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Jelena Paliska[1], Andro Stipetić[2], Zrinka Tarle[3], Mira Ristić[4], Ticijana Ban[5], Nataša Vujičić[5], Goran Pichler[5]

Kolorimetrijska prosudba učinkovitosti različitih postupaka izbjeljivanja zuba

Colorimetric Assessment of Different Tooth Whitening Procedures

[1] Studentica Stomatološkog fakulteta Sveučilišta u Zagrebu
Student, School of Dental Medicine, University of Zagreb
[2] Privatna stomatološka ordinacija, Zagreb
Private dental office, Zagreb
[3] Zavod za endodonciju i restaurativnu stomatologiju Stomatološkog fakulteta Sveučilišta u Zagrebu
Department of Endodontics and Restorative Dentistry, School of Dental Medicine, University of Zagreb
[4] Institut Ruđer Bošković, Zagreb
Rudjer Boskovic Institute, Zagreb
[5] Institut za fiziku, Zagreb
Institute of Physics, Zagreb

Sažetak

Svrha: Nakana je bila ispitati učinkovitost četiriju različitih postupaka izbjeljivanja te usporediti 30-postotni gel karbamid-peroksid s dva, danas dostupna *"in office"* postupka izbjeljivanja kod kojih se, osim gela, koristimo i modernim izvorima svjetlosti (Discus Dental, Culver City, CA, SAD i Beyond Technology Corp., Santa Clara, CA, SAD) te klinički još neprimijenjenim femtosekundnim uređajem u koji je ugrađena zelena laserska pumpa (Millennia, Spectra Physics) i femtosekundni laserski oscilator (Tsunami, Spectra Physics). **Materijali i metode:** U zeleni čaj osam je sati bilo uronjeno 40 pastila hidroksilapatita. Nakon sušenja nasumce su podijeljene u četiri skupine, u svakoj po deset. Svaka skupina tretirana je jednim od četiriju postupaka izbjeljivanja. Boja pastila određena je kolorimetrom u RGB-indeksu prije bojenja u čaju, poslije toga i nakon tretmana određenim postupkom za izbjeljivanje. Za analizu ukupnih kolorimetrijskih vrijednosti koristili smo se i postupcima neparametrijske statistike – Kruskal-Wallisovim i Mann-Whitneyjevim testom za nezavisne uzorke i Wilcoxovim testom za zavisne uzorke. **Rezultati:** Ukupne kolorimetrijske vrijednosti pastila obrađenih samo gelom bile su 3024,42, onih tretiranih izvorom svjetlosti ZOOM 2 iznosile su 2999,74, pastila tretiranih Beyondom 2944,12 te laserom 2687,22. Najbolji rezultati postignuti su 30-postotnim gelom karbamid-peroksida i ZOOM-om 2, a slijede Beyond i femtosekundni laser, kod kojih je učinak izbjeljivanja bio proporcionalan trajanju tretmana i koncentraciji gela. **Zaključak:** Iako su se sva četiri postupka izbjeljivanja pokazala uspješnima, konačni rezultat ovisi o trajanju tretmana te vrsti i koncentraciji primijenjenoga gela.

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Adresa za dopisivanje
Prof.dr.sc. Zrinka Tarle
Sveučilište u Zagrebu
Stomatološki fakultet
Gundulićeva 5, 10 000 Zagreb
tarle@sfzg.hr

Ključne riječi
zub, izbjeljivanje; karbomid peroksid; laser

Uvod

Suvremeni postupci izbjeljivanja zuba uključuju tretmane gelovima karbamid-peroksida i vodikova peroksida u različitim koncentracijama, uz ili bez uporabe izvora svjetlosti ili bez nje (1,2,3,4). Karbamid-peroksid raspada se na vodikov peroksid i ureu, a koncentracija vodikova peroksida iznosi otprilike trećinu početne koncentracije karbamid-peroksida (2). Prema dosadašnjim spoznajama vrijeme potrebno da se postigne maksimalni učinak izbjeljivanja izravno ovisi o trajanju tretmana i koncentraciji gela, a ne o vrsti gela (1,2,5).

Pri izbjeljivanju mogu biti uporabljeni gelovi različitih koncentracija s izvorom svjetlosti ili bez njega. Svjetlost pritom ima zadaću katalizatora koji povećava apsorpciju gela i ubrzava kemijski proces oksidacije (1,6).

Introduction

Modern tooth whitening procedures include treatments with carbamide peroxide and hydrogen peroxide gels of different concentrations, with or without the application of light from various sources (1, 2, 3, 4). Carbamide peroxide breaks down into hydrogen peroxide and urea, with the hydrogen peroxide concentration being approximately one-third of the original carbamide peroxide percentage (2). According to current scientific data, the time required to achieve the greatest whitening effect depends directly on treatment duration and the concentration of the applied gel, but does not depend on the gel type (1, 2, 5).

Various concentrations of tooth whitening gels can be used during whitening procedures, with or without the use of different light sources. Light is the catalyst that increases

Izvori svjetlosti mogu se temeljiti na halogenoj i infracrvenoj svjetlećoj diodi (LED-u) i laserskoj tehnologiji (7,8,9). U literaturi se navodi da ZOOM 2 poboljšava učinak 20-postotnog gela vodikova peroksida za 26 posto (6,10). Femtosekundni laseri rabe se za istraživanja u području prirodnih znanosti, medicini i industriji te u vojsci i telekomunikacijama, no još nema istraživanja o njihovoj primjeni u dentalnoj medicini u postupku izbjeljivanja zuba.

U dosadašnjim istraživanjima istaknuto je da konačni uspjeh izbjeljivanja ovisi o koncentraciji primijenjenoga gela, uporabi izvora svjetlosti i ukupnom trajanju tretmana (1,2,5).

Svrha ovog istraživanja bila je usporediti različite postupke izbjeljivanja zuba, ne mijenjajući pritom parametre proizvođača, kao što su trajanje tretmana, izvor svjetlosti te vrsta i koncentracija gela.

