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

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Abstract

Several important properties associated with light-emitting diode (LED) polymerization lights and dental materials treated using LED technology, such as compressive and flexural strength, bond strength, temperature rise, power density, and material thickness and opacity, have been reviewed in this paper.

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

Kratak sadržaj

U ovom radu prikazano je nekoliko važnih osobina u vezi svetlosno-polimerizujuće diode (LED) polimerizacionog svetla i dentalnih materijala tretiranih upotrebom LED tehnologije, kao što su kompresivna i fleksuralna snaga vezivanja, porast temperature, gustina snage, debljina materijala i neprovidnost.

***Ključne reči:** polimerizacija, svetlosno emitujuća dioda, dubina polimerizacije, tvrdoća, stepen konverzije, kompresivna snaga, fleksuralna snaga, snaga vezivanja*

Degree of Conversion

The introduction of Fourier transform infrared spectroscopy (FTIR) of polymers has brought about a renewal interest in infrared spectroscopy as a method of determining degree of conversion.[1] The term degree of conversion describes the percentage of C=C double bonds that react during the free-radical polymerization process and is a major determinant for the properties of composite resin. The degree of conversion with photo initiation ranges from about 65 percent to 80 percent, whereas chemical initiation results in values from 60 percent to 75%.[2] As described by Asmussen et al.[3], FTIR involves analyzing thin films of resin composite which are immersed in strong solvents such as methanol, and the IR absorption peak of the C=C double bond at 1,640 cm^{-1} and the absorp-

Stepen konverzije

Uvođenje Fourier transformacione infrared spektroskopije (FTIR) polimera je ponovo oživelo interesovanje za infrared spektroskopiju kao metodu za određivanje stepena konverzije.[1] Pojam stepen konverzije opisuje procenat C=C dvogubih veza koje reaguju za vreme polimerizacije slobodnih radikala i to je glavna determinanta za određivanje of composite resin. Stepen konverzije foto inicijatorima se kreće od 65% do 80%, dok hemijska inicijacija rezultira vrednostima od 60% do 75%.[2] Kao što su to već opisali Asmussen i saradnici[3], FTIR uključuje analizu tankih filmova resin kompozita koji se potapaju u jake rastvarače poput metanola. IR apsorpciona maksimalna vrednost C=C dvogube veze na 1,640 cm^{-1} i apsorpcija aromatičnog lepka od 1,610 cm^{-1} određuju se pre i posle polimerizacije.

tion of the aromatic bond of 1,610 cm^{-1} are determined before and after polymerization.

A few studies have shown a lower degree of conversion when polymerized with LED polymerization lights[3-6], while other studies have shown equal[7-9] or better[10-12] degree of conversion compared to quartz-tungsten-halogen (QTH) light. Two of the studies that demonstrated lower conversion values were using experimental LED lights.[4, 5] The experimental LED light used by Tarle et al.[5] had a reported power density of only 9 mW/cm^2, while the LED used by Knezevic et al.[4] had an output of only 12 mW/cm^2. Asmussen and Peutzfeldt[3] also reported that the LED polymerization lights used in their study, the Elipar FreeLight and the E-Light resulted in lower degrees of conversion compared to a halogen light. As noted previously in this review, the E-Light was not used at maximum power which could have an influenced the results. Another study comparing 7 LED lights to a standard QTH control demonstrated the importance of the power output from the light source. It was concluded that degree of conversion was independent of the light used at the top surface, but at 2mm, was strongly correlated to the light intensity.[10] Using FTIR spectroscopy, Vandewalle et al. concluded that the 5 high powered LED lights investigated provided degree of conversion ratios similar to or better than the halogen curing light at curing distance of 5mm.[11] Yoon et al.[7] demonstrated that LED conversion performance was not significantly different from a halogen light when the total energy was set for both lights to 16 J/cm^2. This is an important finding, for by controlling the total energy emitted from both lights, they were able to rule out the light source (LED or QTH) given the same energy output.

