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Light-curing units for composite resin polymerization

Jelena Vučetić
University of Belgrade, School of Dental Medicine, Department of Restorative Odontology and Endodontics, Belgrade, Serbia

SUMMARY
Light-curing units for light polymerization of composite resins are important instruments of dental practice, and their proper use has a direct impact on the physical characteristics of the material being illuminated, its biocompatibility, as well as on the overall clinical success and durability of dental composites. Irradiance represents the power of radiation per unit of irradiated surface and should be distinguished from irradiance measured directly at the lamp head, which is called output irradiance or emittance. Also, different areas on the surface of the material can be exposed to different radiation powers, which sometimes significantly deviate from the given average value. The reason for this is the inhomogeneity of the radiation beam. The 3D profile of the light beam gives the most precise information about the quality of radiation to which the material will be exposed. Due to the existence of different photoinitiator systems, the use of devices with a wider emission spectrum that covers a larger range of light wavelengths is often recommended today. An important characteristic of the light-curing unit is its power, but the use of lamps of higher power does not mean a proportional reduction in polymerization time. The quality and maintenance of light sources are certainly one of the important factors that influence the success of restorations.
Keywords: polymerization lamps; irradiance; composite materials; light polymerization

INTRODUCTION

Light-curing units are an important and daily-used equipment part of every dental practice. The quality of the lamp, as well as its proper handling, have a direct impact on the physical characteristics of the curing material, its biocompatibility, and the overall clinical success and durability of dental photopolymer systems (composites, adhesive systems, luting agents, cements). However, numerous studies testify to dentists' lack of information on characteristics of the light-curing units to which they should pay attention when choosing, that is, buying a lamp, as well as to their inappropriate use and maintenance in practice [1, 2, 3]. This can be one of the reasons for the failure of dental restorations.

The goal during light curing is to deliver a sufficient amount of light energy, of a precisely determined wavelength, which is required by the photoinitiator system of the material being cured. In addition, during light curing, it is necessary that all parts of the restoration are irradiated, as well as that all points receive the same amount of energy [4]. The information that manufacturers point out, as well as the information that dentists pay attention to when choosing a lamp, are often not enough to get a realistic insight into the quality of polymerization that can be achieved with a particular lamp.

LIGHT-CURING UNITS – IMPORTANT PARAMETRES

The characteristic that is often put in the foreground is irradiance. Irradiance represents the power of radiation [Watt] per unit area [m^2], but for the requirements of dentistry, we are using mW/cm^2. Therefore, irradiance is inversely proportional to the area on which it is measured. The larger the irradiated surface, the lower the irradiance and vice versa. In other words, irradiance depends on two parameters: the radiant power of the light source and the distance of the curing material. Laboratory data of clinical importance are irradiance values measured at real distances from the light source. This is done in order to simulate clinical conditions as closely as possible.

However, what is problematic is that manufacturers often emphasize a general irradiance value, measured directly next to the light source. Since in this case the measured surface is actually the surface of the lamp head, the irradiance value obtained in this way directly depends on the size of the lamp head and has nothing to do with the real irradiance to which the material will be exposed. If we assume that two lamps with two completely identical sources of radiation, of equal power [W], have heads of different dimensions, it is clear that the irradiance measured on their heads will not be the same. A lamp with a smaller head will have a dramatically higher output irradiance value. That is, a weaker lamp with a smaller head diameter can have the same irradiance value as a much higher power lamp with a larger head, which is needed to cover the entire restoration. In this way, by reducing

Address for correspondence: Jelena VUČETIĆ, Rankeova 4, Beograd, Serbia; *jelenavucetic92@gmail.com*

the diameter of the lamp head, the manufacturer can advertise a lamp with low radiation power as a lamp with high irradiance. In order to avoid confusion, another term should be used for irradiance measured directly at the lamp head – output irradiance or simply emittance. This value, considered in isolation, for the reasons mentioned, is not of clinical significance. It would be more useful to look for data such as radiant power [W], lamp head diameter, and irradiance values from clinically relevant distances per relevant unit area.