Materijal i postupci

Istraživanje je obavljeno na 40 pastila hidroksilapatita, a svaka je bila promjera 12,5 milimetara i debljine 2,5 milimetara. Bile su izrađene od praha hidroksilapatita (Hydroxylapatite for analysis, ACROS Organics Co., Lot A0229866, Fair Lawn, NJ, SAD) na Institutu Ruđer Bošković. Svaka je sadržavala 400 mg hidroksilapatitnog praha izvaganog na vagi (Mettler PM200, Švicarska) i zatim prešanog (Universal GP1, Banja Luka, 1990) pod tlakom od 20 bara. Dobivene pastile su se nakon toga dva sata sušile u sterilizatoru (Instrumentarija, ST-01/02, Zagreb, 1989.) na temperaturi od 150°C kako bi dobile na čvrstoći.

Zbog veće objektivnosti, umjesto ljudskih ili goveđih zuba, koristili smo se pastilama jer su bile potpuno jednake, s istim RGB-indeksom i nije bilo drugih parametara osim izbjeljivanja koji bi mogli utjecati na ishod izbjeljivanja.

Nakon izrade pastile su obojene u zelenom čaju (Fannings, Cedevita d.o.o., Hrvatska) (slika 1.), a zatim, nakon sušenja, podijeljene u četiri skupine – u svakoj po deset. Svaka skupina tretirana je određenim postupkom izbjeljivanja. Boja pastila mjerena je pet puta uzastopce kolorimetrom (PCE RGB2 Color analyzer, PCE Group, Njemačka) i to prije bojenja u čaju, poslije toga i nakon tretmana određenim postupkom izbjeljivanja.

Postupak 1: gel karbamid-peroksid

Prva skupina tretirana je 30-postotnim gelom karbamid-peroksida (VivaStyle gel, Ivoclar Vivadent, Liechenstein) prema uputama proizvođača. Gel je aplikatorom nanesen na površinu pastila u debljini od milimetra do dva i ostavljen 30 minuta te zatim uklonjen plastičnom špatulom i sterilnom gazom. Boja pastila izmjerena je odmah nakon postupka. Postupak se ponavljao pet dana po 30 minuta i svaki put je kolorimetrom izmjerena boja pastila.

the absorption of the gel and accelerates the chemical oxidation process (1, 6).

Light sources can be based on halogen, infrared, light diode (LED) and laser technology (7, 8, 9). The literature states that ZOOM 2 enhances the effect of 20% hydrogen peroxide gel by 26% (6, 10). Femtosecond lasers are used in scientific research, medicine, industry as well as in the military and telecommunications, but they have not yet been tested in the dental context, specifically in whitening procedures.

Previous studies have shown that ultimate success in tooth whitening depends on the concentration of the tooth whitening gel, the light source and total treatment duration (1, 2, 5).

The aim of this study was to compare different teeth whitening procedures, without adjusting the manufacturer's parameters, such as treatment duration, use of light source or the gel type and concentration.

Materials and Methods

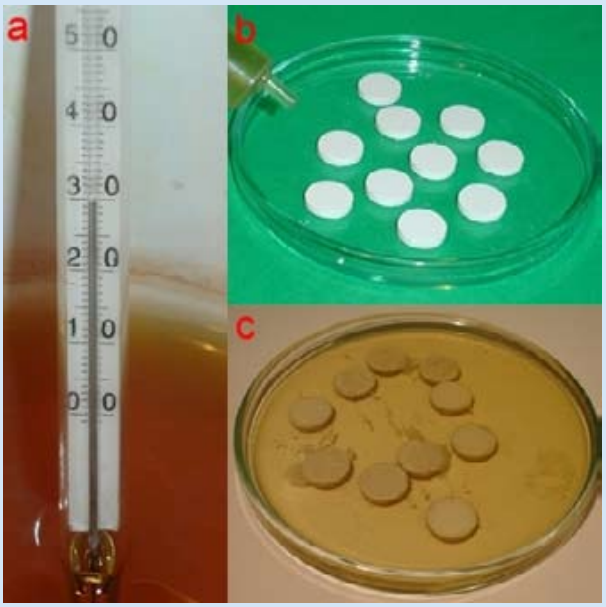
The research was conducted on 40 pastilles of hydroxyapatite and each was 12.5 mm in diameter and 2.5 mm thick. Pastilles were made of hydroxyapatite powder (Hydroxyapatite for analysis, ACROS Organics Co., Lot A0229866, Fair Lawn, NJ, USA) at the 'Ruđer Bošković' Institute. Each pastille contained 400 mg of hydroxyapatite powder weighted in the scale (Mettler PM200, Switzerland) and then compressed (Universal GP1, Banja Luka, 1990) under the pressure of 20 bar. The pastilles were dried in the dry sterilizer (Instrumentaria, ST-01/02, Zagreb, 1989) at a temperature of 150°C for 2 hours to obtain the strength.

For better objectivity, instead of using human or bovine teeth, we used pastilles that were absolutely equal, had the same RGB index and we did not have any other parameter apart from the bleaching process that could affect the outcome.

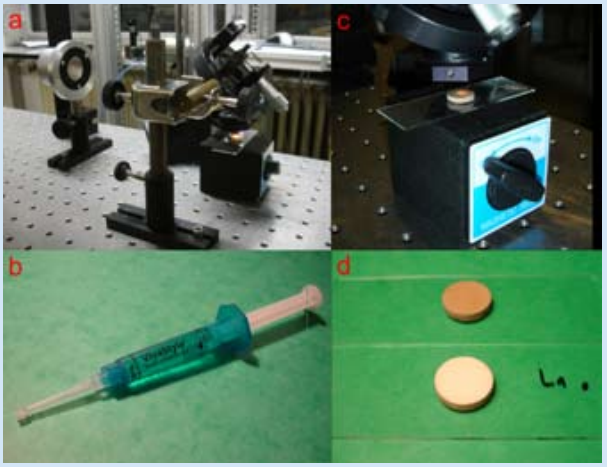
Upon manufacture, the pastilles were immersed in green tea (Fannings, Cedevita d.o.o., Croatia), Figure 1, and then, after drying, they were divided into 4 groups of 10 pastilles each. Each group was treated with one of the tooth whitening procedures. The color of each pastille was determined 5 consecutive times using a colorimeter (PCE RGB2 Color Analyzer, PCE Group, Germany) on 3 separate occasions: prior to immersion in the tea, after immersion and after the whitening treatment.