Compressive and Flexural Strength

Mechanical properties such as compressive strength and flexural strength are important predictors of how well a material will perform under function. Research has shown no difference in compressive strength of resin composite when high-powered LED prototype units (>300 mW/cm^2) where compared to standard QTH lights.[13, 14] Flexural strength of resin composite[3] was found to be lower when two commercial LED polymerization lights were compared to a commercial halogen light. Despite this fact,

Nekoliko studija je ukazalo na niži stepen konverzije kada se polimerizacija vrši LED svetlima[3-6], dok su ostale studije pokazale jednak[7-9] ili bolji stepen konverzije u poređenju sa QTH svetlima.[10-12] Dve studije koje su pokazale niže vrednosti konverzacije koristile su LED svetla.[4-5] Eksperimentalno LED svetlo koje su upotrebili Tarle i saradnici[5] imalo je gustinu snage od 9 mW/cm^2, dok je svetlo koje su koristili Knežević i saradnici[4] imalo izlaz od samo 12 mW/cm^2. Amussen i Peutzfeld[3] su pokazali da su polimerizaciona svetla korišćena u njihovoj studiji (Elipar FreeLight i E-Light) dovela do nižeg stepena konverzije u poređenju sa halogenim svetlom. Kao što je već pokazano u ovom članku, E-svetlo nije upotrebljavano pri maksimalnoj snazi, što je moglo da utiče na rezultate. Jedna druga studija koja je upoređivala sedam LED svetala sa standardnim QTH svetlom pokazala je značaj izlazne snage svetlosnog izvora. Zaključak je da je stepen konverzacije nezavisan od svetla koje se usmerava na površinu vrha. Međutim, na 2mm je bio u jakoj vezi sa intenzitetom svetlosti.[10] Upotrebom FTIR spektroskopije, Vandavelle i saradnici su zaključili da je pet LED svetala visoke snage odnos stepena konverzije koji je bio sličan ili bolji od halogene svetlosti koja se koristila u procesu lečenja na udaljenosti od 5mm.[11] Yoon i saradnici[7] su pokazali da se LED konverzija značajno razlikovala od halogenog svetla, kada je ukupna energija bila na oba svetla podešena na 16 J/cm^2. Ovo je važan nalaz, jer kontrolisanjem ukupne energije emitovane iz oba svetla, oni su mogli da eliminišu svetlosni izvor (LED ili QTH) pod uslovom da je dat isti energetski izlaz.

Kompresivna i fleksuralna snaga

Mehaničke osobine, kao što su kompresivna i fleksuralna snaga, važni su prediktori toga kako se materijal ponaša kada je u funkciji. Istraživanje nije pokazalo nikakvu razliku u kompresivnoj snazi resin kompozita kada su jedinice LED prototipa visoke snage (>300 mW/cm^2) poređene sa standardnim QTH svetlima.[13-14] Fleksuralna snaga resin kompozita[3] bila je niža kada su upoređena dva komercijalna polimerizaciona svetla sa komercijalnim halogenim svetlom. Uprkos ovoj činjenici, vrednosti fleksuralne snage su bile više od 80 mPa, što je iznad minimalnih zahteva ISO standarda.[15]

the flexural strength values were greater than 80 MPa, which exceeded the minimum requirement of the ISO standard.[15]

Bond Strength

When we look to the literature to determine how well LED lights have performed in bond strength studies, for the most part, we find favorable results. Previous research has shown that some LED lights bond orthodontic brackets to etched enamel as well a standard QTH light.[16-31] One study showed two high powered LED lights (Ortholux LED, UltraLume 5) bonded orthodontic brackets to enamel in as little as 10 seconds.[33] These results were comparable to the QTH control which used a standard cure time of 40 seconds. One study using a high powered multimode LED light (MiniLED) showed 20 seconds of LED exposure in fast mode gave enamel bond strength values comparable to those obtained with 40 seconds of QTH exposure, while exposure in the soft start mode for 40 seconds showed higher bond strengths than the QTH control.[32] Swanson et al. compared two 1st generation LED units (Freelight and E-Light) and a 2nd generation unit (UltraLume 2) to a QTH controls (Ortholux XT) using 40, 20, or 10 second exposure times. They found that the 2nd generation LED light produced superior enamel bond strengths with 40 seconds exposure time.[33]

With regards to composite bond strengths to dentin, it has been demonstrated that 2nd generation LED lights were as effective as the standard QTH light.[34, 35]

Temperature rise

A welcomed advantage of LED units is a minimal generation of heat. As a consequence, a relatively small increase in the temperature of the tooth may be expected during polymerization of a direct restoration.[4, 17-25, 36, 37] Mills et al.[38] attributed the efficient heat dissipation from the prototype LED light used in their study to the presence of copper heat sinks. This efficient heat dissipation allowed for no cooling fan, which resulted in a more quite and lighter unit.

