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LIGHT-EMITTING DIODE POLYMERIZATION: A REVIEW OF PERFORMANCE, PART I

POLIMERIZACIJA SVETLOSNO-EMITUJUĆE DIODE TEHNOLOGIJOM: PREGLED KARAKTERISTIKA - I DEO

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Abstract
Bonded direct and indirect restorations have become the appropriate choice in many clinical situations where conservation of tooth structure and esthetics are paramount. Inadequate polymerization is known to have deleterious effects on resin bonded restorations such as tooth sensitivity, microleakage, fractures or complete debonding of restorations. Quartz-tungsten-halogen (QTH) units have been widely used for polymerizing resin-based dental materials for decades. However, QTH lamps exhibit several shortcomings, which is probably why the light-emitting diode (LED) polymerization lights were introduced as the alternative means for polymerizing light cured restorations. Some drawbacks of Quartz-tungsten-halogen technology have been reviewed in this paper, together with several important properties associated with LED polymerization lights and dental materials treated using LED technology, such as depth of cure and hardness.

Key words: *polymerization, light-emitting diode, quartz-tungsten-halogen, depth of cure, hardness, degree of conversion, compressive strength, flexural strength, bond strength*

Kratak sadržaj
Direktne i indirektne „bonded" restauracije zuba su indikovane u mnogim kliničkim situacijama, gde je očuvanje strukture zuba i estetike od vrhunskog značaja. Dokazano je da neadekvatna polimerizacija ima štetan uticaj na restauracije smolama, koji se ogleda u osetljivosti zuba, mikro curenju, frakturi ili potpunom odvajanju restauracije. Kvarc-tungsten-halogenske (QTH) lampe su već decenijama u širokoj upotrebi za polimerizaciju stomatološkim materijalima na bazi smola. Međutim, QTH lampe imaju i nekoliko nedostataka, što je verovatno i razlog zbog čega je LED polimerizaciona svetlost uvedena kao alternativno sredstvo za ove restauracije.
Ovaj rad obrađuje dubinu polimerizacije i tvrdoću, važne karakteristike stomatoloških materijala koji se tretiraju upotrebom LED tehnologije.

Ključne reči*: polimerizacija, LED, kvarc-tungsten-halogen, dubina polimerizacije, tvrdoća, stepen konverzacije, kompresivna snaga, fleksuralna snaga, snaga vezivanja*

Introduction

One of the primary objectives of modern dentistry is to restore missing tooth structure using strong, esthetic materials that conserve as much natural tooth structure as possible.With the advent of dental adhesives and light-activated resin cements, bonded direct and indirect restorations have become the restoration of choice in many clinical situations where conservation of tooth structure and esthetics are paramount. Inadequate polymerization is known to have deleterious effects on resin bonded restorations such as tooth sensitivity, microleakage, frac-

Uvod

Jedan od primarnih ciljeva moderne stomatologije je uspostavljanje strukture zuba koja nedostaje upotrebom kvalitetnih estetskih materijala koji čuvaju prirodnu strukturu zuba što je to više moguće. Napretkom tehnologije stomatoloških adheziva aktiviranih svetlom, direktne i indirektne restauracije, upotrebom lepkova postale su restauracije izbora u mnogim kliničkim situacijama, gde je očuvanje strukture zuba i estetike od vrhunskog značaja. Dokazano je da neadekvatna polimerizacija ima štetan uticaj na osetljivost zuba, mikro curentures or complete debonding of restorations. Visible light-polymerization units are an indispensable part of the dental armamentarium. All light-cured composites require a certain amount of energy to carry out the polymerization process. Energy is work or the capacity for work and is measured in joules (J). The energy density required to cure composite resins have been reported in the range of 21 to 24 J/cm[1]. In the dental literature, energy is typically reported in the form of *power density* and is expressed as milliwatts by centimeters squared (mW/cm^2). The power density is derived from the power (mW), which is the number of photons per second emitted by a light source divided by the area of the polymerization light tip.[2] Power density and intensity will be used interchangeably throughout this paper.