Procedure 1: Carbamide peroxide gel

The first group was treated by 30% carbamide peroxide gel (VivaStyle gel, Ivoclar Vivadent, Liechtenstein) according to the manufacturer's instructions. A layer of gel 1-2 mm thick was applied to the surface with the applicator and left for 30 minutes and then removed using a plastic spatula and sterile gauze. The pastille color was determined immediately after the procedure. The procedure was repeated on the same pastille over a 5-day period for 30 minutes each time, followed by color determination by a colorimeter.



Slika 1. Bojenje pastila u čaju – (a) čaj temperature 29ºC; (b) pastile prije bojenja; (c) pastile tijekom bojenja čajem
Figure 1 Immersion of the pastilles in green tea. (a) Tea temperature of 29,5°C; (b) Pastilles before immersing in the tea; (c) Immersed pastilles



Slika 2. Izbjeljivanje femtosekundnim laserom – (a) femtosekundni laserski sustav; (b) VivaStyle gel; (c) osvjetljavanje laserom; (d) usporedba pastila prije tretmana laserom i nakon toga postupka
Figure 2 Whitening procedure with femtosecond laser. (a) VivaStyle gel; (b) Femtosecond laser application on the pastille; (c) A comparison of pastilles before and after laser treatment.

Postupak 2: ZOOM 2

Druga skupina pastila tretirana je izvorom svjetlosti ZOOM 2 (Discus Dental, SAD), uz primjenu izvornog gela ZOOM 2 (25% gel vodikova peroksida) prema uputama proizvođača. Nakon što je sloj gela debljine milimetar do dva kistom nanesen na površinu, pastile su 15 minuta bile izložene izvoru svjetlosti. Nakon toga gel je uklonjen plastičnom špatulom i sterilnom gazom. Postupak je ponovljen tri puta po 15 minuta, koliko traje jedan tretman izvorom svjetlosti ZOOM 2. Boja pastila izmjerena je nakon tretmana.

Postupak 3: Beyond

Treća skupina pastila tretirana je izvorom svjetlosti Beyond (Beyond Technology Corp., SAD), uz primjenu izvornog Beyondova gela (35-postotnog gela vodikova peroksida) prema uputama proizvođača. Nakon što je sloj gela debljine milimetar do dva bio nanesen na površinu pastila, one su osam minuta bile izvrgnute Beyondovu izvoru svjetlosti, te je nakon toga gel uklonjen plastičnom špatulom i sterilnom gazom. Postupak je ponovljen tri puta koliko traje jedan tretman Beyondom. Boja pastila izmjerena je nakon tretmana.

Postupak 4: Femtosekundni laser

Četvrta skupina pastila tretirana je femtosekundnim laserom (slika 2.a), uz primjenu 30-postotnog gela karbamid-peroksida (VivaStyle gel, Ivoclar Vivadent, Liechtenstein) (slika 2.b). Femtosekundni laser je uređaj koji emitira pulsove od 100 femtosekundi prosječne snage od 1 W i valne duljine od

Procedure 2: Zoom 2

The second group of pastilles was treated by the ZOOM 2 light source (Discus Dental, USA) using the ZOOM 2 gel (25% hydrogen peroxide gel), according to the manufacturer's instructions. After applying a layer of gel 1-2 mm thick to the surface of the pastilles, the light source was applied for 15 minutes. The gel was then removed with a plastic spatula and sterile gauze. The procedure was repeated 3 times for 15 minutes each time, since the manufacturer determined this to be the treatment duration for the ZOOM 2 tooth color lightening system. The pastille color was determined immediately after the procedure.

Procedure 3: Beyond

The third group was treated by the Beyond light source (Beyond Technology Corp., USA) using the gel provided with the light source (35% hydrogen peroxide gel), according to the manufacturer's instructions. After a 1-2 mm layer of gel was applied to the surface using a brush, the light source was applied for 8 minutes. The gel was then removed using a plastic spatula and sterile gauze. The procedure was repeated 3 times for 8 minutes, since this is the treatment duration specified by the manufacturer. The pastille color was determined immediately upon procedure completion.

Procedure 4: Femtosecond laser

The fourth group was treated by a femtosecond laser using 30% carbamide peroxide gel (VivaStyle gel, Ivoclar Vivadent, Liechtenstein) (Fig. 2a). The Femtosecond laser is a pulse laser which emits pulses lasting 100 femtoseconds with an average power of 1W and wavelength of 780 nm.

780 nm. Cijeli sustav sastoji se od zelene laserske pumpe od 6 W (Millennia, Spectra Physics) i femtosekundnog laserskog oscilatora; Ti: safir lasera (Tsunami, Spectra Physics) u kojem se generiraju femtosekundni pulsovi. Laseru se može mijenjati valna duljina u intervalu od 780 do 950 nm.

Na pastile je nanesen 30-postotni gel karbamid-peroksida (VivaStyle gel, Ivoclar Vivadent, Liechtenstein) u debljini milimetar do dva, a zatim su bile izložene djelovanju lasera 10 minuta (slika 2c) nakon čega je gel uklonjen plastičnom špatulom i gazom. Boja pastila izmjerena je nakon tretmana.

Na slici 2.d je usporedbu pastila prije tretmana laserom i nakon toga postupka.