It is equally important to keep in mind that irradiance represents only the average value of radiation power per unit area. However, the light source and subsequently the light beam are never homogeneous [5]. Different areas on the surface of the material being cured can be exposed to different radiation power values, which sometimes deviate significantly from the displayed average value. Thus, it can happen that certain regions of the restoration are irradiated with less than 400 mW/cm^2 – the so-called cold zones, and conversely, that certain regions of the restoration are extremely highly irradiated, with as much as 5000 mW/cm^2 – the hot zones. Neither cold nor hot zones are desirable. These are spots where polymerization does not take place in optimal dynamics and completely, although the average value of irradiance for the given surface can be ideal (Figure 1).

For the real insight, finally, we should look for data on the 3D beam profile, which will inform us most precisely about the quality of the radiation to which the material will be exposed [7]. The goal is to find as homogeneous a beam as possible, without the so-called hot and cold zones, with sufficient radiation power, and an adequate emission spectrum, which matches the absorption spectrum of the photoinitiator system in the material.

The minimum radiation value that the composite material should receive is usually around 400 mW/cm^2 [8]. ISO standard 10650/2018 defines the maximum value of output irradiance in the part of the spectrum as 380–515 nm and is 4000 mW/cm^2. Using stronger lamps or long-term light curing without air cooling and making breaks carries the risk of injuring the tissue due to the high temperature that develops during polymerization.

Another interest when choosing a lamp concerns the choice of emission spectrum. One of the big changes in the world of composite materials is the composition of photoinitiator systems. Camphorquinone is still the most commonly used one, with an absorption maximum at around 468 nm – blue light. Because of its intense yellow color, camphorquinone is now almost regularly replaced or supplemented with some of the alternative photoinitiators to achieve brighter shades and improve the polymerization process. These alternative photoinitiators, like Lucirin-TPO, have an absorption maximum in the violet part of the spectrum [9]. Unfortunately, the material composition and precise content of photoinitiator systems is often hidden and protected. For this reason, as well as due to the fact that dentists in their practices usually cure different materials with the same curing unit, the use of light-curing units with two or more emission spectra is recommended (Figure 2).

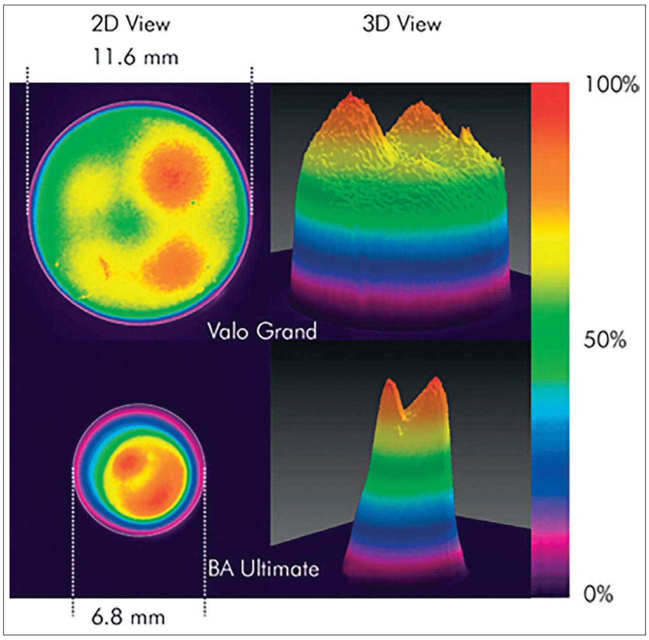

Figure 1. Light beam uniformity from two curing lights, one with a uniform light output (top figures) and one with “hot spots” of very bright light and “cold spots” (bottom figures); source: Rueggeberg et al., 2017 [6]