Dentist have used quartz-tungsten-halogen (QTH) polymerization units to polymerize composite resin for nearly 30 years.[3] However, since the introduction of light-emitting diode (LED) polymerization lights, an increasing number of manufactures are providing alternative means for polymerizing light cured restorations. If this trend continues, LED polymerization lights, which are reported to generate less heat, be more energy efficient, and more compact in construction, may eventually replace the QTH polymerization light as the polymerization light of choice.

Some Draw Backs of QTH

Quartz-tungsten-halogen (QTH) units are the most widely used light source currently available for polymerizing resin-based dental materials. They produce light by passing a current through a tungsten filament housed in a quartz bulb filled with halogen gas. As the current passes through the filament, most of the energy generated is changed into heat, but a small portion is given off as light.[4] A reflector located behind the bulb reflects the light through an infrared (IR) and a band-pass filter so that only blue light is emitted.[5] The radiation emitted by these incandescent lamps is band-pass filtered to a spectrum starting between 380 nm and 400 nm and ending between 500 and 520 nm[6,7]. Despite the popularity of halogen polymerization lights, there are some shortcomings related to this technology. Adequate polymerization of resin-based dental materials depends on the

je, frakture ili potpuni debonding restauracije. Aparati za polimerizaciju vidljivom svetlošću sastavni su deo stomatološkog materijala. Svi kompoziti zahtevaju izvesnu količinu energije da bi se obavio polimerizacioni proces. Energija je rad ili kapacitet za rad i izražava se u džulima (J). Neophodna energija za tretiranje kompozitnih smola kreće se u opsegu od 21 do 24 J/cm (1).[1] U stomatološkoj literaturi, energija se obično opisuje u obliku *gustine snage* i izražava u milivatima (mW) po santimetru kvadratnom (mW/cm^2). Gustina snage se dobija iz snage (mW), što predstavlja broj fotona u sekundi koji se emituju iz svetlosnog izvora.[2] Gustina snage i intenzitet se koriste sa gotovo identičnim značenjem u ovom radu.

Stomatolozi su skoro trideset godina koristili kvarz-tungsten-halogen (QTH) polimerizacione jedinice za polimerizaciju kompozitnih smola.[3] Međutim, od uvođenja LED polimerizacione svetlosti, sve veći broj proizvođača nalazi alternativne načine za polimerizaciju restoracije. Ukoliko se ovaj trend nastavi, LED polimerizaciona svetlost, za koju je dokazano da emituje manje toplote, da je energetski efikasnija i kompaktnija, može postati polimerizaciono svetlo izbora umesto QTH.

Nedostaci QTH

Kvarz-tungsten-halogenske (QTH) lampe su najčešće korišćeni svetlosni izvor trenutno dostupan za polimerizaciju stomatoloških materijala na bazi smola. One proizvode svetlost na taj način što struja prolazi kroz vlakna koja su smeštena u sijalici ispunjenoj halogenim gasom. Kako struja prolazi kroz vlakna veći deo energije se pretvara u toplotu, a manji deo u svetlost.[4] Reflektor koji se nalazi iza sijalice reflektuje svetlost kroz infracrveni i band-pass filter,[5] tako da se emituje samo plava svetlost. Zračenje koje dolazi iz ovih lampi prolazi kroz filtere i pretvara se u spektrum opsega između 380 i 400 nm, a završava se između 500 i 520 nm.[6,7] Uprkos popularnosti halogenih polimerizacionih lampi, postoje i nedostaci ove tehnologije. Adekvatna polimerizacija stomatoloških materijala na bazi smola zavisi od intenziteta svetlosnog izvora, talasne dužine i vremena polimerizacije.[8]