However, the previous findings that LED curing lights induce less temperature rise that

Snaga lepka

Kada razmotrimo podatke iz literature, da bi odredili kolika je efikasnost LED svetla u studijama o ispitivanju snage lepka, u većini slučajeva smatramo da su povoljni. Prethodno istraživanje je pokazalo da neka LED svetla spajaju ortodonske bravice na nagrizanu gleđ isto tako dobro kao standardno QTH svetlo.[16-31] Jedna studija je pokazala da su dva LED svetla visoke snage (Ortholux LED, UltraLume 5) lepila ortodontske bravice za gleđ za desetak sekundi.[33] Rezultati su se poredili sa QTH kontrolom, gde je standardno vreme lečenja bilo 40 sekundi. Jedna studija, u kojoj je korišćeno LED svetlo visoke snage (Miniled), pokazala je da je 20 sekundi brze LED ekspozicije dalo vrednosti vezivanja gleđi koje su mogle da se uporede sa vrednostima dobijenim za 40 sekundi QTH ekspozicije, dok je ekspozicija sa umerenijom brzinom, za 40 sekundi QTH ekspozicije pokazala veću snagu vezivanja nego QTH kontrola.[32] Swanson i saradnici su upoređivali dve LED jedinice prve generacije (Freelight i E-Light) i jedinicu druge generacije (UltraLume 2) sa QTH kontrolom (Ortholux XT) primenjujući vreme ekspozicije od 40, 20 i 10 sekundi.[33.]

Što se tiče kompozitne snage vezivanja za dentin, pokazalo se da je druga generacija LED svetala bila podjednako efektivna kao QTH svetla.[34-35]

Porast temperature

Jedna od prednosti LED jedinica je minimalna proizvodnja toplote. Kao rezultat toga, za vreme polimerizacije direktne restauracije može se očekivati relativno malo povećanje temperature zuba.[4, 17-25, 36-37] Mills i saradnici[38] su efikasno odavanje toplote sa prototipa LED svetala pripisali copper heat sinks. Ovo efikasno odavanje toplote nije podrazumevalo ventilator, što je rezultovalo tišim radom ove jedinice, ali i jačim svetlom.

Međutim, prethodni nalazi o tome da LED svetla izazivaju manji porast temperature nego QTH svetla nisu se pokazali kao tačni u studiji na kojoj su radili Asmussen i Peutzfeld, gde su ispitivali deset LED svetala i uporedili ih sa tri QTH svetla. Pokazali su da je temperatura bila u mnogo jačoj vezi sa gustinom snage nego tip

QTH unites, did not hold true in an study by Asmussen and Peutzfeldt in which they investigated ten LED lights compared to three QTH lights. They demonstrated that temperature was more strongly correlated with power density than the type of light.[39]

Another distinct advantage of LEDs is that they have lifetimes of more than 10,000 hours and experience little degradation of light over this time.[40] This durability is clearly superior to the halogen bulbs, which have a limited effective lifetime of approximately 40-100 hours.[41] Although QTH polymerization lights are the most common unit used in dentistry today, LED technology continues to improve. As LED technology moves forward, it will continue to be investigated as an alternative source for polymerization in dentistry.

Power density, material thickness and opacity

The results of the previous studies[42-44] indicate the need to monitor power density, which is usually performed in the office with a hand--held radiometer. Unfortunately, the consistency of the measured intensity from most hand-held radiometers is poor. Except for the Optilux 500 built-in radiometer with the 10.5-mm tip, all five of the commercial radiometers studied by Leonard and Charlton exhibited intensity values significantly different from those of a laboratory-grade power meter.[45] They suggested that a laboratory-grade power meter, such as the PowerMax radiometer (Molectron PowerMax 500D with PM 10 probe), was a more accurate means of determining light intensity, since this radiometer could accommodate variable curing tip diameters.