Slika 1. Analiza homogenosti svetlosnog snopa dve različite lampe, jedne sa uniformnim izvorom zračenja (gornje slike) i jedne sa „vrelim zonama“ veoma jakog svetla i „hladnim zonama“ (donje slike); izvor: Rueggeberg et al., 2017 [6]

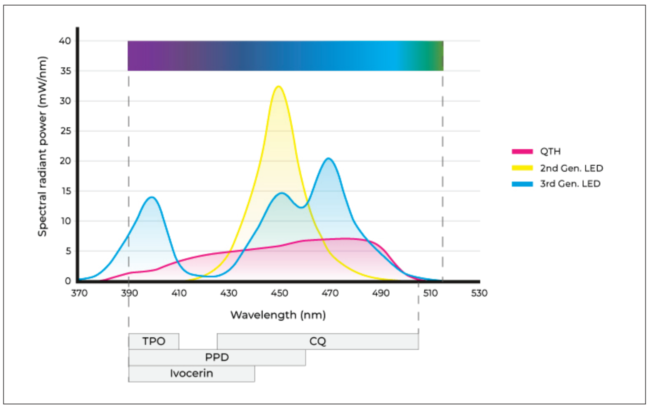

Figure 2. Emission spectra from quartz–tungsten halogen and light-emitting diode (LED) curing lights; the bars underneath show the relationship of the photo-initiators to the light-curing unit spectra; the second-generation LED shown in blue is “monowave” or curing unit with output wavelengths only in one part of the spectrum – blue light; the third-generation LED shown in green is “multiwave” or curing unit with output in two or more parts of the spectrum; source: Hasanin and Nassar, 2021 [10];

QTH – quartz–tungsten halogen; CQ – camphorquinone; TPO – diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide; PPD – phenyl-propanedione

Slika 2. Emisioni spektri iz kvarc-tungsten halogene (QTH) i svetlećih diodnih (LED) lampi za polimerizaciju. Ispod grafika prikazana je veza između fotoinicijatora i emisionih spektara dentalnih lampi. Druga generacija LED označena plavom bojom je „monowave“ ili lampa koja zrači u okviru jednog dela spektra – plavo svetlo. Treća generacija LED označena zelenom bojom je „multiwave“ ili lampa koja zrači u dva ili više dela spektra; izvor: Hasanin, Nassar, 2021 [10];

CQ – kamforhinon, TPO – difenil (2,4,6-trimetilbenzoil) fosfin-oksid; PPD – fenil-propanedion

Lately, there has been a tendency towards shortening the exposure time. However, any use of light-curing units outside the manufacturer's instructions, as well as self-calculated reduction of polymerization time when using curing units of higher radiant power, leads to inadequate polymerization and poorer mechanical characteristics of the material. Using higher power curing units does not mean a proportional reduction in polymerization time and cannot be calculated as easily. Although dentists have the need for faster polymerization and although curing units of increased radiant power and spectrum width appear on the market, it is believed that rapid polymerization can have a negative effect on the formation of the polymer network. Fast polymerization reaction does not leave enough time for the formation of long polymer chains before vitrification of the material. The formed chains are short, the material transitions to the solid phase faster, so a greater internal stress develops during polymerization, which directly leads to a greater degree of failure of the adhesive joint [4].

According to the classification of the Centers for Disease Control and Prevention of the United States, light polymerization units belong to the group of semi-critical instruments [11]. They are in contact with the mucous membrane, blood, saliva, as well as respiratory particles and viruses present in the oral cavity. Protection, not only of the lamp head, but of the entire lamp, control buttons, and the whole body is important in the fight against cross-infections in dental offices. In addition, the protection will prevent accidental contamination of the lamp head with adhesives, which often happens (35–68%) and endangers any subsequent polymerization [12]. On the market there are several different, disposable protective covers based on plastic (polyethylene, polyvinyl chloride) and less often latex. Although these covers are, to the eye, transparent, they attenuate some of the radiation. And that, when used properly, tightened, they attenuate 5–16% of radiation, while that percentage can reach up to 30% if they are wrinkled and not tightened over the lamp's head [13]. It is recommended to use protective covers based on plastic rather than latex – ordinary plastic rolls for food packaging have been shown to perform especially well [13].