Kamforkinon (CQ) je široko primenjen fotoinicijator koji apsorbuje energiju i reaguje sa foto umanjivačem i tercijarnim aminom da bi light source intensity, wavelength, and polymerization time.[8] Camphorquinone (CQ),[9] is a commonly used photoinitiator that absorbs energy and reacts with a photo reducer, a tertiary amine, to begin the polymerization process. The absorption curve of CQ has been reported to be between 360 to 520 nm with a maximum of 468 nm.[10] According to Nomoto,[11] the most efficient wavelength is 470 nm and the most adequate wavelength is in the 450-490 nm range. If one compares the CQ absorption spectrum with emission characteristics of halogen lights, one finds that only a small portion of the halogen emission spectrum actually is used to active the photoinitiator molecules.[4]

Another drawback of the halogen polymerization light is the heat generated during operation leads to degradation of bulb components over time, resulting in a reduction of polymerization effectiveness over time.[12-15] Barghi et al.[12] measured the light intensity of 209 halogen polymerization lights from 122 private dental offices and found that 65 percent of the lights had outputs of less than 200 mW/cm^2, which is well below the intensity of 300 mW/cm^2 recommended by Fan et al.[16] Many of the offices were unaware that the output of the lights was inadequate to completely cure resin composites. Rueggeberg and Caughman suggested that a power density of 300 mW/cm^2 still might not be adequate[17]. They recommended using an intensity of 400 mW/cm^2 for 60 seconds to cure a 1-mm thick specimen of resin composite.

LED Technology

In 1995, Mills et al.[18] proposed using solid-state light-emitting diode (LED) technology to overcome the disadvantages associated with halogen polymerization lights. Instead of heated filaments used in halogen bulbs, LEDs use junctions of doped semiconductors (p-n junctions) for the generation of a monochromatic light.

When subjected to an electric current, electrons and holes recombine at the LEDs p-n junction of a semiconductors material such as gallium nitride, leading to the emission of blue light[19]. The spectral output for most LED polymerization lights in dentistry is a narrow band with a peak emission of 460 nm to 490 nm[5]. This narrow band does not include the infrared (I.R.) spectrum, which reduces heat output and

se započeo proces polimerizacije.[9] Apsorpciona krivulja CQ se kreće između 360 i 520 nm, sa maksimalnom vrednošću od 468 nm.[10] Prema Nomotu,[11] najefikasnija talasna dužina iznosi 470 nm, a najadekvatnija talasna dužina se kreće u opsegu od 450 do 490 nm. Ako se uporede CQ apsorpcioni spektrum i osobine emisije halogenog svetla, dolazi se do zaključka da se samo mali deo spektra halogene emisije koristi da bi se aktivirali molekuli fotoinicijatori.[4]

Drugi nedostatak halogenog polimerizacionog svetla je da toplota koja se stvara u toku ovog procesa vremenom dovodi do potrošnje komponenata sijalice, što dovodi do smanjenja efektivnosti polimerizacije.[12-15] Barghi i saradnici[12] su izmerili intenzitet svetlosti sa uzorka od 209 halogenih polimerizovanih sijalica iz 122 privatne stomatološke ordinacije i otkrili su da je 65% svetlosti imalo izlaz manje od 200 mW/cm^2, što je ispod minimalnog intenziteta od 300mW/cm^2 koji preporučuju Fan i saradnici.[16] U mnogim ordinacijama, izlazni napon svetlosti nije bio adekvatan da bi se tretirali kompoziti. Rueggeberg i Caughman su predložili da bi gustina snage od 300 mW/cm^2 bila adekvatna.[17] Oni su preporučili da se 1mm debeo uzorak kompozitne smole tretirao jačinom od 400 mW/cm^2 u trajanju od 60 sekundi.