Statistička analiza

Na temelju dobivenih mjerenja izračunata je srednja vrijednost RG-indeksa pastila prije bojenja, nakon toga postupka te poslije određenog tretmana izbjeljivanja.

Radi lakše interpretacije podataka srednje vrijednosti RGB-indeksa prikazane su kao zbroj R+G+B.

Za testiranje normalnosti razdiobe podataka koristili smo se Shapiro-Wilkovim testom, a za ispitivanje homogenosti varijanca Leveneovim testom. Za izračun pouzdanosti mjerenja odabran je intraklasni korelacijski koeficijent, a pogreška mjerenja izračunata je kao drugi korijen prosječnoga kvadrata reziduala iz tablice ANOVA. Koeficijenti varijabilnosti rabili su se za procjenu homogenosti svojstva te za usporedbu varijabiliteta pojedinih mjerenja.

Za testiranje promjena zbrojenih kolorimetrijskih vrijednosti prije bojenja čajem i nakon njega te poslije izbjeljivanja, korišteni su postupci neparametrijske statistike. Kruskal-Wallisov i Mann-Whitneyjev test odabrani su za nezavisne uzorke, a Wilcoxonov za zavisne. Svi testovi su rađeni uz razinu značajnosti $p<0,05$, s pomoću statističkog softvera SPSS 10,0 (SPSS Inc., Chicago, IL, SAD).

Rezultati

Srednja vrijednost RGB-indeksa pastila tretiranih gelom nakon pet tretmana iznosila je (R = 1015,68; G = 1021,94; B = 986.80, a zbrojena kolorimetrijska vrijednost 3024,42), pastila tretiranih ZOOM-om 2 (R = 1013,64; G = 1022,16; B = 963,94, a zbrojena kolorimetrijska vrijednost 2999,74), pastila tretiranih Beyondom (R = 989,24; G = 1003,98; B = 950,90, a zbrojena kolorimetrijska vrijednost 2944,12) i pastila tretiranih laserom (R = 915,86; G = 918,38, B = 852,98, a zbrojna kolorimetrijska vrijednost 2687,22).

Intraklasni korelacijski koeficijenti pokazali su da su očitanja kolorimetrijskih vrijednosti boja jako pouzdana ($ICC\geq0,97$; $p<0,001$), a i pogreška u mjerenju uvijek je bila manja od standardne devijacije ($ME\leq0,823$), odnosno manja od raspršenja podataka za pet mjerenja. Koeficijent varijabilnosti sugerira da je najveći varijabilitet u očitavanju kolorimetrijske vrijednosti plave boje te da je veći nakon tretmana laserom, negoli ostalim postupcima.

Rezultati pouzdanosti mjerenja prikazani su u tablici 1.

Kako ukupna kolorimetrijska očitanja (R+G+B) nisu bila normalno distribuirana, za njihovu analizu rabljeni su

The whole system consists of a 6W green laser pump (Millennia, Spectra Physics) and the femtosecond laser oscillator; (Ti:sapphire laser, Tsunami, 0,6 W Spectra Physics) which generates the femtosecond pulses. The laser wavelength can be adjusted within the 780-950 nm spectral interval.

A 1-2 mm layer of 30% carbamide peroxide gel (VivaStyle gel, Ivoclar Vivadent, Liechtenstein) was brushed onto the surface of each pastille, followed by femtosecond laser application for 10 minutes (Figure 2b) after which the gel was removed using a plastic spatula and sterile gauze. The color was determined upon procedure completion. Figure 2c illustrates a comparison of pastilles before and after the laser treatment.

Statistical analysis

Based on the measurements taken, the mean value of RGB index was calculated prior to immersion, following immersion, and after the tooth whitening procedure.

In order to facilitate data interpretation, the RGB index mean values were presented as the colorimetric sum value, R + G + B.

The Shapiro Wilk test was used to assess the normality of data distribution, and Levene's test was used to assess the equality of variances in the samples. Intraclass correlation was used to calculate the reliability of the measurement coefficient, and the measurement error was calculated as the square root of the average square residuals from the ANOVA table. The coefficient of variation was used to evaluate the homogeneity of the properties and to compare the variability of individual measurements.

Non-parametric tests were used in the analysis of colorimetric sum values before and after immersion in the tea. Namely, the Kruskal-Wallis and Mann-Whitney tests were applied to independent samples and the Wilcoxon test was used for dependent samples. All the tests were conducted with the significance level at $p <0.05$, using SPSS 10.0 statistical software (SPSS Inc., Chicago, IL, USA).

Results

The mean RGB index values for the pastilles treated by gel after 5 treatments (R = 1015.680, 1021.940 G =, B = 986 800; the colorimetric sum value was 3024.420), for the pastilles treated with ZOOM 2 (R = 1013.640, 1022.160 G =, B = 963 940; the colorimetric sum value was 2999.740), for the pastilles treated by Beyond (R = 989.240, G = 1003.980, B = 950.900; the colorimetric sum value was 2944.120) and for the laser-treated pastilles (R = 915 860, G = 918 380, B = 852 980; the colorimetric sum value was 2687.220).

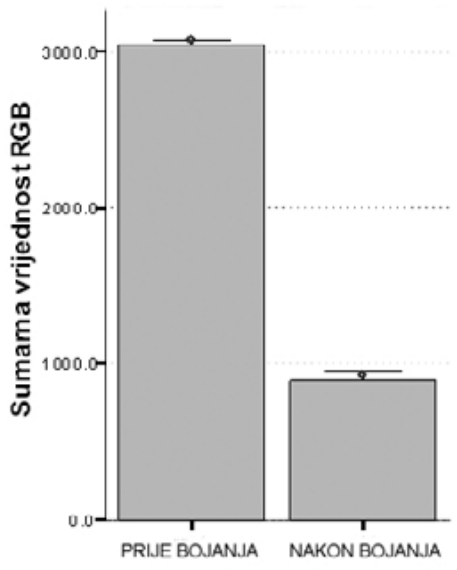
The intraclass correlation coefficients indicated that the colorimetric color values readings were highly reliable ($ICC \geq 0.97$, $p <0,001$), and the measurement error was always lower than the standard deviation ($ME \leq 0823$), or less than the scattering data for the five measurements. The coefficient of variation suggests that greater variability occurs after laser treatment in comparison with the other procedures, whereas the greatest variability in colorimetric readings occurred within the blue color range.