CONCLUSION

There are many factors that influence the success of our restorations, and the quality and maintenance of light sources is certainly one of them. It is important to note that we can control these factors by choosing the proper device, maintaining the hygiene of the device, using the protective covers correctly, as well as regularly measuring the radiation power of the light-curing units that we have been using for certain time.

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Lampe za svetlosnu polimerizaciju kompozitnih materijala

Jelena Vučetić
Univerzitet u Beogradu, Stomatološki fakultet, Klinika za bolesti zuba, Beograd, Srbija

KRATAK SADRŽAJ
Lampe za svetlosnu polimerizaciju su značajni instrumenti svake stomatološke ordinacije, a njihova pravilna upotreba ima direktan uticaj na fizičke karakteristike materijala koji se prosvetljava, njegovu biokompatibilnost, kao i na sveukupni klinički uspeh i dugotrajnost dentalnih kompozita. Iradijansa ili ozračenost predstavlja snagu zračenja po jedinici ozračene površine i treba je razlikovati od ozračenosti merene direktno uz glavu lampe, koja se zove izlazno ozračenje ili emitansa. Takođe, različite tačke na površini materijala mogu biti izložene različitim snagama zračenja, koje nekada značajno odudaraju od date prosečne vrednosti. Razlog za ovo je nehomogenost snopa zračenja. Najpreciznije informacije o kvalitetu ozračenja kojem će materijal biti izložen daje 3D profil svetlosnog snopa. Zbog postojanja različitih fotoinicijatornih sistema, danas se često preporučuje upotreba lampi šireg emisionog spektra, koji pokriva veći raspon talasnih dužina svetlosti. Značajna karakteristika lampe je i njena snaga, ali korišćenje lampi veće snage ne znači proporcionalno smanjenje vremena polimerizacije. Kvalitet i održavanje svetlosnih izvora svakako su jedan od bitnih faktora koji utiču na uspeh restauracija.
Ključne reči: polimerizacione lampe; iradijansa; kompozitni materijali; svetlosna polimerizacija

UVOD

Lampe za svetlosnu polimerizaciju su značajan i svakodnevno korišćen deo opreme svake stomatološke ordinacije. Kvalitet lampe, kao i njena pravilna upotreba, imaju direktan uticaj na fizičke karakteristike materijala koji se prosvetljava, njegovu biokompatibilnost, kao i na sveukupni klinički uspeh i dugotrajnost dentalnih fotopolimernih sistema (kompozita, adhezivnih sistema, zalivača, cemenata). Međutim, brojne studije svedoče o nedovoljnoj informisanosti stomatologa o karakteristikama svetlosnog izvora na koje treba da obrate pažnju pri odabiru, odnosno kupovini lampe, kao i o njihovom neadekvatnom korišćenju i održavanju u praksi [1, 2, 3]. Ovo može biti jedan od razloga neuspeha dentalnih restauracija.

Cilj tokom prosvetljavanja jeste dopremiti dovoljnu količinu svetlosne energije, tačno određene talasne dužine, koju zahteva fotoinicijatorni sistem materijala koji se prosvetljava. Pored toga, tokom prosvetljavanja, neophodno je da su svi delovi restauracije ozračeni, kao i da sve tačke dobijaju istu količinu energije [4]. Informacije koje proizvođači ističu, kao i informacije na koje stomatolozi obraćaju pažnju tokom odabira lampe, često nisu dovoljne da bi se stekao realan uvid o kvalitetu polimerizacije koji se može postići određenom lampom.