LED Tehnologija

Mills i saradnici su predložili 1995. godine upotrebu LED tehnologije u čvrstom stanju kako bi se prevazišli nedostaci halogene polimerizacione svetlosti. Umesto zagrevanja niti u halogenim sijalicama, LED diode koriste poluprovodnički materijal za generisanje monohromatskog svetla. Kada se propusti električna struja, elektroni i šupljine se rekombinuju u LED p-n spoju poluprovodnih materijala kao što je galijum nitrit, što dovodi do emisije plave svetlosti.[19] Spektralni izlaz za većinu polimerizacionih svetlosti u stomatologiji je u vidu uzanog snopa sa maksimalnom emisijom od 460 do 490 nm[5]. Ovaj snop ne uključuje infracrveni spektar, što smanjuje izlaznu toplotu i ulazi u opseg apsorpcionog spektra CQ (450-490 nm) kao što je to slučaj kod mnogih materijala koji se aktiviraju svetlošću. Spektrum eliminiše potrebu za filterima.[18,20] Leonard i saradnici[21] su upoređivali emisioni spektar tri LED izvora svetlosti (VersaLux, LumaCure, Zap) sa konvencionalnim halogenim svetlom (Optilux 401) conveniently falls within the most adequate absorption spectrum of CQ (450-490 nm) present in most light-activated materials. This spectrum eliminates the need for filters.[18,20] Leonard et al.[21] compared the emission spectrum of three LED lights (VersaLux, LumaCure, Zap) to a conventional halogen light (Optilux 401) and found that 95 to 78 percent of the emission spectrum of the LED units fell between 450 nm to 500 nm. In contrast, only 56 percent of the emission spectrum of the halogen light fell within this optimal range. This result also seems to suggest why LED units perform better than halogen units with respect to light energy. et al.[22], compared energy efficiencies of an LED and halogen unit by quantifying the primary radicals generated by irradiation using spin resonance (ERS) spectroscopy and emitted light energy (J/cm^2). They found that energy required to generate a given amount of radicals using the LED light was significantly smaller than for the halogen lights.

Although the studies previously cited on the polymerization efficiency of LED polymerization lights seems promising, further research on selected properties of resin composite polymerized with LED lights must be considered and compared to a standard QTH light source.

Depth of Cure

Depth of cure is one of many tests that can be applied to cured resin materials for determining degree of polymerization. Depth of cure is dependent upon the light permeability of the fillers, exposure duration and resin shade.[17,21,23-25] Monomer type and composition, concentration of initiator and accelerator have also been reported to influence depth of cure.[26] With regards to light intensity, several studies have shown the depth of cure of resin materials decreases with decreasing intensity.[1,27-31] One study found the depth of cure was inversely proportional to the attenuation of light caused by the composite resin at 470 nm. The relationship between depth of cure and light intensity at 470 nm was not a simple linear one over all intensity values. Above a certain critical value of intensity (about 550 lux for a 3.5-mm aperture in these experiments), the depth of cure appeared to be almost independent of intensity.[21] Shortall and Harrington[31] measured the influence of polymerization light intensity

i utvrdili da se 95-78% emisionog spektra LED jedinica kreće između 450 i 500 nm. Za razliku od toga, samo 56% halogenog svetla se kreće u optimalnom opsegu. Izgleda da ovaj rezultat ukazuje na to zašto LED lampe rade bolje od halogenih u pogledu svetlosne energije. Teschima i saradnici[22] su upoređivali energetsku efikasnost LED i halogenih jedinica kvantifikovanjem primarnih radikala koji nastaju u procesu zračenja primenom ERS-a i emitovanjem svetlosne energije (J/cm^2). Otkrili su da je energija koja je neophodna za stvaranje određene količine radikala, upotrebom LED svetlosti, bila značajno manja nego u slučaju halogene svetlosti.

Premda su prethodno pomenute studije koje se bave polimerizacionom efikasnošću LED polimerizacije ohrabrujuće, dalja istraživanja pomenutih svojstava kompozita polimerizovanih LED svetlošću moraju se razmotriti i i uporediti sa standardnim QTH svetlosnim izvorom.

