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Intenzitet svjetlosti polimerizacijskih uređaja u ordinacijama dentalne medicine u Zagrebu, Hrvatska

Light Intensity of Curing Units in Dental Offices in Zagreb, Croatia

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Sažetak

Svrha rada: Svjetlosni polimerizacijski uređaj osnovni je dio svake ordinacije dentalne medicine. Tijekom godina njihov intenzitet svjetlosti postupno opada i to može rezultirati nedostatnom polimerizacijom materijala, što se klinički ne može detektirati odmah nakon osvjetljavanja. Svrha ovog istraživanja bila je ispitati zadovoljava li intenzitet svjetlosti polimerizacijskih uređaja u zagrebačkim ordinacijama dentalne medicine minimalne operativne uvjete. **Materijali i postupci:** Intenzitet svjetlosti 111 ispitanih polimerizacijskih uređaja bio je izmjeren radiometrom (Bluephase® meter, Ivoclar Vivadent, Schaan, Liechtenstein). Za svaki je obavljeno šest mjerenja – tri na početku osvjetljavanja i tri od 35 do 40 sekundi nakon početka iluminacije. Također su zabilježeni podaci o vrsti uređaja, starosti, učestalosti korištenja i ima li ugrađen radiometar. **Rezultati:** Intenzitet svjetlosti niži od 300 mW/cm^2 imalo je 34 posto polimerizacijskih uređaja, a njih 44 posto niži od 400 mW/cm^2. Prosječna jakost svjetlosti preostalih uređaja bila je 675,3 mW/cm^2. Polimerizacijski uređaji u Zagrebu koji su bili uključeni u ovo istraživanje bili su u prosjeku korišteni pet godina. **Zaključak:** Iako prosječan intenzitet svjetlosti polimerizacijskih uređaja u Zagrebu ispunjava opće zahtjeve za učinkovitu polimerizaciju kompozitnih smolastih materijala, činjenica da je jakost više od trećine uređaja nedovoljna treba upozoriti stomatologe da moraju redovito kontrolirati uređaje.

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Uvod

Restauracije u boji zuba ubrajaju se u osnovne estetske zahtjeve, a to za većinu doktora dentalne medicine znači upotrebu kompozitnih materijala. Visok stupanj polimerizacije nužan je za postizanje optimalnih fizičkih svojstava i kompatibilnost s biološkim strukturama. Nepolimerizirane metakrilatne skupine, koje mogu zaostati u dubokim dijelovima loše polimeriziranih kompozitnih ispuna, ne samo da predstavljaju citotoksični i genotoksični rizik (1-3), nego njihova topljivost može potaknuti nastanak šupljina i sekundarnog karijesa (1, 4-6). Polimerizacija kompozitnih materijala ovisi o mnogobrojnim unutarnjim čimbenicima, tako osim sastava organske matrice (7) oni uključuju i vrstu fotoinicijatora (8), nijansu i stupanj translucencije materijala (9).

Na stupanj polimerizacije svjetlosno stvrdnjavajućih materijala, osim svojstva materijala, znatno utječu i svjetlosno polimerizacijski uređaji (SPU). Polimerizacijski uređaj nužni je dio opreme svake ordinacije dentalne medicine. U nedavno provedenom istraživanju u kojem se evaluirala učinkovitost halogenih polimerizacijskih uređaja u Torontu, istaknuto je da je čak 78 posto ordinacija koje su sudje-

Introduction

Tooth colored restorations are among primary dental esthetic demands, which, for most dentists, means the use of composite materials for their patients. A high degree of composite polymerization is essential for the optimal physical properties and the compatibility with biological structures. Not only do the residual unconverted methacrylate groups which may remain in lower parts of poorly polymerized composite fillings present a cytotoxic and genotoxic risk (1-3), but also their solubility might cause the formation of cavities and the occurrence of secondary caries (1, 4-6). The polymerization of composite materials depends on many intrinsic factors. Apart from the composition of organic matrix (7), these involve the type of the photoinitiator (8), shade and the degree of translucency of the material (9).

Together with the material characteristics, the degree of polymerization of light cured composites is significantly influenced by light curing units (LCU). A light curing unit is an unavoidable part of dental equipment in every dental office. A recent study evaluating the efficacy of halogen photopolymerization units in Toronto states that 78%

lovale u istraživanju imalo više od jedne polimerizacijske svjetiljke (10). Od prve pojave svjetlosno polimerizirajućih kompozita, u upotrebi su različiti SPU-i – od onih kvarc-tungsten-halogenih (QTH) i plazme, do današnjih visoko sjajnih svjetlećih dioda (engl. „light emmiting diode"; LED) te laserskih polimerizacijskih uređaja. QTH-svjetiljke imaju halogenu žarulju koja emitira bijelo svjetlo koje se zatim filtrira kako bi postalo plavo u valnim duljinama od 350 do 520 nm. Razmjerno su jeftine i još u širokoj uporabi. Polimerizacijski uređaji na temelju LED-tehnologije imaju maksimalnu valnu duljinu od 455 do 480 nm. To su lagani, bežični i prijenosni aparati s većom trajnošću i stvaraju manje topline (11).

Intenzitet svjetlosti, izlazni spektar svjetlosnog izvora i način polimerizacije najvažnije su značajke učinkovitosti SPU-a (12). Izlazni spektar većine tih uređaja prilagođen je najčešće korištenom fotoinicijatoru – kamforkinonu koji ima najvišu apsorpciju oko 468 nm. Drugi fotoinicijatori, kao što su fenilpropandion i lucirin TPO, koji se često upotrebljavaju u jako svijetlim nijansama nekih smolastih materijala, aktiviraju se apsorpcijom svjetla u ultraljubičastom spektralnom području (380 do 430 nm). Takvi materijali zahtijevaju i posebno prilagođene polimerizacijske uređaje. Različiti SPU-i imaju dostupne razne načine polimerizacije. Većina se temelji na promjenama intenziteta svjetlosti tijekom postupka, kako bi se smanjili negativni učinci polimerizacijskog skupljanja koje je izrazito povezano s visokim stupnjem polimerizacije (13-15). Najvažnije varijable koje utječu na stupanj polimerizacije smolastih kompozitnih materijala su gustoća svjetlosne energije (16-18) i trajanje ekspozicije svjetlosti (19).

«Intenzitet svjetlosti», odnosno površinska gustoća elektromagnetskog zračenja, pojam je koji se upotrebljava u radiometriji za snagu elektromagnetskog zračenja po površini. Dostupna literatura nedosljedna je u vezi s pitanjem minimalnog operativnog intenziteta svjetlosti SPU-a. U mnogobrojnim istraživanjima rabila su se 233 mW/cm^2 kao minimum, prema preporuci Rueggeberga i suradnika (20). No, u tom radu preporučuje se vrijeme ekspozicije od 60 sekundi, koristeći se polimerizacijskim izvorima svjetlosti od najmanje 400 mW/cm^2 ako debljina sloja materijala ne prelazi dva milimetra. Te tvrdnje podupiru rezultati Yapa i Seneviratna, koji tvrde da je ekspozicija od 500 mW/cm^2 tijekom 30 sekundi dostatna za optimalnu polimerizaciju (21). Internacionalna organizacija za standardizaciju (ISO) preporučuje minimalni intenzitet svjetlosti od 300 mW/cm^2 u valnom području od 400 do 515 nm, na vrhu svjetlosnog nastavka uređaja za polimerizaciju (22).