POLIMERIZACIONE LAMPE – ZNAČAJNI POJMOVI

Karakteristika koja se često stavlja u prvi plan jeste iradijansa. Iradijansa ili ozračenost predstavlja snagu zračenja [vat] po jedinici površine [m], odnosno za uslove stomatologije govori se o mW/cm^2. Prema tome, iradijansa je obrnuto proporcionalna površini na kojoj se meri. Što je veća ozračena površina, ozračenost će biti manja i obrnuto. Drugim rečima, iradijansa zavisi od dva parametra: snage svetlosnog izvora i od udaljenosti materijala koji se prosvetljava. Laboratorijski podaci od kliničkog značaja su vrednosti iradijanse merene na realnim udaljenostima od svetlosnog izvora, kako bi se što bliže simulirali klinički uslovi.

Međutim, ono što je problematično jeste to što proizvođači često ističu jednu uopštenu vrednost iradijanse, merenu direktno uz svetlosni izvor. Budući da je u ovom slučaju merena površina zapravo površina glave lampe, ovako dobijena vrednost iradijanse direktno zavisi od veličine glave lampe i nema veze sa realnom ozračenošću kojoj će materijal biti izložen. Ako pretpostavimo da dve lampe sa dva potpuno identična izvora zračenja, jednake snage [W], imaju glave različitih dimenzija, jasno je da ozračenost merena na njihovim glavama neće biti ista. Lampa čija je glava manja imaće drastično veću vrednost izlazne ozračenosti. Odnosno, slabija lampa manjeg dijametra glave može imati jednaku vrednost iradijanse kao lampa mnogo veće snage i veće glave, kakva je i potrebna da bi se prekrila cela restauracija. Na taj način, smanjivanjem dijametra glave lampe, proizvođač može lampu male snage zračenja da reklamira kao lampu visoke iradijanse. Kako ne bi dolazilo do zabune, za ozračenost merenu direktno uz glavu lampe trebalo bi koristiti drugi termin – izlazno ozračenje ili jednostavno emitansa. Ova vrednost, posmatrana izolovano, iz pomenutih razloga, nije od kliničkog značaja. Bilo bi korisnije tražiti podatke poput snage zračenja [W], dijametra glave lampe i vrednosti iradijanse sa klinički relevantih udaljenosti po relevantnoj jedinici površine.

Jednako važno je i imati na umu da iradijansa predstavlja samo prosečnu vrednost snage zračenja po jedinici površine. Međutim, svetlosni izvor, a potom ni svetlosni snop nikada nisu homogeni [5]. Različite tačke na površini materijala mogu biti izložene različitim snagama zračenja, koje nekada značajno odudaraju od prikazane prosečne vrednosti. Tako se može desiti da određene regije restauracije budu osvetljene sa manje od 400 mW/cm^2 – takozvane hladne zone, a i suprotno tome, da određene regije restauracije budu izuzetno visoko ozračene, čak i sa 5000 mW/cm^2 – vrele zone. Ni hladne, ni vrele zone nisu poželjne. To su mesta gde se polimerizacija ne odvija optimalnom dinamikom i u potpunosti, iako prosečna vrednost iradijanse za datu površinu može biti idealna (Slika 1).

Za pravi uvid, konačno, trebalo bi tražiti podatke o 3D profilu svetlosnog snopa, koji će nas najpreciznije informisati o kvalitetu ozračenja kojem će materijal biti izložen [7]. Cilj je nalaženje što homogenijeg snopa, bez takozvanih vrelih i hladnih zona, dovoljne snage zračenja i adekvatnog emisionog spektra, koji se poklapa sa apsorpcionim spektrom fotoinicijatornog sistema u materijalu.

Minimalna vrednost ozračenja koju kompozitni materijal treba da primi obično iznosi oko 400 mW/cm^2 [8]. ISO standardom 10650/2018 definisana je maksimalna vrednost izlazne iradijanse u delu spektra između 380 i 515 nm i iznosi 4000 mW/cm^2. Korišćenje jačih lampi ili dugotrajno prosvetljavanje bez hlađenja i pauza nosi rizik od povređivanja tkiva visokom temperaturom koja se razvija u toku polimerizacije.