Dubina polimerizacije

Dubina polimerizacije jedan je od mnogih testova koji se primenjuju na smole kako bi se odredio stepen polimerizacije. Dubina polimerizacije zavisi od svetlosne propustljivosti filtera, trajanju ekspozicije i boje kompozita,[17,21,23-25] Takođe je zabeleženo da na dubinu polimerizacije utiče monomerski tip i kompozicija, koncentracija inicijatora i akceleratora.[26] Što se tiče intenziteta svetlosti, nekoliko studija je pokazalo da se dubina polimerizacije kompozita smanjuje sa smanjenjem intenziteta.[1,27-31] Jedna studija je otkrila da je dubina polimerizacije kompozita inverzno proporcionalna slabljenju svetlosti na 470 nm. Odnos između dubine polimerizacije i intenziteta svetlosti na 470 nm nije jednostavna linearna krivulja iznad svih vrednosti intenziteta. Izgleda da je iznad izvesne kritične vrednosti intenziteta (oko 550 lux-a za 3.5 mm aperture u ovim eksperimentima) dubina polimerizacije skoro nezavisna od intenziteta.[29] Shortall i Harrington su izmerili uticaj intenziteta polimerizacionog svetla na dubinu polimerizacije i otkrili da kada su očitavanja intenziteta svetlosti normalizovana, (ukoliko se uzme standardizovana apertura od 4 mm u obimu), javljao se linearni odnos između dubine polimerizacije i logaritma intenziteta svetlosti.[31] U jednoj od narednih studija, Fan i saradnici[16] su izmerili dubinu polimerizacije u skladu sa Internacionalnom organizacijom za on depth of cure and found that when light intensity readings were normalized, with regard to a standardized aperture of 4 mm diameter, a linear relationship existed between depth of cure and the logarithm of the intensity of light. In a later study, Fan et al.[16], measured depth of cure according to the International Organization for Standardization (ISO). ISO-4049 specification defines depth of cure as 50 percent of the length of the cured composite after the soft, uncured portion has been scraped away manually.[32] A specified pass/fail criterion then is used to compare the depth of cure with the 1.5 mm requirement to determine if the materials meet the standard. The results of the study concluded that a polymerization light with an intensity of 300 mW/cm^2 would effectively cure most composite shades within the manufacturer's time, but some materials might require longer exposure times. Asmussen and Peutzfeldt[33] also used the ISO standard to determine the depth of cure for three hybrid composites (Z250, Pertac II, and Definite) with two different LED lights (Elipar Freelight and E-Light) and a QTH light (XL3000) . They reported both the resin composite and the polymerization light had an effect on the depth of cure. The depth of cure was less when the LED lights where used, however, the values obtained were in excess of the minimal values required to meet the standard. It should also be noted that the power density reported for the E-light (GC) was only 290 mW/cm^2 and that this light was not used in its maximum power mode, which if corrected, might have improved its performance. While the depth of cure measurements have been shown to be more effective with an LED light compared to a QTH light[34], differences in performance correlate to the generation which in turn correlates to the intensity of the light. A study by compared depth of cure for a contemporary composite using first and second generation LED (Freelight 1 and Freelight 2) to a QTH control (XL 3000). It was reported that the second generation LED light achieved depth of cure which approached those of the control QTH unit in half the radiation time; 20 seconds compared to 40 seconds. Aravamudhan et al. evaluated seven LED lights and found that two LED lights required additional cure time to reach a depth of cure similar to the QTH control.