The results of the measurement reliability analysis are shown in Table 1.

Tablica 1. Parametri pouzdanosti mjerenja.
Table 1 The results of the measurement reliability analysis

Mjerenje • Measurement	RGB-indeks • RGB index	n	ICC	95% CI	p	ME	CV (%)
Prije bojenja • Prior to the immersion	R	40	0.993	0.989-0.996	<0.001	0.585	0.73
	G	40	1	1	<0.001	0.000	0.00
	B	40	0.997	0.995-0.998	<0.001	0.561	1.03
Nakon bojenja • After the immersion	R	40	0.998	0.997-0.999	<0.001	0.823	0.16
	G	40	0.999	0.998-0.999	<0.001	0.646	0.18
	B	40	0.999	0.999-0.999	<0.001	0.525	0.89
ZOOM2	R	10	0.987	0.967-0.996	<0.001	0.539	0.52
	G	10	0.97	0.93-0.991	<0.001	0.302	0.16
	B	10	0.995	0.987-0.999	<0.001	0.529	0.78
GEL	R	10	0.994	0.984-0.998	<0.001	0.527	0.85
	G	10	0.996	0.989-0.999	<0.001	0.203	0.30
	B	10	0.998	0.996-0.999	<0.001	0.532	1.31
BEYOND	R	10	0.991	0.968-0.998	<0.001	0.616	0.95
	G	10	0.994	0.973-0.998	<0.001	0.469	0.97
	B	10	0.996	0.989-0.999	<0.001	0.577	1.13
FS LASER	R	10	0.998	0.994-0.999	<0.001	0.564	1.69
	G	10	0.998	0.996-0.999	<0.001	0.469	1.83
	B	10	0.999	0.998-0.999	<0.001	0.445	2.24

Legenda • Legend:
ICC - intraklasni korelacijski koeficijent • the intraclass correlation coefficient; 95 % CI – interval pouzdanosti • the measurement reability; ME – pogreška u mjerenju • measurement error; CV – koeficijent varijabilnosti • the coefficient of variation



Slika 3. Usporedba ukupnih kolorimetrijskih vrijednosti prije bojenja pastila u čaju i nakon toga
Figure 3 Differences in the colorimetric sum values calculated before and after immersion in the tea

postupci neparametrijske statistike. Wilcoxonovi testovi za parove pokazuju statistički značajne razlike zbrojenih kolorimetrijskih vrijednosti prije i nakon bojenja (slika 3.) te nakon bojenja i izbjeljivanja kod svih postupaka izbjeljivanja ($p<0,05$). Ukupna kolorimetrijska vrijednost je nakon bojenja čajem bila 70,97 posto niža od vrijednosti pastila prije toga postupka.

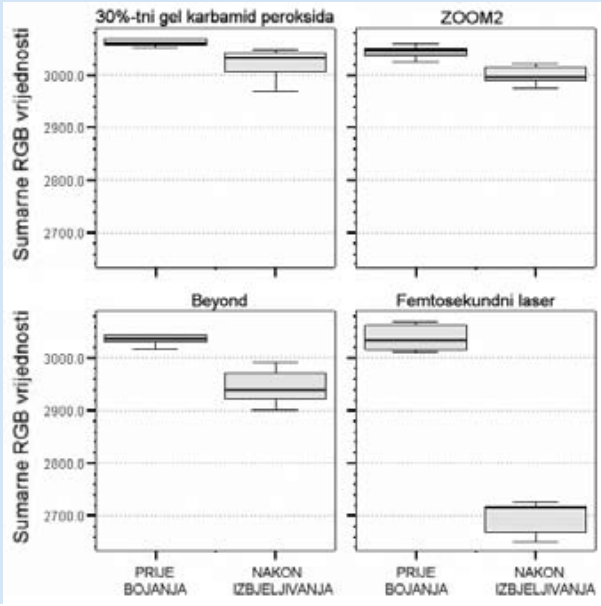
Nakon izbjeljivanja zbrojene kolorimetrijske vrijednosti približavaju se inicijalnim vrijednostima prije bojenja, no još su nešto niže ($p<0,05$). Najbolji rezultati dobiveni su izbjeljivanjem 30-postotnim gelom karbamid-peroksida kojim se postiglo 99,3 posto inicijalne zbrojene kolorimetrijske vri-

Since the colorimetric sum values (R + G + B) did not display normal distribution, non-parametric statistics was used in their analysis. The results of the Wilcoxon paired tests showed statistically significant differences in the colorimetric sum values calculated before and after immersion in tea (Figure 3), after immersion in the tea and after all of the tested tooth whitening procedures ($p <0.05$). The colorimetric sum value after immersion in the tea was found to be 70.97% lower than the values obtained for pastilles prior to immersion.

After tooth whitening procedures, the colorimetric sum values tended to approach the initial value (prior to immer-

Tablica 2. Učinak izbjeljivanja pojedinih postupaka u odnosu prema pastilama prije bojenja (%).
Table 2 Whitening effect comparing to the initial colorimetric sum value of non-immersed pastilles (%).

Neobojene pastile • Non-immersed pastilles	100.00%
30-postotni gel karbamid-peroksida • 30% carbamide peroxide gel	99.29%
ZOOM2	98.48%
Beyond	96.65%
Femtosekundni laser • Femtosecond laser	88.22%



Slika 4. Usporedba distribucija ukupnih kolorimetrijskih vrijednosti prije bojenja pastila i nakon izbjeljivanja s obzirom na postupak izbjeljivanja
Figure 4 The comparison of the distribution of colorimetric sum values calculated before and after immersion in the tea and after the tooth whitening procedure

Tablica 3. Zbrojne vrijednosti RGB-indeksa (R+G+B).
Table 3 The comparison of the distribution of colorimetric sum values (R+G+B).