Intenzitet SPU-a može se mjeriti direktno radiometrom (RM-om), uređajem za mjerenje fluksa elektromagnetskog zračenja. Osim nekih preciznih fizikalnih instrumenata za mjerenje intenziteta svjetlosti, postoje i stomatološki radiometri koji mogu biti zasebni uređaji ili ugrađeni u SPU. Njihova pouzdanost nekoliko je puta bila dovedena u pitanje (23, 24). Indirektno, učinkovitost SPU-a može se ustanoviti testiranjem kakvoće materijala nakon polimerizacije, određivanjem stupnja polimerizacije kompozitnih materijala različitim spektroskopskim metodama (25, 26), testom struganja (27), testom mikrotvrdoće (28) i ostalim (9).

of dental offices participating in the study had more than one light curing unit (10). Since the first introduction of light curing composite resins, various LCUs have been in use, from quartz tungsten halogen (QTH), plasma arc to today's light emitting diode (LED) and laser curing units. Quartz tungsten halogen curing units have a halogen light bulb which emits the white light which is than filtered and the output is the blue light with wavelengths from 350-520 nm. They are relatively low-cost and still widely used. Curing units based on LED technology have the peak wavelength in range from 455-480 nm. They are lightweight, cordless and portable, have a longer life span and generate less heat (11).

The light intensity, spectral output of the light source and the curing mode are the most important features associated with the effectiveness of LCUs (12). The spectral range of most LCUs is adjusted to the most commonly used photoinitiator, camphorquinone, which has the peak absorbance at around 468 nm. However, another two photoinitiators phenylpropanedione and lucirin TPO, mostly used in "bleach" shades of some resin materials, are activated by absorption of light in UV part of the spectra (380-430 nm). Most of them are based on variations of the irradiance during curing period in order to minimize negative effects of polymerization contraction, which is strongly associated with a high degree of composite polymerization (13-15). Also, some of the most important variables governing the degree of conversion of composite resin materials are the light energy density (16-18) and the duration of light exposure (19).

Irradiance is the radiometry term for the power per unit area of electromagnetic radiation at a surface, also known as "light intensity". Various curing modes are available in different LCUs. There has been an inconsistency in literature regarding the minimal operational irradiance of LCUs. A number of studies use 233 mW/cm^2 as minimum, according to the recommendation of Rueggeberg et al. (20). However, the authors point out that routine exposure time periods of 60 seconds are recommended using light-source intensities of at least 400 mW/cm^2, providing that incremental layer thickness does not exceed 2 mm. These findings are supported by the results of Yap and Seneviratne, who claim that 500 mW/cm^2 is enough for optimal cure after 30 seconds of irradiation (21). The International Organization for Standardization (ISO) suggests the minimum intensity of 300 mW/cm^2 in the 400-515 nm wavelength bandwidths at the light curing tip (22).

The intensity of LCU can be measured directly, using so called radiometers (RM), devices for measurement of radiant flux of electromagnetic radiation. Apart from some precise physical instruments used to measure light intensity, there are also dental radiometers, which can be hand-held or integrated in the curing unit. Their reliability has been repeatedly compromised (23, 24). Indirect test of the efficiency of LCUs is the establishment of the quality of the materials after polymerization, such as the determination of the degree of vinyl conversion of composite materials using spectroscopic methods (25, 26), scrape test (27), microhardness test (28) and others (9).

Svrha ovog istraživanja bila je ustanoviti zadovoljava li jakost svjetla polimerizacijskih uređaja u ordinacijama dentalne medicine u Zagrebu minimalne operativne zahtjeve, otkriti distribuciju vrsta polimerizacijskih uređaja u privatnim i državnim ordinacijama te promjenu intenziteta svjetla na početku i kraju polimerizacije. Zadatak istraživanja bio je također usporediti rezultate sadašnjeg istraživanja intenziteta svjetlosti polimerizacijskih uređaja s onim obavljenim u Zagrebu prije 11 godina.

Materijali i postupci

U ovom istraživanju bio je izmjeren intenzitet 111 SPU-a u 22 državne i privatne ordinacije na području grada Zagreba. S liječnicima u ordinacijama dentalne medicine najprije se telefonski razgovaralo te su zamoljeni da dopuste dolazak ispitivačima. Svima je najprije bio objašnjen postupak i svrha ispitivanja, a zatim se obavilo testiranje polimerizacijskih uređaja.

Sva mjerenja obavio je jedan ispitivač. Za svaku polimerizacijsku svjetiljku u ovom istraživanju zabilježeni su podaci o vrsti (halogena, plazma ili LED), proizvođaču, starosti, učestalosti uporabe te ima li ugrađen radiometar. Vrijednosti intenziteta emitiranog svjetla dobivene su uzimanjem prosjeka nakon tri uzastopna mjerenja na početku polimerizacijskog razdoblja i tri u razdoblju od 35 do 40 sekundi nakon početka iluminacije. S obzirom na to da mnoge polimerizacijske svjetiljke mogu raditi na više načina, a da je svrha istraživanja bila dobiti uvid u maksimume intenziteta polimerizacijskih uređaja na području grada Zagreba, jakost svjetlosti uvijek se mjerila u najjačem režimu rada. Ako polimerizacijski uređaj nije imao kao opciju trajanje polimerizacije od 40 sekundi, birao se režim rada koji je, uz najjači mogući intenzitet svjetla, imao i najdulje razdoblje polimerizacije.

Jakost se mjerila metrom Bluephase® (Ivoclar Vivadent, Schaan, Liechtenstein). Površina fiber-optičkog vrha fotopolimerizacijskog uređaja i snaga svjetla određuju se senzorom na radiometru. Intenzitet svjetla izračunava se integriranim mikroprocesorom dijeljenjem snage svjetlosti i površine tubusa polimerizacijskog tijela. Raspon valnih dužina koje je moguće očitati jest od 380 do 520 nm, a raspon intenziteta svjetla od 300 do 2500 mW/cm^2. Mjerenja su obavljena prislanjanjem tubusa na senzor radiometra i zatim su se vrijednosti intenziteta svjetlosti očitavale sa zaslona na početku iluminacije te 35 i 40 sekundi nakon njezina početka.

Točnost radiometra Bluephase® provjerena je paralelnim mjerenjima na 14 polimerizacijskih svjetiljki s integrirajućom kuglom - Ulbrichtovom kuglom (Gigahertz Optik GmbH, Puchheim, Njemačka), preciznim fizikalnim uređajem koji mjeri apsolutnu snagu svjetlosti izraženu u vatima (W). Kako bi se dobile vrijednosti intenziteta polimerizacijske svjetiljke izmjerene integrirajućom kuglom, apsolutna snaga bila je podijeljena s površinom izvora svjetlosti. Uzorak je činilo 14 polimerizacijskih uređaja (Kavo Polylux II, Astralis 7, Bluephase, ESPE Elipar II, ESPE Elipar Trilight i ESPE Elipar Highlight).