standardizaciju (ISO). ISO-4049 specifikacija definiše dubinu polimerizacije kao 50% dužine tretiranog kompozita pošto se mek, nelečeni deo odstrani ručno.[32] Primenjuje se specifičan kriterijum da bi se uporedila dubina polimerizacije sa zahtevom od 1.5 mm da bi se odredilo da li materijal zadovoljava standarde. Rezultati studije ukazuju da bi se polimerizacionom svetlošću intenziteta 300 mW/cm^2 efektivno – polimerizovale mnoge nijanse kompozita, ali u okviru vremena koji daje proizvođač, s tim što bi za neke materijale bila potrebna duža ekspozicija. Asmussen i Peutzfeld su takođe koristili ISO standard da bi odredili dubinu polimerizacije u slučaju tri hibridna kompozita (Z250, Pertac II, and Definite) upotrebom dva različita LED svetla (Elipar Freelight i E-Light) i QTH svetlom (XL3000).[33] Oni su pokazali da su i kompozit i polimerizaciono svetlo imali efekat na dubinu polimerizacije. Dubina polimerizacije je bila manja nego kada je upotrebljeno LED svetlo. Međutim, dobijene vrednosti bile su premale da bi zadovoljile standard. Treba obratiti pažnju da je zabeležena gustina snage za E-svetlost (GC) iznosila 290 mW/cm^2 i da svetlost nije bila maksimalne snage, što bi, ukoliko dođe do korekcije, moglo dovesti do poboljšanja rezultate. Dok su se vrednosti dubine polimerizacije pokazale kao mnogo efektivnije upotrebom LED svetla u poređenju sa QTH svetlom[34], razlike u dejstvu odgovaraju generaciji koja za uzvrat odgovara intenzitetu svetla. Jedna studija je uporedila dubinu polimerizacije upotrebom prve i druge generacije LED svetlosti (Freelight 1 i Freelight 2) sa QTH kontrolom (XL 3000). Primećeno je da je druga generacija LED lampi postigla dubinu polimerizacije koja se približila vrednosti koja se postiže kontrolnom QTH lampom za upola vremena zračenja – 20 sekundi u poređenju sa 40 sekundi. Aravamudhan i saradnici su analizirali sedam LED izvora svetlosti i otkrili da je kod dva LED izvora svetlosti bilo potrebno dodatno vreme da bi se postigla dubina polimerizacije slična QTH kontroli.

Tvrdoća

Nekoliko studija primenilo je testove za proveru tvrdoće pomoću LED polimerizacione svetlosti u poređenju sa QTH jedinicama kao način za određivanje efektnosti polimerizacije. Mnogo metoda je korišćeno poput Knoop, Vickers, Barcol kao i drugi penetrometarski tes-

Hardness

Several studies have used hardness tests with LED polymerization lights compared to QTH lights as a means of determining polymerization effectiveness. A variety of methods were used such as the Knoop,Vickers, Barcol, and other penetrometer indention tests. The Knoop hardness test is an indirect method of evaluating depth of cure. The bottom: top Knoop hardness values are used to obtain a ratio, and if that value exceeds 80 percent, specimens are considered to be adequately cured.[1,57,58] A strong correlation was found between the Knoop hardness ratio and light intensity for QTH units used in private dental offices.[59]

A number of studies have reported inferior Knoop hardness ratios using LED lights compared to halogen lights.[21,40,60,61] However, more recent studies have reported LED hardness ratios greater than or equivalent to QTH lights.[41-46, 48, 49, 51, 52, 62] The percentage depth of cure calculation from hardness ratios easily can be misinterpreted. A specimen could be poorly cured throughout, but if the bottom hardness was similar to the top hardness, the ratio still could exceed 80 percent. Dunn et al.[60] reported a top and bottom Knoop hardness value of 24 kg/mm^2 and 19 kg/mm^2, respectively, for the LED VersaLux LED light. This was compared to a top and bottom Knoop hardness value of 39 kg/mm^2 and 30 kg/mm^2, respectively, for a QTH light (Optilux 501). The reported Knoop hardness ratio of 79 percent for the LED unit would suggest a better depth of cure than the 77 percent reported for the QTH unit. A closer examination of the actual top hardness values shows that the composite was much softer when cured with the LED light.

Some of the initial research done with LED technology demonstrated favorable depths of cure. However, these studies used prototype LED units rather than commercial products, and in some instances, the intensity of the halogen light which the LED unit was compared was reduced to coincide with the reduced power density output of the LED unit .