Early LED lights introduced to the market were not as powerful as standard QTH lights. Burgess reported low power density for three, 1st generation LED lights as follows: 152-mW/cm^2 (Versalux), 265 mW/cm^2 (CoolBlu), 279 mW/cm^2 (Elipar Freelight). In the same report, power densities of two, 2nd generation LED lights showed much improved power densities of 500 mW/cm^2 (Ultra-Lume 2) and 800 mW/cm^2 (Freelight 2). This increase in power density may explain why in that study, the Ultra-Lume 2 performed equally as well as a stan-

svetla.[39] Još jedna prednost LED svetala je da je njihov vek preko 10.000 sati i da za to vreme nema velike promene kvaliteta svetla.[40] Ovakva izdržljivost je daleko iznad halogenih sijalica čiji je efektivni vek 40-100 sati.[41] Premda su QTH polimerizaciona svetla najprimenjenije jedinice u stomatologiji danas, LED tehnologija i dalje napreduje. Kako se LED poboljšava, o njoj će se razmatrati kao alternativnom izvoru polimerizacije u stomatologiji.

Gustina snage, debljina materijala i neprovidnost

Rezultati prethodnih studija[42-44] ukazuju na potrebu za nadgledanjem gustine snage, što se najčešće obavlja u kancelarijama pomoću ručnog radiometra. Na žalost, doslednost izmerenog intenziteta ovakvih radiometara je slaba. Osim Optilux 500 ugrađenog radiometra sa 10.5 mm vrhom, svih pet komercijalnih radiometara koje su ispitivali Leonard i Charlton pokazalo je da su vrednosti intenziteta značajno različite od laboratorijskih merača snage.[45] Oni su uočili da je laboratorijski merač snage, kao što je PowerMax radiometar (Molectron PowerMax 500D PM 10 sonda) bio efikasnije sredstvo određivanja intenziteta svetlosti, jer je ovaj radiometar mogao da prilagodi varijabilne dijametre vrhova koji su se koristili u procesu lečenja.

Rane generacije LED svetala koje su se pojavile na tržištu nisu bile tako dobre kao QTH svetla. Burgess je prikazao nisku gustinu snage za tri LED svetla prve generacije, a to su: 152 mW/cm^2 (Versalux), 265 mW/cm^2 (CoolBlu), 279 mW/cm^2 (Elipar Freelight). U istom radu, gustina snage dva LED svetla druge generacije imala su veću gustinu snage od 500 mW/cm^2 (Ultra-Lume 2) i 800 mW/cm^2 (Freelight 2). Ovo povećanje gustine snage može da objasni zašto je kod Ultra-Lume 2 zabeleženo podjednako dobro funkcionisanje kao i QTH svetla (Optilux 501) u pogledu poređenja tvrdoće vrha i dna.[46]

Drugi važan faktor u razmatranju polimerizacije spojenih restauracija je dizajn i udaljenosti vrha polimerizacionog svetla od vrha do površine restauracije. Istraživanje je pokazalo jaku direktnu povezanost između udaljenosti i smanjenja gustine.[47-48] Turbo vrh je sužena svetlosna smernica koja usmerava svetlosnu dard QTH light (Optilux 501) when comparing the top and bottom hardness.[46]

Another important factor to consider for polymerization of bonded restorations is the design and distance of the polymerization light guide tip to the surface of the restoration. Research has shown a strong direct correlation between distance and the attenuation of power density.[47, 48] The turbo tip is a tapered light guide that collimates the light energy by narrowing the beam, producing higher output compared to a standard a light guide. While the turbo tip will concentrate and increase power density, the opposite effect is seen as the turbo tip moves away from the target. In other words, a greater drop in power density is seen with distance for the turbo tip compared to a standard tip. Price et al. showed that at 6 mm the power density from a turbo tip dropped 77% compared to 50% from the stand light guide.[47]

The amount of light energy available to bond dental restorations may be influenced by the thickness and opacity of material placed between the polymerization light and the resin. These restorations are often fabricated by layering porcelain of different opacities. The degree of opacity can range from very translucent to match the optical properties of human enamel to very opaque to mask dark discoloration.