The purpose of this study was to examine whether the light intensity of curing units used in dental offices in Zagreb satisfies minimum operational requirements and to investigate the distribution of the types of light curing units in private and public dental offices as well as the change of light intensity at the start and the end of curing period. Also, the aim of this study was to compare the results of the survey on the efficiency of light curing units in Zagreb conducted 11 years ago with the present study.

Materials and methods

In this study, the intensity of 111 different LCUs in 22 public and private dental offices in the area of Zagreb, Croatia was measured. The dental offices were contacted by phone and the dentists were asked for the permission to visit their offices. The procedure and the purpose of the investigation were first explained in each office and the testing of the LCUs followed.

One examiner performed all the measurements. The data about the type of LCU (QTH, plasma-arc or LED), the manufacturer, age, frequency of use and the existence of integrated radiometer were recorded for each LCU. The values of the intensity of emitted light were median values from three consecutive measurements at the beginning of polymerization and three at the period from 35 to 40 sec after the start of irradiation. Considering that many LCUs have more polymerization modes, and that the aim of this study was to get insight in the maximum light intensity of the LCUs in the area of Zagreb, the light intensity was always measured in the strongest mode of operation. If the LCU did not have as option duration of irradiation period of 40 seconds, the regime of work with the longest period of illumination, along with the strongest light intensity was measured.

Bluephase® meter (Ivoclar Vivadent, Schaan, Liechtenstein) was used for measurement of LCU's light intensity. The sensor in the radiometer determines the surface of the fiber optic tip on the polymerization unit as well as its light power. The irradiance is calculated by dividing the light power and the surface of the light guide tip by means of an integrated microprocessor. It is possible to detect the range of wavelengths from 380 to 520 nm and the light intensity from 300 do 2500 mW/cm^2 with it. The measurements were performed by pressing the light guide directly onto the sensor and reading the irradiance values from the screen at the start and at the 35-40 second period of the illumination.

The credibility of the Bluephase® meter was validated by comparative measurements of 14 LCUs using an integrating sphere (Ulbricht's sphere; Gigahertz Optik GmbH, Puchheim, Germany), an accurate device used in physics which measures the total light power, expressed in watts (W). In order to calculate the irradiance of LCU measured with integrating sphere, it was necessary to divide the value of total light power with the surface of the output tip of each light source. The sample consisted of 14 LCUs (Kavo Polylux II, Astralis 7, Bluephase, ESPE Elipar II, ESPE Elipar Trilight and ESPE Elipar Highlight).

Statistička analiza

Usporedba radiometra Bluephase i integrirajuće sfere

Za testiranje normalnosti razdiobe podataka bio je rabljen Shapiro-Wilkov test, a za testiranje homogenosti varijanci Leveneov test. Za usporedbu rezultata mjerenja između radiometra (RM-a) i integrirajuće sfere (IS-a) te između početka i nakon 40 sekundi, upotrijebljen je t-test za zavisne uzorke. Za izračun pouzdanosti mjerenja odabran je intraklasni korelacijski koeficijent. Pogreška mjerenja izračunata je kao drugi korijen reziduala iz tablice ANOVA, prema preporuci Blanda i Altmana (29, 30). Koeficijent varijabilnosti korišten je za usporedbu varijabiliteta pojedinih mjerenja. Svi testovi rađeni su uz razinu značajnosti p<0,05 pomoću statističkog softvera SPSS 10,0 (SPSS Inc., Chicago, IL, SAD).

Glavno istraživanje

Uzorak se sastojao od 72 uređaja. Početni uzorak činilo je 111 SPU-a, no kako je 38 imalo intenzitet svjetlosti manji od 300 mW/cm², apsolutne vrijednosti njihovih intenziteta svjetlosti nisu se mogle utvrditi radiometrom Bluephase®, tako da je otpalo 35 posto uzoraka. Testiranje normalnosti razdiobe podataka obavljeno je Shapiro-Wilkovim testom, a ispitivanje homogenosti varijanci Leveneovim testom. Intenziteti svjetlosti bili su normalno distribuirani i za njihovu analizu rabljene su metode parametarske statistike (t-test i višefaktorska analiza varijance - ANOVA) dok starost svjetiljki nije bila normalno distribuirana te je za njezinu analizu rabljen neparametarski Mann–Whitneyjev U test. Za ispitivanje mogućeg utjecaja starosti svjetiljke kao kovarijance na razlike u intenzitetu svjetla između LED i QTH-svjetiljki, a uzimajući u obzir vrstu ordinacije, postoji li radiometar u uređaju te koristi li se svakodnevno, rabljena je analiza kovarijance (ANCOVA). Logističkom regresijom željela se ustanoviti korelacija između vrste ordinacije, vrste svjetla, postoji li radiometar u uređaju, njegove starosti, svakodnevnog korištenja te intenziteta svjetla na početku i nakon 35 sekundi. Za procjenu statističke značajnosti regresijskih koeficijenata u modelu rabljen je test Likelihood ratio, a prediktorske varijable za multipli logistički regresijski model izabrane su metodom „backward". Omjeri rizika s 95-postotnim intervalima pouzdanosti korišteni su za izražavanje povezanosti između pojedinih varijabli. Za ispitivanje korelacija između pojedinih normalno distribuiranih varijabli rabljena je Pearsonova korelacija, a za one koje nisu bile normalno distribuirane Spearmanova. Procedure trofaktorske analize varijance za ponovljena mjerenja općeg linearnog modela sa Sidakovom korekcijom korištene su za ispitivanje razlika između ponovljenih mjerenja intenziteta svjetlosti na početku i nakon 35 sekundi, uzimajući u obzir učinke termina mjerenja, vrste svjetla i vrste ordinacija. Sfericitet podataka parova varijabli provjeren je Mauchlyjevim testom. Za slučajeve s narušenim sfericitetom korištene su Greenhouse–Geisserove korekcije stupnjeva slobode povezane s F-vrijednosti. Svi testovi rađeni su uz razinu značajnosti p<0,05, pomoću statističkog softvera SPSS 10,0 (SPSS Inc., Chicago, IL, SAD).

Statistical analysis

Comparison of Bluephase® meter and integrating sphere

Shapiro-Wilk test was used for testing of the regularity of data distribution, and for the testing of homogeneity of variance Levene's test. The paired-samples t-test was used eor the comparison of the results of measurements made with radiometer (RM) and integrating sphere (IS) and between start and 40 second values, and for the calculation of reliability of measurements, interclass correlation coefficient was used. Measurement error was calculated as square root of the residual mean square from ANOVA table, according to the recommendation of Bland and Altman (29, 30). The variability of all measurements was compared using the coefficient of variability. All the tests were performed with the significance level of p<0.05 using the statistical software SPSS 10.0 (SPSS Inc., Chicago, IL, USA).

