća distorzija slike (7). Za prilagodbu otvora blende stražnje telefotokamera 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, koristena 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 rasvetom pune snage (7).

Statistička analiza
Izmjereni podatci 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 univariatnom analizom varijanse. 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 rasvetom 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 for zavise 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 različitih svjetlosnih uvjeta. Razina značajnosti postavljena je na 0.05 (5%).

Rezultati

Univarijatna analiza varijanci 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) mjere spektrofotometrom i digitalno na kalibriranim i nekalibriranim RAW fotogramama s mobilnog uređaja u pet različitih uvjeta osvjetljenja prikazane su na slici 2.

Srednje a* i b* vrijednosti na kalibriranim te srednje L* vrijednosti na nekalibriranim RAW fotogramama s mobilnog uređaja nisu se značajno razlikovali u različitim svjetlosnim uvjetima (slika 2., tablica 1.; P>0.05). Na kalibriranim RAW fotogramama s mobilnog uređaja srednje L* vrijednosti značajno su se razlikovale ovisno o svjetlosnim uvjetima,
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).

| Calibration | t | df | p  |
|-------------|---|----|----|
| L*          | 8.84 | 3 | 0.00 |
| a*          | -16.24 | 29 | 0.00 |
| b*          | -0.96 | 29 | 0.35 NS |
| L*          | 5.29 | 29 | 0.00 |
| a*          | -13.56 | 29 | 0.00 |
| b*          | -0.10 | 29 | 0.92 NS |
| D*          | 6.03 | 29 | 0.00 |
| a*          | -13.15 | 29 | 0.00 |
| b*          | 2.44 | 29 | 0.02 |
| L*          | 11.52 | 29 | 0.00 |
| a*          | -14.54 | 29 | 0.00 |
| b*          | 1.35 | 29 | 0.19 NS |
| P*          | 8.49 | 29 | 0.00 |
| a*          | -14.49 | 29 | 0.00 |
| b*          | 1.30 | 29 | 0.21 NS |

| No calibration | t | df | p  |
|----------------|---|----|----|
| L*            | 2.17 | 29 | 0.04 |
| a*            | -6.74 | 29 | 0.00 |
| b*            | 8.56 | 29 | 0.00 |
| L*            | -0.02 | 29 | 0.99 NS |
| a*            | -5.94 | 29 | 0.00 |
| b*            | 10.92 | 29 | 0.00 |
| L*            | 1.10 | 29 | 0.28 NS |
| a*            | -7.60 | 29 | 0.00 |
| b*            | 6.85 | 29 | 0.00 |
| P*            | 0.95 | 29 | 0.35 NS |
| a*            | -1.92 | 29 | 0.06 NS |
| b*            | 0.64 | 29 | 0.53NS |
| H*            | 1.25 | 29 | 0.22 NS |
| a*            | -12.49 | 29 | 0.00 |
| b*            | 5.39 | 29 | 0.22 NS |

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 različitih svjetlosnih uvjeta (F-prednje svjetlo; L-lateralno svjetlo; D-lateralno svjetlo s difuzorima; P-polarizirajući filtir na prednjem svjetlu; H-hibridni filtir kao kombinacija polarizirajućeg filtra na prednjem svjetlu i lateralnih svjetala s difuzorima) s LED svjetlećom diodnom rasvjetom puno snage. Najbolje podudaranje označeno je u tablici masnim brojevima (P > 0.05), (df – stupanj slobode; t – t vrijednost; p – razina značajnosti)
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\(^\circ\).

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 chip’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

Srva ovog istraživanja bila je ispitati podudaraju li se CIE L\(^*\)a\(^*\)b\(^*\) vrijednosti jedne RAW fotografije s mobilnog telefona slikane u pet različitih svjetlosnih uvjeta s istim vrijednostima izmjerenima 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 nekalibriranima 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, padało 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 sječutic, a oni kod ostalih fotografija bili su manji od 90\(^\circ\).

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 ispiti i kalibrirane (standardni protokol za fotografiju s digitalnog fotoaparata) objašnjava se činjenicom da mobilni uređaji produciraju fotografije potpuno drukčije od digitalnog fotoaparata. Pri obradi fotografije Appleovom Deep Fusion tehnologijom koristi se set elektroničkih komponenti neuralne mere 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 kaliranje tako dobivenih fotografija može kalibrirajući sluk učiniti još različitijom od stvarnoga svijeta, a to se željelo ispitati u ovom istraživanju.

Druga nulta hipoteza djelomično je prihvaćena jer je pronaden samo jedan tip RAW fotografije s mobilnog uređaja čije su CIE L\(^*\)a\(^*\)b\(^*\) vrijednosti bile podudarne s istim vrijednostima izmjerenima 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 izradenima digitalnim fotoaparatom uporaba polarizacijskog filtra obično se preporučuje jer ublažava zracnu refleksiju i eliminira utjecaj površinskih struktura (cahkline) koje izazivaju prezašćenu kromatiziranu boju (22, 23, 28). Uz to, za postizanje što realnijih boja za tu se vrstu fotografiju 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 cakhline, izbjegavajući tako utjecaj refleksija koje se pojavljaju 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 Đozić 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 possibility of achieving 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

Assessment of Color Parameters

Već godinama postoji zanimanje za korištenje različitih alata za natočniju procjenu boje zuba u stomatologiji. Do danas je već dokazano da su digitalni spektrofotometri znatno pouzdаниji od vizualnih tehnića 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 mjerenje digitalno u kompjutorskom programu u istraživanju Đozića i suradnika pokazale su da su im gornji središnji sjekurići bili tamsnije boje, zeljeniji i žući od istih vrijednosti izmjerenih spektrofotometrom u našem istraživanju u kojem su ispitanici bili mladi (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 najsavršenijih metoda koja koristi fotografijom s polarizacijskim filtrom, kalibracijom svom 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 onom za digitalni fotoaparat. S obzirom na to da mobilni uređaj korišten u ovom istraživanju ne omogućuje individualnu prilagođbu kamere, odlučeno je koristiti se posebnom aplikacijom koja je omogućila postizanje jednaka uvjeta pri balansu bijele boje, otvoru blende, brzini okvirche te opciju RAW formata fotografije kao kod digitalnog fotoaparata.

Jedino što je kod digitalnog aparata bolje od kamere mobilnog uređaja jest dubinska oštrina (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 priblizavanje objektu bez fizičkoga primitanja (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 sjekurići 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.C. - gave the equipment for the research; D.K.Z. – created the idea for this research, helped with statistical analysis;
Saget

Svrsna istraživanja: Svrsna istraživanja bila je usporediti tri metoda boje gornjih desni srednjijsih zuba na osnovu nekalibriranih RAW fotografija s mjenjenjem sadašnjim standardom te kalibriranim RAW fotografijama snimljena mobilnim uređajem u različitim uvjetima osvjetljenja. Materijal i postupci: U istraživanju je sudjelovalo ukupno 30 studenata dentalne medicinе. CIE L*a*b* vrijednosti na srednjem desnom središnjem sbirku (P > 0,05). Rezultati: Srednje a* i b* vrijednosti na kalibriranim RAW fotografijama s mobilnog uređaja nisu se u različitim svjetlosnim uvjetima značajno razlikovala (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 izmjerena na spektrofotometru s redoslijedom izvrsnosti ispitanika (P < 0,05). Završni i sjajni rezultati 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 nekalibrira-

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

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