Druga nedoumica pri odabiru lampe tiče se odabira emisionog spektra. Jedna od velikih promena u svetu kompozitnih materijala jeste sastav fotoinicijatornih sistema. Kamforhinon je i dalje najčešće korišćen, sa maksimumom apsorpcije na oko 468 nm – plavo svetlo. Zbog intenzivno žute boje kamforhinon je sve češće zamenjen ili dopunjen nekim od alternativnih fotoinicijatora za postizanje svetlijih nijansi i poboljšavanje procesa polimerizacije. Ovi alternativni fotoinicijatori, poput Lucirin-TPO, imaju maksimum apsorpcije u ljubičastom delu spektra [9]. Nažalost, sastav materijala i precizan sadržaj fotoinicijatornih sistema je često sakriven i zaštićen. Iz tog razloga, kao i zbog činjenice da stomatolozi u svojim praksama najčešće istom lampom polimerizuju različite materijale, sve se više preporučuje korišćenje lampi sa dva ili više emisiona spektra (Slika 2).

U poslednje vreme postoji tendencija ka skraćivanju vremena polimerizacije. Međutim, svako korišćenje lampi van uputstva proizvođača, kao i samoinicijativno smanjivanje vremena polimerizacije kada se koriste lampe veće snage, dovodi do neadekvatne polimerizacije i lošijih mehaničkih karakteristika materijala. Korišćenje lampi veće snage ne znači proporcionalno smanjenje vremena polimerizacije i ne može se tako jednostavno izračunati. Iako stomatolozi imaju potrebu za što bržom polimerizacijom i iako se pojavljuju lampe sve veće snage i širine spektra, smatra se da brza polimerizacija može imati negativan uticaj na formiranje polimerne mreže. Brza polimerizacija ne ostavlja dovoljno vremena za formiranje dugih polimernih lanaca pre vitrifikacije materijala. Formirani lanci su kratki, materijal prelazi u čvrstu fazu brže, pa se razvija i veći unutrašnji stres tokom polimerizacije, koji direktno dovodi do većeg stepena neuspeha adhezivnog spoja [4].

Prema klasifikaciji Centra za prevenciju i kontrolu bolesti, lampe za svetlosnu polimerizaciju spadaju u grupu polukritičnih instrumenata [11]. U kontaktu su sa mukoznom membranom, krvlju, pljuvačkom, kao i respiratornim partikulama i virusima prisutnim u usnoj duplji. Zaštita, ne samo glave lampe, već cele lampe, komandnih dugmića i tela je od značaja u borbi protiv unakrsnih infekcija u stomatološkim ordinacijama. Pored toga, zaštita će sprečiti i slučajnu kontaminaciju glave lampe adhezivnim sredstvima, što se neretko dešava (35–68%) [12] i ugrožava svaku sledeću polimerizaciju. Na tržištu postoji nekoliko različitih, jednokratnih zaštitinih košuljica na bazi plastike (polietilen, polivinil-hlorid) i ređe lateksa. Iako ove košuljice jesu, na oko, transparentne, one atenuišu deo zračenja. I to, kada se koriste pravilno, zategnute, atenuišu 5–16% zračenja, dok taj procenat može dostići i do 30% ukoliko su naborane i nezategnute [13]. Preporuka je da se koriste pre košuljice na bazi plastike nego lateksa – posebno se obična plastična folija za pakovanje hrane pokazala dobro [13].

ZAKLJUČAK

Mnogo je faktora koji utiču na uspeh naših restauracija, a kvalitet i održavanje svetlosnih izvora svakako su jedan od njih. Ono što je važno jeste da ih možemo sami kontrolisati ispravnim odabirom lampe, održavanjem higijene lampe, pravilnim korišćenjem zaštitnih košuljica, kao i redovnim merenjem snage zračenja lampi koje neko vreme koristimo.