Mean research

The sample consisted of 72 LCUs. The initial sample had 111 LCUs, but since 38 of them had irradiance lower than 300 mW/cm², their absolute irradiance values could not be detected with Bluephase® meter, so the drop-out rate was 35%. For testing of the regularity of data distribution Shapiro-Wilk test was used, and for the testing of homogeneity of variance the Levene test was used. The irradiance values had normal distribution and for their analysis, methods of parametric statistics (t-test and multifactorial anaylsis of variance – ANOVA) were used, while the age of LCUs, which was not normally distributed, was analyzed by non-parametric Mann-Whitney U test. For testing the possible influence of LCUs' age as a covariance on the differences in irradiance of LED and QTH curing units, taking the type of dental office, the existence of built-in radiometer and the everyday use of LCU into the consideration, the data were tested with analysis of covariance (ANCOVA). The correlation between the type of dental office, LCU type, integration of radiometer, everyday usage and the irradiance at the start and after 35 seconds of irradiation was established by logistic regression. Likelihood ratio test estimated the statistical significance of regression coefficients in the model and predictor variables for multiple logistic regression models were chosen by backward method. Risk ratio with 95% confidentiality intervals was used to express the connection between variables. Pearson's correlation was used for testing the correlation between normal distributed variables, and for the ones which were not normally distributed - Spearman's correlation. Procedures of three-factor variance analysis for repeated measurements of general linear model with Sidak's correction were used for testing the differences between repeated measurements of irradiance at the beginning and after 35 seconds, considering the timing of the measurement, the type of light source and the office. All the tests were performed with the significance level of p<0.05 using SPSS 10.0 statistical software (SPSS Inc., Chicago, IL, USA).

Rezultati

Usporedba intenziteta svjetlosti dobivenih radiometrom Bluephase® i integrirajućom sferom

Intraklasni korelacijski koeficijenti pokazali su da je svaki od postupaka mjerenja pouzdan (ICC=0,92-0,98; p<0,001), a pogreška u mjerenju (ME=19,40-38,74) uvijek je bila manja od standardne devijacije (SD=129,39-159,55), odnosno manja od raspršenja podataka za tri mjerenja kod oba mjerna instrumenta i oba vremena očitanja (Tablica 1.). Koeficijent varijabilnosti upućuje na to da najmanje variraju vrijednosti svjetla za lightmeter nakon 40 sekundi (CV=2,84%), a najviše Ulbrichtova kugla na početku (CV=5,45%).

Results

The comparison of the irradiance values obtained by Bluephase® meter and integrating sphere

Intraclass correlation coefficients (Table 1) show that both measurement methods are reliable ICC=0.92-0.98; p<0.001) and that the measurement error (ME=19.40-38.74) is always lower than the standard deviation (SD=129.39-159.55), namely lower than data dispersion in both measurement instruments and timings (Table 1). The coefficient of variability shows that the values of irradiance for radiometer after 40 seconds are the least variable (CV=2.84%), whereas the measurements with Ulbricht's sphere at the start of the measurement are the most variable (CV=5.45%).

Tablica 1. Parametri pouzdanosti mjerenja
Table 1 The parameters of the reliability of measurements.

Mjerenje • Measurement	n	ICC	95% CI	p	ME	CV (%)
RM start	14	0.92	0.8-0.97	<0.001	35.38	5.11
RM 40s	14	0.98	0.94-0.99	<0.001	19.40	2.84
IS start	14	0.92	0.8-0.97	<0.001	38.74	5.45
IS 40 s	14	0.94	0.86-0.98	<0.001	35.48	5.17

Legenda • Legend:
RM – radiometar • radiometer, IS – integrirajuća sfera • integrating sphere, ICC – intraklasni korelacijski koeficijent • intra-class correlation coefficient, CI – interval pouzdanosti • confidence interval, ME – pogreška mjerenja • measurement error, CV – koeficijent varijabilnosti • coefficient of variability

Rezultati mjerenja intenziteta svjetlosti- glavno istraživanje

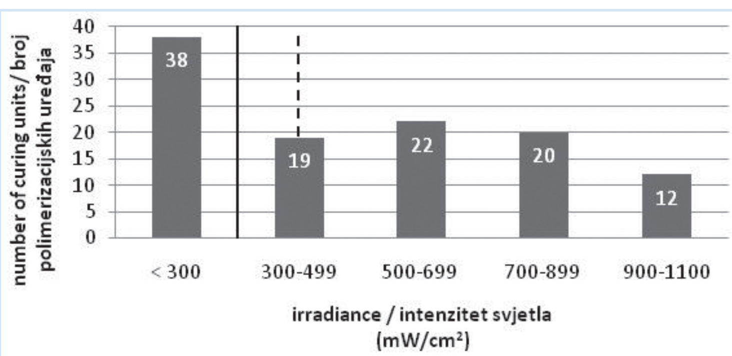
Početni uzorak činilo je 111 SPU-a na području Zagreba i među njima su bila 44 različita modela. Od toga je 49,55 posto bilo LED-uređaja, a 50,45 posto halogenih. U državnim ustanovama (Stomatološki fakultet, Perkovčeva, Dom zdravlja Željezničar, Dom zdravlja Centar) ispitano je 48,65 posto svjetiljki, a u privatnim ordinacijama 51,35 posto. Prosječna starost bila je 5,55 godina. U svakodnevnoj uporabi je 87,38 posto SPU-a. Ugrađeni uređaj za mjerenje intenziteta ima 42,34 posto svjetiljki.

Intenzitet manji od 300 mW/cm^2 imalo je 34 posto (38) svih SPU-a (Slika 1.), pa su izbačeni iz uzorka koji se statistički analizirao (Tablica 2.). Vrijednosti jakosti svjetlosti bile su normalno distribuirane te smo se koristili parametarskom statistikom, a starost uređaja nije pa je za razlike u starosti upotrijebljena neparametarska statistika.

Irradiance data – main research

The initial sample consisted of 111 LCUs in the area of Zagreb, which comprised 44 different models. Out of that number, 49.55% were LED and 50.45% were QTH. In public institutions (School of Dental Medicine Zagreb, Dental Polyclinic Zagreb, Medical Centre Željezničar, Medical Centre Downtown) 48.65% were measured, and in private dental practices 51.35%. The average age of curing units was 5.55 years. 87.38% are used daily. 42.34% of LCUs had integrated radiometers.

34% of all LCUs had irradiance lower than 300mW/cm^2 (Figure 1), so they had to be taken out of the sample which was statistically analyzed (Table 2). Irradiance values were normally distributed, so the parametric statistics was used, but for the age of LCUs, non-parametric statistics was used, since it was not normally distributed.