Zbrojna vrijednost RGB-indeksa • Sum value of RGB index	Prosjek • Mean	St. pogreška • St. error	95% interval pouzdanosti • 95% CI	
			Donja granica • Lower limit	Gornja granica • Upper limit
Prije bojenja • Prior to the immersion	3046.115	2.738	3040.577	3051.653
Nakon bojenja • After the immersion	884.335	9.083	865.963	902.707
30-postoni gel karbamid-peroksida • 30% carbamide peroxide gel	3024.420	10.776	3002.565	3046.275
ZOOM2	2999.740	10.776	2977.885	3021.595
Beyond	2944.120	10.776	2922.265	2965.975
Femtosekundni laser • Femtosecond laser	2687.220	10.776	2665.365	2709.075

jednosti neobojenih pastila, a najlošiji rezultati dobiveni su femtosekundnim laserom kojim se postiglo 88,2 posto vrijednosti prije bojenja (tablica 2).

Usporedba distribucija ukupnih kolorimetrijskih vrijednosti prije bojenja pastila i nakon izbjeljivanja s obzirom na postupak izbjeljivanja prikazana je na slici 4.

Kruskal–Wallisov i Mann–Whitneyjev test pokazali su da postoje statistički značajne razlike u ukupnim kolorimetrijskim vrijednostima između svih postupaka izbjeljivanja ($p<0,05$). Gel je imao najveću – 3024,420±10,776 (95 % CI: 3002,565 – 3046,275), a femtosekundni laser najmanju – 2687,220±10,776 (95 % CI: 2665,365 - 2709,075).

U tablici 3. prikazane su ukupne vrijednosti RGB-indeksa pastila prije bojenja i nakon toga postupka te nakon tretmana određenim postupkom za izbjeljivanje.

sion), but were still slightly lower ($p <0.05$). The best results were obtained by 30% carbamide peroxide gel, which reached 99.3% of the initial colorimetric sum value of non-immersed pastilles, and the lowest results were obtained by the femtosecond laser which reached 88.2% of the colorimetric sum value calculated prior to staining with the tea (Table 2).

The comparison of the distribution of colorimetric sum values calculated before and after immersion in the tea and after the tooth whitening procedure is shown in Figure 4.

The results of the Kruskal-Wallis and Mann-Whitney tests showed a statistically significant difference in the colorimetric sum values for all tooth whitening procedures ($p <0.05$). The gel procedure gained highest colorimetric value, calculated to be 3024.420 ± 10 776 (95% CI: 3002,565

- 3046.275), whereas the femtosecond laser procedure obtained the least colorimetric sum value of 2687.220 ± 10 776 (95% CI: 2665.365 - 2709.075).

Table 3 shows the colorimetric sum values of RGB index before and after pastille immersion in the tea and after treatment with certain whitening procedures.

Rasprava

U ovom istraživanju najbolji rezultati izbjeljivanja postignuti su primjenom 30-postotnoga gela karbamid-peroksida, zatim izvorom svjetlosti ZOOM 2 uz odgovarajući gel, a slijede izvor svjetlosti Beyond uz odgovarajući gel i femtosekundni laser uz 30-postotni gel karbamid-peroksida, pri čemu je učinak izbjeljivanja bio proporcionalan trajanju tretmana.

Premda se u literaturi navodi da je primjena 10 do 15-postotnoga gela karbamid-peroksida najadekvatnija za izbjeljivanje kod kuće (2,11), za potrebe ovog istraživanja upotrebljena je viša koncentracija (30%) jer je istraživanje rađeno na pastilama, a ne na vitalnim zubima pa nije postojala opasnost od preosjetljivosti ili oštećenja cakline, što se može dogoditi pri višim koncentracijama gela (12).

Vrijeme tretmana gelom (30 minuta) unaprijed je zadao proizvođač. Kako je broj ponavljanja tretmana prema proizvođaču proizvoljan, ponavljan je pet dana jer je na temelju dosadašnjih istraživanja pokazano da 30-postotni gel karbamid-peroksida postiže maksimalni učinak upravo za pet dana (5).

Iako su u uvjetima *in vitro* postignuti najbolji rezultati gelom, mora se uzeti u obzir da ne mogu reprezentirati situaciju *in vivo* u kojoj je prisutan i učinak sline, bez obzira na korištenje udlage (13). Naime, slina razrjeđuje koncentraciju gela i remeti idealni pH potreban za proces izbjeljivanja (iznosi između 9,5 i 10,8), a u kojemu gel ostvaruje maksimalni učinak (11).

Različita su mišljenja o tome poboljšava li izvor svjetlosti učinak gela ili ne. Prema podacima u literaturi, u istraživanju provedenom izvorom svjetlosti ZOOM 2, kojim smo se koristili i u ovom istraživanju, dokazano je da je učinak 20-postotnoga gela vodikova peroksida poboljšan za 26 posto ako se upotrebljavao i izvor svjetlosti ZOOM 2 (6,10).

Iako je tretman ZOOM-om 2 u odnosu na Beyond, pokazao ukupnu kolorimetrijsku vrijednost bližu onoj prije bojenja, potrebno je uzeti u obzir vrijeme u kojem su pastile bile tretirane. Ukupno vrijeme tretiranja pastila izvorom svjetlosti ZOOM 2 bilo je 45 minuta, a Beyondom 24 minute, tj. gotovo upola kraće. Razlog kraćem tretiranju pastila može biti veća koncentracija gela vodikova peroksida koja kod Beyonda iznosi 35 posto, a 25 posto kod ZOOM-a 2. S obzirom na to da su vrsta i koncentracija gela te vrijeme tretmana unaprijed odredili proizvođači, nisu se mogli mijenjati. Kako je svrha ovog istraživanja bila usporediti različite postupke izbjeljivanja ne mijenjajući pritom parametre proizvođača, ne može se reći koji je od tih dvaju postupaka učinkovitiji. Kako bi se to istražilo, potrebna su daljnja istraživanja s istim parametrima, poput koncentracije gela i vremena ekspozicije. Kako u dostupnoj literaturi nisu nađeni podaci

Discussion

In this study the best results were achieved using a 30% carbamide peroxide gel, followed by the ZOOM 2 light source used in conjunction with the provided gel, followed by the Beyond light source used in conjunction with the gel, and finally the femtosecond laser used with 30% carbamide peroxide gel, where the bleaching effect was proportional to the duration of the treatment.