Studies have shown that adequate polymerization at the bottom of restorations depends not only on the power density, but also on the type, shade, thickness, and opacity of material.[49-51] The study by O'Keefe et al.[52] showed that thickness of porcelain was the primary factor affecting light transmission of a QTH light through different thicknesses of porcelain. However, it was not found that opacity affects the light intensity to the extent of thickness. It was noted that several bottles of different shades of porcelain were combined for the opaque formulations which could have led to inconsistencies. A study by Barghi and McAlister was conducted comparing the effect of porcelain shade and thickness on surface hardness of composite resin using an LED (Ultra-Lume2) and a QTH polymerization light (Optilux 501).[53] Two shades of porcelain representing a low (C4) and high value (A1) restoration were compared at 1 mm and 2 mm. A comparison of mean surface hardness values showed no difference between the two lights.

Since the correlation between power density and polymerization has been established with

energiju suženjem zraka, dovodeći do većeg izlaza u poređenju sa standardnim svetlosnim smernicama. Dok se turbo vrh usmerava i povećava gustinu snage, suprotan efekat se vidi kada se ovaj vrh udaljava od cilja. Drugim rečima, primećuje se veći pad u gustini snage sa povećanjem gustine kada se turbo vrh uporedi sa standardnim vrhom. Price i saradnici su pokazali da je na 6 mm gustina snage turbo vrha pala za 77% u poređenju sa 50% standardnih svetlosnih smernica.[47]

Na količinu svetlosne energije potrebne za stomatološke restauracije uz upotrebu lepka može se uticati debljinom i neprovidnošću materijala koji se postavlja između polimerizacionog svetla i resina. Stepen neprovidnosti može da se kreće od veoma prozirnog i da odgovara optičkim osobinama ljudske gleđi do veoma neprozirnog, kako bi se pokrila tamna prebojenost.

Studije su pokazale da adekvatna polimerizacija na samom dnu restauracije ne zavisi samo od gustine snage, već i od tipa, nijanse, debljine i neprozirnosti materijala.[49-51] Studija na kojoj su radili O' Keefe i saradnici[52] pokazala je da je debljina materijala bila primarni faktor koji je uticao na svetlosnu transmisiju QTH svetla kroz različite debljine porcelana. Međutim, nije pronađeno da neprovidnost utiče na intenzitet svetlosti. Uočeno je da je nekoliko bočica sa različitim nijansama porcelana kombinovano da bi se dobila neprozirna formula, što je moglo da dovede do nekih nedoslednosti. Studija koju su vodili Barghi i McAlister poredila je efekat porcelanskih nijansi i gustine na tvrdoću površine kompozitnog resina uz upotrebu LED (Ultra-Lime2) i QTH polimerizacionog svetla (Optilux 501).[53] Dve nijanse porcelana koje su predstavljale restauracije niske vrednosti (C4) i visoke vrednosti (A1) su poređene na 1 mm i 2 mm. Poređenje srednjih vrednosti površinske tvrdoće nije ukazalo na razliku između ova dva svetla.

Pošto je korelacija između gustine snage i polimerizacije ustanovljena sa QTH svetlima[54], to predstavlja važan faktor kada se procenjuju LED svetla. Kada je gustina snage (mw/cm^2) standardnog QTH polimerizacionog svetla (Optilux 501) bila poređena sa onom koja je karakteristična za LED svetlo (L.E.Demetron) delovanjem kroz tri neprozirna keramička materijala (niska, srednja i visoka neprozirnost) i četiri gusta keramička materijala (1,2,3 i 4

QTH lights[54], it is also an important consideration when evaluating LED lights. When power density (mw/cm^2) of a standard QTH polymerization light (Optilux 501) was compared to that of a LED light (L.E.Demetron) by curing through three opacities (low, medium, high) and four thicknesses (1, 2, 3, and 4 mm) of ceramic, no differences in power attenuation were found between the LED light and the standard QTH light.[55] Overall, power density decreased as porcelain thickness and opacity increased at all levels with the greatest power reduction reaching 89% curing through the 4 mm, high opaque material for both lights.

mm), nije registrovana nikakva razlika u slabljenju snage između LED i standardnih QTH svetala.[55]

Na kraju, gustina snage je opadala kako su se gustina porcelana i neprozirnost povećavale na svim nivoima sa najvećom redukcijom snage do 89%. Proces lečenja je išao i do 4 mm dubine kroz visoko neprozirne materijale uz upotrebu oba svetla.

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