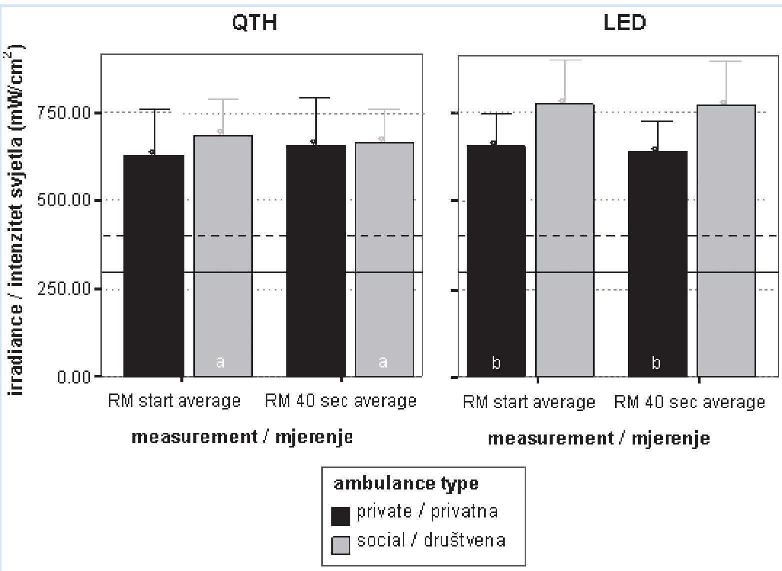


Slika 1. Distribucija polimerizacijskih uređaja prema izmjerenom intenzitetu svjetla –vertikalne crte predstavljaju minimalne operativne intenzitete prema različitim autorima: puna crta – 300 mW/cm^2, ISO standard (22); isprekidana crta – 400 mW/cm^2, prema autorima Yapu i Seneviratnu (21).

Figure 1 The distribution of curing units according to the measured irradiance. Vertical lines determine minimum operational requirements according to different authors: full line - 300 mW/cm^2, an ISO standard (22); dashed line - 400 mW/cm^2, according to Yap and Seneviratne (21).

Tablica 2. Prosječna starost i intenzitet SPU-a s obzirom na vrstu ambulante i vrstu uređaja
Table 2 Average age and irradiance of LCUs, with respect to the dental office and LCU type.

Tip ordinacije • Dental office type	Vrsta svjetla • Light type	N	Starost • Age	Intenzitet start • Start intensity	Intenzitet 40s • Intensity 40s
			Prosjek±SD • Mean±SD	Prosjek±SD • Mean±SD	Prosjek±SD • Mean±SD
Privatna • Private	QTH	11	6.1±2.6	631.2±198.7	658.5±205.6
	LED	24	2.2±1.8	657.1±214.8	637.6±210.5
	Total	35	3.4±2.7	649.0±207.3	644.2±206.2
Društvena • Public	QTH	26	9.4±4.5	690.4±252.2	668.9±240.4
	LED	11	0.8±0.7	777.9±181.0	774.2±185.2
	Total	37	6.8±5.5	716.4±234.3	700.2±228.2
Total	QTH	37	8.4±4.3	672.8±236.4	665.8±227.8
	LED	35	1.8±1.6	695.0±210.0	680.6±210.3
	Total	72	5.2±4.7	683.6±222.7	673.0±218.1



Slika 2. Usporedba intenziteta svjetla s obzirom na tip SPU-a, mjerno vrijeme i vrsta ambulante. Stupci prikazuju prosječne vrijednosti, a brkovi 95 % interval pouzdanosti. Ista slova označavaju skupine među kojima postoje statistički značajne razlike. Horizontalne crte predstavljaju minimalne operativne intenzitete prema različitim autorima: puna crta – 300 mW/cm², ISO standard (22); isprekidana crta – 400 mW/cm², prema autorima Yapu i Seneviratnu (21).
Figure 2 Comparison of irradiance data considering the LCU type, the time of the measurement and dental office type. Columns represent average values and whiskers 95% confidence interval. The same letters indicate groups with statistically significant difference among them. Horizontal lines determine minimum operational requirements according to different authors: full line - 300 mW/cm², an ISO standard (22); dashed line - 400 mW/cm², according to Yap and Seneviratne (21).

Usporedba rezultata intenziteta svjetlosti, ovisno o modelu SPU-a, vremenu mjerenja i vrsti ambulante, prikazana je na Slici 2.

Spearmanova korelacija pokazala je blagu linearnu korelaciju između intenziteta svjetlosti i starosti uređaja.

Trofaktorska ANOVA (Tablica 3.) za ponovljena mjerenja općeg linearnog modela upućuje na to da postoje razlike u kombinaciji vremena mjerenja, vrste SPU-a i vrste ordinacije (p=0,029). Analiza kovarijance (ANCOVA) pokazuje da je znatan utjecaj starosti svjetiljke na prosječne vrijednosti intenziteta svjetla (prosjek vrijednosti na početku i 35 do 40 sekundi od starta) (p<0,001). Starost utječe na razliku u vrsti SPU-a (p=0,042) te između privatnih i državnih am-

Comparison of irradiance data considering the LCU type, the time of the measurement and dental office type is shown in Figure 2.

Spearman's correlation showed a weak linear correlation between irradiance and the age of LCU.

Three-factor ANOVA (Table 3) for repeated measurements of General linear model showed the differences in the combination of the time of measurement, type of LCU and dental office type (p=0.029). The analysis of covariance (ANCOVA) points to the significant influence of the average value of irradiance (average of the data from the measurements at the start and at the 35-40 second period), (p<0.001). The age of LCU had influence on the difference between the

Tablica 3. Rezultati t-testova za razlike u intenzitetu svjetla s obzirom na vrstu svjetla i je li ugrađen radiometar
Table 3 The results of t-tests for differences in irradiance considering the type of curing unit and the existence of integrated radiometer.

		Start average*	40 sec average*	Start/40s#
QTH	privatna / društvena	p=0.485	p=0.790	
LED	privatna / društvena	p=0.092	p=0.078	
private / privatna	QTH / LED	p=0.930	p=0.612	
public / društvena	QTH / LED	p=0.441	p=0.349	
QTH	Start/40s			p=0.548
LED	Start/40s			p=0.002
QTH private/QTH privatna	Start/40s			p=0.518
QTH public/QTH društvena	Start/40s			p<0.001
LED private/LED privatna	Start/40s			p=0.003
LED public/LED društvena	Start/40s			p=0.399

* t-test za neovisne uzorke • independent samples t-test, # t-test za ovisne uzorke • paired samples t-test

bulanti (p=0,032), ali ne i na kombinaciju vrsta svjetla i vrsta ambulanti.

Prvi model logističke regresije pokazao je da se državne ambulante razlikuju od privatnih samo po starosti uređaja i prosječnom intenzitetu njihova svjetla na startu. Državne ambulante imaju 1,3 puta veću mogućnost da u svojoj opremi imaju stariju svjetiljku (95% CI 1,1-1,5; p<0,001) te je njihov startni intenzitet svjetla nešto veći od privatnih (p=0,010), no omjer mogućnosti za ove druge vrlo je mali i jedva prelazi 1. Model logističke regresije opisuje tek 21 posto varijabiliteta (Cox i Snell pseudo r^2=0,214)

Drugi model logističke regresije pokazao je da QTH-SPU-i imaju sedam puta veću mogućnost da budu stariji od LED-uređaja. Mogućnost da će se QTH-svjetiljka pronaći u državnim ambulantama veća je 41 puta nego da će se pronaći u privatnim ordinacijama (95% CI=1,8-931,6; p=0,020). Taj model opisuje gotovo 65 posto varijabiliteta (Cox i Snell pseudo r^2=0,645).