A well controlled in-vitro study[20,37,63,64] demonstrated that power density of three 1st generation, commercial available LED polymerization lights (ZAP Dual Polymerization, LumaCure, and VersaLux) were too low to adequately cure a resin composite using the

tovi. Knoop test na tvrdoću je indirektna metoda za procenu dubine polimerizacije. Vrednosti ovog testa se koriste da bi se dobio odnos i ako ta vrednost pređe 80%, smatra se da su uzorci adekvatno polimerizovani.[1,57,58] Utvrđeno je da postoji jaka veza između odnosa tvrdoće po Knoopu i intenziteta svetlosti[59] za QTH jedinice koje se koriste u privatnim stomatološkim ordinacijama.

Veliki broj studija je utvrdio da su upotrebom LED lampi dobijene lošije vrednosti Knoop testa tvrdoće u poređenju sa halogenom svetlošću.[21,40,60,61] Međutim, najnovije studije su pokazale da je odnos tvrdoće, upotrebom LED lampi, veći ili ekvivalentan QTH lampi.[41-46,48,49,51,52,62] Procenat dubine polimerizacije koji se dobija iz odnosa tvrdoće se vrlo lako može pogrešno interpretirati. Rezultat polimerizacije uzoraka je zato slab, ali ako je tvrdoća dna ista kao i tvrdoća vrha, odnos može da pređe 80%. Dun i saradnici[60] su upotrebom LED VersaLux LED lampi dobili sledeće rezultate za tvrdoću: 24 kg/mm^2 za vrh i 19 kg/mm^2 za dno. Ove vrednosti su upoređene sa vrednostima tvrdoće dna – 39 kg/mm^2 i vrha – 30 kg/mm^2 koje su dobijene upotrebom QTH lampe (Optilux 501). Pokazani odnos Knoop tvrdoće od 79% pokazuje bolju dubinu polimerizacije od 77% koji se dobijaju QTH lampama. Detaljniji pregled pravih vrednosti tvrdoće vrha pokazuje da je kompozit bio mekši kada je bio tretiran LED lampom.

Neka od prvih istraživanja urađenih LED tehnologijom pokazala su veću dubinu polimerizacije. Međutim, ove studije su pre koristile LED jedinice nego komercijalne proizvode, i u nekim slučajevima je intenzitet halogenog svetla bio poređen sa LED jedinicom i vrednost je bila smanjena i podudarala se sa izlazom smanjene gustine snage LED jedinice.[20,37,63,64]

Dobro kontrolisana in-vitro studija[21] je pokazala da je gustina snage tri komercijalne LED lampe prve generacije (Zad Dual Polimerization, LumaCure i VersaLux) bila isuviše mala da bi adekvatno polimerizovala kompozit, poštujući vreme koje sugeriše proizvođač. LED polimerizacione lampe koje su korišćene u ovoj studiji imale su visoki procenat izlaza u apsorpcionom spektru CQ u poređenju sa halogenim svetlom (Optilux 401). Međutim, čak i kad je spektralna emisija ograničena između 450 i 500 nm, kao što predlaže Nomoto (11), dokazano je manufacturer's recommended polymerization times. The LED polymerization lights used in this study had a higher percentage of their output in the absorption spectrum of CQ compared with the halogen light (Optilux 401). However, even when the spectral emission was limited to between 450 nm to 500 nm as suggested by Nomoto , the fact that the power density of the LED lights were at least four times weaker that the QTH lights proved to be a significant factor. Ernst et al. studied the effect of 1^{st} and 2^{nd} generation LED lights on bottom-to-top hardness ratios of composite and demonstrated that the higher power 2^{nd} generation LED lights showed a curing potential equal to the standard Optilux 501 given 40 seconds of exposure time while the 1^{st} generation lights failed to reach clinically sufficient depths of cure.[65]

da je gustina snage najmanje četiri puta slabija. Ernst i saradnici su ispitivali efekat prve i druge generacije LED svetla po pitanju odnosa između tvrdoće vrha i dna kompozita i utvrdili da su LED svetla velike snage druge generacije pokazala potencijal za lečenje koji odgovara Optilux 501 za 40 sekundi ekspozicije, dok prva generacija svetla nije mogla da postigne klinički dovoljnu dubinu polimerizacije.[65]

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