Although the literature states that the application of 10-15% carbamide peroxide gel is the best suited for "home bleaching" (2, 11), a higher concentration of carbamide peroxide gel was used (30%) in this study because the research was done on pastilles, and not on vital human teeth, so there was no risk of hypersensitivity or damage to the enamel that would have been possible when testing higher gel concentrations (12).

The 30-minute treatment duration for the gel bleaching procedure was provided by the product's manufacturer. However, the number of repeated treatments was arbitrary according to the manufacturer, so the treatment was repeated within 5 days based upon research previously conducted and described in the literature, indicating that 30% carbamide peroxide gel achieved maximum effect after precisely 5 days (5).

Although the gel bleaching approach showed best results within *in vitro* conditions, it should be taken into consideration that such results are not representative of the environment *in vivo* in the presence of saliva and its effects, regardless of the use of nightguard during bleaching (13). Saliva causes dilution of the gel, lowering its concentration and disturbing the ideal pH which is required for the whitening process, which ranges from 9.5 to 10.8, for the gel to achieve its peak effect (11).

Opinions differ on whether or not a light source enhances the effect of a bleaching gel. According to the literature, regarding the results obtained with the ZOOM 2 light source, it was proven that the effect of the 20% hydrogen peroxide gel was improved by 26% when used in conjunction with the ZOOM 2 light source (6, 10).

Although the treatment with ZOOM 2 light source showed a colorimetric sum value closer to the one obtained prior to immersion in the tea when compared with Beyond, it is also necessary to take into account the time in which the pastilles were treated. Total treatment time with the ZOOM 2 light source was 45 minutes, while the total treatment time with Beyond was 24 minutes, almost half of the recommended ZOOM 2 treatment time. The reason for a shorter treatment may be the higher concentrations of hydrogen peroxide gel which is 35% for Beyond, and 25% for ZOOM 2. Given that the type and concentration of the gel and pre-treatment time were determined by the manufacturer, they could not be

o istraživanjima za izvor svjetlosti Beyond, kao ni usporedba učinka ZOOM-a 2 i Beyonda, dobivene rezultate nije bilo moguće usporediti s rezultatima drugih autora.

Dosad su se za izbjeljivanje zuba uporabljali infracrveni, LED/diodni, argonski i CO_2 laseri (7). U ovom istraživanju primijenjen je femtosekundni laser uz 30-postotni gel karbamid-peroksida pri valnoj duljini od 780 nm, umjesto idealnih 511 nm kada se postiže najveća apsorpcija primijenjenoga gela. Iako femtosekundni laser naizgled daje slabije rezultate u odnosu prema drugim ispitanim postupcima izbjeljivanja, treba uz valnu duljinu uzeti u obzir i druge parametre, kao što su vrsta i koncentracija gela te duljina tretmana. Laserska zraka koja je djelovala na pastilu nije pokrila cijelu njezinu površinu, nego je bila nešto uža jer se trebala postići veća snaga lasera, što je također moglo utjecati na konačni rezultat.

Usporedimo li rezultate izbjeljivanja 30-postotnim gelom karbamid-peroksida te istoga gela uz primjenu femtosekundnog lasera kao izvora svjetlosti, moramo uzeti u obzir ukupno vrijeme izloženosti pastila koje je kod gela bilo 150 minuta, a kod femtosekundnog lasera 10 minuta.

U odnosu na rezultate dobivene izvorima svjetlosti ZOOM 2 i Beyond, učinak femtosekundnog lasera bio je slabiji. No, potrebno je istaknuti vrstu primijenjenoga gela, njegovu koncentraciju i vrijeme ekspozicije pastila. Gel primijenjen kod izvora svjetlosti ZOOM 2 bio je 25-postotni vodikov peroksid, kod Beyonda 35-postotni vodikov peroksid, a kod lasera 30-postotni karbamid-peroksid. Premda su koncentracije gelova bile približno iste, ± 5 %, poznato je da gel karbamid-peroksida ima tri puta slabiji učinak od vodikova peroksida iste koncentracije. Vrijeme kojemu su pastile bile izložene pri izbjeljivanju ZOOM-om 2 iznosi 45 minuta, Beyondom 24 minute, a kod femtosekundnog lasera samo 10 minuta.

Na kraju, uzme li se u obzir prilagodba valne duljine, tri puta slabija koncentracija gela i 2,4 do 15 puta kraće vrijeme tretmana u odnosu prema drugim postupcima, smatramo da se rezultati dobiveni laserom ne mogu zanemariti.

Kako u dostupnoj literaturi nema podataka o primjeni toga lasera u stomatologiji i njegovu učinku u postupcima izbjeljivanja zuba, potrebna su daljnja istraživanja djelovanja femtosekundnog lasera u izbjeljivanju zuba, uz primjenu različitih valnih duljina te različitih vrsta i koncentracija gelova i trajanja tretmana. Također treba razmotriti i temperaturu lasera tijekom postupka izbjeljivanja (14).

changed. Since the aim of this study was to compare different teeth whitening procedures without changing the parameters predefined by the manufacturer, we are uncertain as to which is the more effective of these two whitening methods. In order to investigate this, further research is required using the same parameters such as gel concentration and exposure time. Since the available literature did not reveal any research information on the Beyond product, or any comparison of the effect of ZOOM 2 and Beyond light sources, it was not possible to compare our results with the results of other authors.