Rasprava

Ispravno funkcioniranje i prikladan intenzitet svjetlosti fotopolimerizacijskih uređaja nužni su za dugotrajnost i biokompatibilnost kompozitnih ispuna. Postupno opadanje jakosti svjetlosti SPU-a tijekom godina može rezultirati slabom polimerizacijom (31). Zato što se površina materijala odmah nakon polimerizacije čini tvrda, klinički nije moguće utvrditi jesu li dublji slojevi ostali nepolimerizirani, pa je potrebno redovito kontrolirati intenzitet svjetlosti uređaja. U ovom radu izmjereni su intenziteti svjetlosti SPU-a u stomatološkim ordinacijama u Zagrebu te zabilježeni podaci o vrsti uređaja i stomatološke ordinacije te starosti uređaja i je li u njega ugrađen radiometar.

Rezultati ovog istraživanja pokazuju da je 34 posto SPU-a imalo intenzitet svjetlosti niži od 300 mW/cm², što je minimalna vrijednost koju preporučuje ISO za ispravnu polimerizaciju kompozitnih smolastih materijala. Kao što je poznato, za stvrdnjavanje gornje plohe kompozitnog sloja dovoljno je samo 20 sekundi polimerizacije s intenzitetom od 200 mW/cm². S druge strane, za isti stupanj polimerizacije dva milimetra ispod površine, potrebno je 120 sekundi iluminacije s intenzitetom od 300 mW/cm². Isto istraživanje sugerira da se učinkovita polimerizacija na dnu kaviteta kroz

LCU type (p=0.042) and the dental office type (p=0.032), but did not influence the combination of the LCU type and the type of dental office.

The first model of logistic regression shows that public dental practices are different from private practices only by the age and the average irradiance of LCUs. Public dental practices have 1.3 times higher chance to have an older LCU (95% CI 1.1-1.5; p<0.001), which also have higher start irradiance than LCUs in private practices, but odds ratio is very small and hardly exceeds 1. The logistic regression model describes only 21% of the variability (Cox & Snell pseudo r^2=0.214).

The second model of logistic regression shows that QTH LCU have seven times higher chance to be older than LEDs. The chance to find a QTH LCU in public dental practices is 41 times higher than in private practices (95% CI=1.8-931.6; p=0.020). That model describes almost 65% of variability (Cox & Snell pseudo r^2=0.645).

Discussion

Proper functioning and an adequate light intensity of photopolymerization units are necessary for the longevity and biocompatibility of composite fillings. The intensity of light curing units gradually decreases over time and can lead to poor polymerization (31). Immediate clinical detection of inadequate curing is not possible because the material surface seems hardened, so it is necessary to regularly monitor the irradiance of LCUs. We measured the irradiances of the LCUs in dental offices in Zagreb and recorded general data on the type of curing unit, dental office, age and the presence of the integrated radiometer.

The results of this study showed that 34% of LCU had the light intensity below 300 mW/cm², which is the minimum irradiance recommended by the ISO for proper polymerization of composite resin materials. It is known that for the hardening of the upper side of the composite resin, only 20 seconds of polymerization with a device of 200 mW/cm² intensity is sufficient. On the other hand, for the same degree of cure 2 mm under the surface 120 seconds of curing with 300 mW/cm² irradiance is needed. The same study indicates that effective cure at the bottom of the 2 mm layer is achieved after 40 seconds with 400 mW/cm², 30 seconds sloj materijala od dva milimetra postiže tek nakon 40 sekundi s 400 mW/cm^2, nakon 30 sekundi s 500 mW/cm^2 ili 20 sekundi sa 600 mW/cm^2 (21). Te činjenice potrebno je implementirati i u kliničku uporabu. Dakle, čak ako SPU ima nizak intenzitet svjetla (ali nikako niži od 300 mW/cm^2), teoretski je moguće osigurati optimalnu polimerizaciju kroz cijelu debljinu sloja ako se dovoljno dugo iluminira. No, u vezi s razumnim vremenom polimerizacije svakoga kompozitnog sloja, mogli bismo zaključiti da 400 mW/cm^2 treba uzeti kao minimum. Kada bismo tu vrijednost uzeli kao graničnu, tada bi u našem uzorku 43 posto fotopolimerizacijskih uređaja bilo preslabo za učinkovitu polimerizaciju.

Prije jedanaest godina u Zagrebu je bilo provedeno slično istraživanje u kojem su se također ispitivali intenziteti svjetlosti SPU-a. Tada je zaključeno da 44 posto polimerizacijskih uređaja ima intenzitet manji od 233 mW/cm^2. Svi SPU-i u uzorku bili su QTH, te je uočeno da jakost svjetlosti nekih uređaja opada na vrijednosti niže od 233 mW/cm^2 (32). Ako uzmemo u obzir današnje spoznaje, jasno je da bi broj neučinkovitih SPU-a bio čak i veći. Kada ga usporedimo s ovim istraživanjem, jasno je da se na području Zagreba proteklih 11 godina poboljšala kvaliteta fotopolimerizacijskih uređaja. Kada se obavljalo ovo istraživanje, 38 posto SPU-a imalo je intenzitet svjetlosti manji od 300 mW/cm^2, što je manje od 44 posto neučinkovitih SPU-a prije 11 godina, s pragom od 233 mW/cm^2. Ovo istraživanje na podupire rezultate tadašnje studije da se intenzitet svjetlosti smanjuje prema kraju polimerizacijskog razdoblja od 40 sekundi. Distribucija modela SPU-a također se znatno promijenila. U sadašnjem istraživanju zabilježen je gotovo jednak postotak QTH i LED-uređaja, a prije su sve svjetiljke bile halogene.

Studije u kojima se proučavao intenzitet svjetla polimerizacijskih uređaja provedene su također u Kanadi (10), Izraelu (4), Japanu (33), Australiji (34) i Njemačkoj (35). Kanadska studija iz 2005. pokazala je da 30 posto uređaja ima intenzitet niži od 400 mW/cm^2 (10), a u Australiji je 1998. godine 52 posto SPU-a bilo neučinkovito u istim uvjetima (34). Pilo i suradnici uzeli su 1999. kao limit od 200 mW/cm^2 te objavili da je 33 posto SPU-a u Tel Avivu imalo očitanje niže od navedene vrijednosti (4). Miyazaki i kolege su 1998. uzeli najviši prag – 42 posto uređaja imalo je intenzitet svjetlosti niži od 500 mW/cm^2 (33). Za razliku od ovoga, sva druga navedena istraživanja imala su uzorak koji se sastojao samo od QTH-uređaja. Studije provedene u drugim zemljama uzimale su različite vrijednosti za minimalni operativni intenzitet svjetlosti. Prema tome teško je uspoređivati rezultate, iako se tijekom godina može vidjeti općeniti napredak. Osim ovog istraživanja, njemačka studija iz 2006. bila je jedina koja je testirala i LED-uređaje, iako su činili manji dio uzorka. Intenzitet manji od 400 mW/cm^2 imalo je 26 posto uređaja i to je najbolji rezultat među navedenim istraživanjima (35).

Kako je točnost radiometara u prošlosti bila dovedena u pitanje (23), preciznost radiometra Bluephase® uspoređena je s integrirajućom sferom te je utvrđeno da su oba postupka pouzdana. Prednost korištenog mjerača intenziteta svjetlosti jest u tome što može mjeriti polimerizacijske uređaje s različitim promjerima svjetlosnih izvoda. Ipak, to što se ne mogu očitati vrijednosti manje od 300 mW/cm^2 može stvarati po-

with 500 mW/cm^2 or 20 seconds with 600 mW/cm^2 (21). Therefore, it is necessary to apply these facts in clinical use. Even if the LCU has low irradiance (but not lower than 300 mW/cm^2), it is theoretically possible to ensure the optimal cure of the composite resin material throughout its depth if sufficient irradiation time is invested. In terms of reasonable time used for polymerization of each composite increment, we might conclude that 400 mW/cm^2 should be taken as a minimum. With this new value set as threshold, 43% of the photopolymerization units in the sample are not able to cure effectively.

Eleven years ago, similar survey was also conducted in Zagreb in order to determine the effectiveness of LCUs in dental practices. It was concluded that 44% of curing devices had the irradiance lower than 233 mW/cm^2. All tested LCUs were QTH and it was observed that the irradiance of some LCUs decreased after 40 seconds to the values below 233 mW/cm^2 (32). With current knowledge, we might presume that the number of inefficient LCUs at that time would have been even higher. When compared to the present study, it is evident that the quality of curing units in the area of Zagreb has improved over 11 years period. At the time of conducting the current study, 38% of LCUs had the irradiance lower than 300 mW/cm^2, which is lower than 44% of inadequate curing units 11 years ago, although with the lower threshold of 233 mW/cm^2. This study does not support the findings of the previous study that the light intensity of LCUs decreases towards the end of polymerization period of 40 seconds. Also, the distribution of the type of LCUs has significantly changed. Almost equal numbers of QTH and LED units were recorded in this study, while in the previous study all the LCUs were halogen.

The measurement of light intensity of curing units in dental offices was conducted in Canada (10), Israel (4), Japan (33), Australia (34) and Germany (35). The 2005 Canadian study reported 30% of units with intensities lower than 400 mW/cm^2 (10), while in an 1998 Australian study, 52% of LCUs were ineffective under the same conditions (34). In 1999, Pilo et al. chose a limit of 200 mW/cm^2 and reported that 33% of LCUs in Tel Aviv had a reading below that value (4). Miyazaki et al. (1998) took the highest threshold; 42% of units had irradiance lower than 500 mW/cm^2 (33). In contrast to the present study, the sample of all of them consisted only of QTH units. These studies conducted in other countries also chose different standards as a minimum operational irradiance. Hence, it is very difficult to compare the results, but an overall improvement over the time can be seen. Apart from the present investigation, a German study from 2006 was the only one which also tested the LED LCUs, although they took a smaller part of the sample. The amount of LCU below 400 mW/cm^2 was 26%, which is the best result among these studies (35).

Since the credibility of the radiometers has been brought into question in the past (23), the accuracy of the Bluephase® meter has been compared with the integrating sphere and it was shown that both devices were reliable. The advantage of used radiometer was that it allowed the measurements of curing units with various tube diameters. However, the lack teškoće u znanstvenim istraživanjima, iako u kliničkom radu može biti od velike pomoći.

U ovom istraživanju nije pronađena statistički značajna razlika između vrijednosti intenziteta svjetlosti u privatnim i državnim ordinacijama, ni između LED i QTH-uređaja. Što se tiče starosti SPU-a, državne ordinacije imale su u našem uzorku općenito starije uređaje nego privatne. Točnije, starije QTH-svjetiljke bile su dominantne u državnim ordinacijama, ali također i noviji LED-SPU-i. Privatne ordinacije imale su razmjerno malo novijih QTH-uređaja, a LED-SPU-i bili su stariji nego u državnima. Možemo pretpostaviti da je razlog težnja stomatologa u privatnim ordinacijama da slijede trenutačni tehnološki napredak, tako da su oni prvi kupovali LED-uređaje čim su se pojavili na tržištu.

Statistički značajan pad u vrijednostima intenziteta svjetlosti na kraju često korištenog vremena iluminacije od 40 sekundi, uočen je kod uporabe LED- fotopolimerizacijskih uređaja. Daljnja analiza podataka pokazala je da se pad odnosi na LED-uređaje u privatnim ordinacijama i na QTH u državnima. Moguće objašnjenje za to moglo bi biti u činjenici da su LED-uređaji u državnim i QTH-uređaji u privatnim ordinacijama noviji, pa zato i bolje funkcioniraju. Tu bi pretpostavku u budućim studijama trebalo detaljnije istražiti.

Zaključci

U uvjetima provedenog istraživanja:

34 posto pregledanih fotopolimerizacijskih uređaja imalo je intenzitet svjetlosti niži od 300 mW/cm^2 i 44 posto niži od 400 mW/cm^2, što je u skladu sa sličnim istraživanjima obavljenima u drugim zemljama; Uspoređujući podatke s rezultatima studije provedene prije 11 godina u Zagrebu, manji je postotak fotopolimerizacijskih uređaja neprikladnih za učinkovitu polimerizaciju; Gotovo jednak broj LED i halogenih uređaja upućuje na to da je tehnološki napredak u području svjetlosne polimerizacije stigao i u stomatološke ordinacije; Doktorima dentalne medicine preporučuje se da redovito provjeravaju intenzitet svjetlosti svojih fotopolimerizacijskih uređaja.

Zahvale

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of precise readings for irradiation values below 300 mW/cm^2 causes difficulties in scientific work although it may be a very useful tool in dental offices.

In this study, no statistical difference was observed between the irradiance values of LCUs in private and public dental offices, nor between LED and QTH LCUs. Regarding the age of LCUs, public practices generally had older devices than private practices. Older QTH devices are predominant in public practices, but the newest LED units as well. Private practices have relatively newer QTH units and the LEDs are older than in public practices. We might presume that the reason is the effort of the dentists in private practices to keep up with current advances in technology and that is why they were the first to purchase LED LCUs when they appeared on the market.

The statistically significant drop in the irradiance values at the end of the usual irradiation period, 40 seconds, is observed in LED curing units in the sample. More specifically, the drop was observed in LED devices in private practices and in QTH units in public practices. One possible explanation of this phenomenon might be the fact that LED units in public dental offices and the QTH units in private practices are newer. However, this presumption should be further investigated in future studies.

Conclusions

Under the conditions of the current study:

34% of examined curing units had the light intensity lower than 300 mW/cm^2 and 44% of them lower than 400 mW/cm^2, which is in range with the studies conducted in other countries; When compared to the previous study conducted 11 years ago in Zagreb, Croatia, the percentage of curing units inadequate for effective polymerization has decreased; Almost equal numbers of LED and QTH units suggest that the technological advances in the field of light polymerization have arrived in dental practices; It is recommended that dentists should regularly monitor the light intensity of photopolymerizaction devices.