So far, tooth whitening procedures have involved infrared LED, argon and CO_2 lasers (7). In this research we investigated the effect of use of a femtosecond laser as a bleaching method at a wavelength of 780 nm in conjunction with a 30% carbamide peroxide gel instead of the ideal 511 nm wavelength at which the peak absorption of the applied gel is usually achieved. Although the femtosecond laser apparently gave poorer results in comparison with other tooth whitening procedures tested, the wavelength should be taken into account along with the other parameters, such as the gel type and the concentration, as well as treatment duration. Also, the laser beam did not cover the entire surface of the pastille due to the adjustment in the wavelength performed in order to increase its intensity, and this could have also affected the final result.

If we compare the results of the 30% carbamide peroxide gel tooth whitening procedure with the procedure using the same gel in conjunction with the femtosecond laser light source, we must take into consideration that the total time of exposure to gel was 150 minutes, whereas the total exposure time to the femtosecond laser was only 10 minutes.

Upon comparison of the results obtained with both the ZOOM 2 and Beyond light sources, the effect of the femtosecond laser was weaker. However, it is necessary to draw attention to the difference in the gel types, concentrations and treatment duration. The gel recommended for use with the ZOOM 2 light source was 25% hydrogen peroxide, the gel provided with Beyond was 35% hydrogen peroxide, and the gel meant for use in conjunction with the femtosecond laser was 30% carbamide peroxide. Although the concentrations of gels were approximately the same (± 5%), it is known that the effect of carbamide peroxide gel is 3 times weaker than the same concentration of hydrogen peroxide gel. Also, the treatment duration was 45 minutes for the ZOOM 2 light source, 24 minutes for Beyond, and only 10 minutes for the femtosecond laser.

Finally, the results obtained using the femtosecond laser should be regarded in view of not adjusted wavelength, three times weaker gel concentration and the short total exposure time, which was 2.4 to 15 times shorter than the exposure times involved with the other procedures tested.

Since the available literature provides no data on the application of these types of lasers in dentistry or their impact on tooth whitening procedures, further studies are required to ascertain the effect of femtosecond lasers on teeth whitening, using different wavelengths, different gel types and concentrations, and different lengths of treatment duration. Also, the heat of the laser device during procedure should be considered (14).

Zaključci

Kolorimetrijskim mjerenjem vrijednosti RGB-indeksa primijenjeni postupci izbjeljivanja pokazali su statistički značajnu razliku. Najbolji rezultati postignuti su 30-postotnim gelom karbamid-peroksida i izvorom svjetlosti ZOOM 2, a slijede Beyond i femtosekundni laser, pri čemu je učinak izbjeljivanja bio proporcionalan trajanju tretmana.

Femtosekundni laser je s obzirom na nedostatke tijekom postupka izbjeljivanja, a to su nedostatna valna duljina, razmjerno kratko vrijeme ekspozicije i niska koncentracija gela, pokazao vrlo dobre rezultate. Potrebna su daljnja istraživanja učinka zračenja femtosekundnog lasera rabljenih u ovom istraživanju kako bi se dokazao mogući superiorni učinak u odnosu prema drugim postupcima izbjeljivanja. U odgovarajućim uvjetima femtosekundni laser mogao bi se primijeniti i u stomatologiji za izbjeljivanje zuba.

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Conclusion

Using colorimetric determination of the RGB index, statistically significant differences were found among the whitening procedures tested. The best results were obtained using a 30% carbamide peroxide gel and ZOOM 2 light source, followed by the Beyond light source and finally, the femtosecond laser, whereby the bleaching effect was proportional to the duration of the treatment.

Despite the deficiencies in the laser parameters during procedures, such as the lack of appropriate wavelength, the relatively short exposure time and the low gel concentration used in conjunction with it, the femtosecond laser has demonstrated very good results. Femtosecond laser illumination used in the present investigation should be further studied in order to demonstrate its possible superior contribution to tooth whitening. By applying the appropriate conditions, the femtosecond laser could prove to be useful in the field of dentistry when applied in tooth whitening procedures.

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Abstract

Objective: To study the efficiency of four different tooth whitening procedures we examined 30% carbamide peroxide gel alone and compared it with two available in-office whitening methods (Discus Dental, Culver City, CA, USA and Beyond Technology Corp, Santa Clara, CA, USA) and a procedure involving a femtosecond laser which consists of a 6W green laser pump (Millennium, Spectra Physics) and a mode-locked laser (Tsunami, Spectra Physics) which have not been clinically tested so far. **Material and Methods:** 40 pastilles of hydroxylapatite were used and immersed in green tea for 8 hours. After drying, pastilles were randomly divided into 4 groups, each consisting of 10 pastilles and treated with one of the 4 bleaching procedures. The color of pastilles was determined by the colorimeter in the RGB index prior to immersion into the tea, after the immersion and after the whitening treatment. Non-parametric tests were used for the analysis of colorimetric sum values - Kruskal-Wallis and Mann-Whitney test for independent samples and Wilcoxon test for dependent samples. **Results:** The colorimetric sum value for the pastilles treated with the gel only was 3024.42, for the pastilles treated with ZOOM 2 it was 2999.74, for the pastilles treated with Beyond it was 2944.12 and for the laser-treated pastilles it was 2687.22. The best results were obtained using the 30% carbamide peroxide gel and ZOOM2, followed by Beyond and the femtosecond laser method, which exhibited a whitening effect proportional to treatment duration and gel concentration. **Conclusion:** Although all four bleaching methods proved effective, the final result of bleaching depends upon the duration of treatment and the type and concentration of the gel applied.

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Address for correspondence
Zrinka Tarle DMD, PhD, professor
University of Zagreb
School of Dental Medicine,
Zagreb, Gundulićeva 5
tarle@sfzg.hr

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