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Abstract

Objective: Photopolymerization unit is an essential part of every dental office. The intensity of light curing units gradually decreases with time and can lead to poor polymerization, which cannot be detected clinically immediately after illumination. The purpose of this study was to examine whether the intensity of light curing units in dental offices in Zagreb satisfies minimum operational requirements. **Materials and methods**: The light intensity of 111 curing units was measured using radiometer (Bluephase® meter, Ivoclar Vivadent, Schaan, Liechtenstein). Six measurements were taken for each unit, three at the beginning of illumination and the other three at 35-40 seconds from the beginning. Data were also collected about the type of curing unit, manufacturer, age, frequency of use and the existence of integrated radiometer. **Results**: Light intensity lower than 300 mW/cm² had 34% of curing units and 44% lower than 400 mW/cm². The average light intensity of the remaining curing units was 675.3 mW/cm². This study included photopolymerization units used in Zagreb which were five years old on average. **Conclusion**: Though the average light intensity of curing units in Zagreb fulfill the general requirements for efficient polymerization of composite resin materials, the fact that more than one third of curing units are ineffective should alert dentists to regularly monitor their appliances.

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Key words
Curing Lights, Dental; Polymerization; Photoinitiators, Dental; Light-Curing Dental Adhesives; Composite Dental Resins

References

1. Santerre JP, Shajii L, Leung BW. Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products. Crit Rev Oral Biol Med. 2001;12(2):136-51.
2. Goldberg M. In vitro and in vivo studies on the toxicity of dental resin components: a review. Clin Oral Investig. 2008;12(1):1-8.
3. Knezevic A, Zeljezic D, Kopjar N, Tarle Z. Influence of curing mode intensities on cell culture cytotoxicity/genotoxicity. Am J Dent. 2009;22(1):43-8.
4. Pilo R, Oelgiesser D, Cardash HS. A survey of output intensity and potential for depth of cure among light-curing units in clinical use. J Dent. 1999;27(3):235-41.
5. Matošević D, Tarle Z, Miljanić S, Meić Z, Pichler L, Pichler G. Laser induced fluorescence of carious lesion porphyrins. Acta Stomatol Croat. 2010;44(2):82-9.
6. Matošević D, Tarle Z, Miljanić S, Meić Z, Pichler L, Pichler G. The detection of carious lesion porphyrins using violet laser induced fluorescence. Acta Stomatol Croat. 2010;44(4):232-40.
7. Peutzfeldt A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci. 1997;105(2):97-116.
8. Pfeifer CS, Ferracane JL, Sakaguchi RL, Braga RR. Photoinitiator content in restorative composites: influence on degree of conversion, reaction kinetics, volumetric shrinkage and polymerization stress. Am J Dent. 2009;22(4):206-10.
9. Antonson SA, Antonson DE, Hardigan PC. Should my new curing light be an LED? Oper Dent. 2008;33(4):400-7.
10. El-Mowafy O, El-Badrawy W, Lewis DW, Shokati B, Soliman O, Kermalli J, et al. Efficacy of halogen photopolymerization units in private dental offices in Toronto. J Can Dent Assoc. 2005;71(8):587.
11. Knezevic A, Tarle Z, Meniga A, Sutalo J, Pichler G, Ristic M. Degree of conversion and temperature rise during polymerization of composite resin samples with blue diodes. J Oral Rehabil. 2001;28(6):586-91.
12. Rahiotis C, Kakaboura A, Loukidis M, Vougiouklakis G. Curing efficiency of various types of light-curing units. Eur J Oral Sci. 2004;112(1):89-94.
13. Knezevic A, Sariri K, Sovic I, Demoli N, Tarle Z. Shrinkage evaluation of composite polymerized with LED units using laser interferometry. Quintessence Int. 2010;41(5):417-25.
14. Jimenez-Planas A, Martin J, Abalos C, Llamas R. Developments in polymerization lamps. Quintessence Int. 2008;39(2):e74-84.
15. Clifford SS, Roman-Alicea K, Tantbirojn D, Versluis A. Shrinkage and hardness of dental composites acquired with different curing light sources. Quintessence Int. 2009;40(3):203-14.
16. Komori PC, de Paula AB, Martin AA, Tango RN, Sinhoreti MA, Correr-Sobrinho L. Effect of light energy density on conversion degree and hardness of dual-cured resin cement. Oper Dent. 2010;35(1):120-4.
17. Baek CJ, Hyun SH, Lee SK, Seol HJ, Kim HI, Kwon YH. The effects of light intensity and light-curing time on the degree of polymerization of dental composite resins. Dent Mater J. 2008;27(4):523-33.
18. Peutzfeldt A, Asmussen E. Resin composite properties and energy density of light cure. J Dent Res. 2005;84(7):659-62.
19. Caughman WF, Rueggeberg FA, Curtis JW, Jr. Clinical guidelines for photocuring restorative resins. J Am Dent Assoc. 1995;126(9):1280-2, 4, 6.
20. Rueggeberg FA, Caughman WF, Curtis JW, Jr. Effect of light intensity and exposure duration on cure of resin composite. Oper Dent. 1994;19(1):26-32.
21. Yap AU, Seneviratne C. Influence of light energy density on effectiveness of composite cure. Oper Dent. 2001;26(5):460-6.
22. International Organization for Standardization. ISO/TS 10650:1999. Dental equipment-powered polymerization activators. Geneva, Switzerland: International Organization for Standardization; 1999.
23. Hansen EK, Asmussen E. Reliability of three dental radiometers. Scand J Dent Res. 1993;101(2):115-9.
24. Rueggeberg FA. Precision of hand-held dental radiometers. Quintessence Int. 1993;24(6):391-6.
25. Tarle Z, Knezevic A, Demoli N, Meniga A, Sutalo J, Unterbrink G, et al. Comparison of composite curing parameters: effects of light source and curing mode on conversion, temperature rise and polymerization shrinkage. Oper Dent. 2006;31(2):219-26.
26. Tarle Z, Meniga A, Knezevic A, Sutalo J, Ristic M, Pichler G. Composite conversion and temperature rise using a conventional, plasma arc, and an experimental blue LED curing unit. J Oral Rehabil. 2002;29(7):662-7.
27. Rueggeberg FA, Cole MA, Looney SW, Vickers A, Swift EJ. Comparison of manufacturer-recommended exposure durations with those determined using biaxial flexure strength and scraped composite thickness among a variety of light-curing units. J Esthet Restor Dent. 2009;21(1):43-61.
28. Rode KM, Kawano Y, Turbino ML. Evaluation of curing light distance on resin composite microhardness and polymerization. Oper Dent. 2007;32(6):571-8.
29. Bland JM, Altman DG. Measurement error. BMJ. 1996;313(7059):744.
30. Bland JM, Altman DG. Measurement error and correlation coefficients. BMJ. 1996;313(7048):41-2.
31. Poulos JG, Styner DL. Curing lights: changes in intensity output with use over time. Gen Dent. 1997;45(1):70-3.
32. Knežević A, Meniga A, Tarle Z, Šutalo J, Pichler G. Measurement of light-curing unit intensity in clinical practice. Acta Stom Croat. 1999;33(1):35-40.
33. Miyazaki M, Hattori T, Ichiishi Y, Kondo M, Onose H, Moore BK. Evaluation of curing units used in private dental offices. Oper Dent. 1998;23(2):50-4.
34. Martin FE. A survey of the efficiency of visible light curing units. J Dent. 1998;26(3):239-43.
35. Ernst CP, Busemann I, Kern T, Willershausen B. Feldtest zur Lichtemissionsleistung von Polymerisationsgeräten in zahnärztlichen Praxen. Dtsch Zahnarztl Z. 2006;61(9):466-71.