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Neimar Sartori[1], Alena Knezevic[1], Lais Dalmagro Peruchi[2], Jin-Ho Phark[1], Sillas Duarte Jr[1]

Effects of Light Attenuation through Dental Tissues on Cure Depth of Composite Resins

Utjecaj gubitka svjetla pri prolasku kroz zubno tkivo na dubinu stvrdnjavanja kompozitnog materijala

[1] Division of Restorative Sciences, Herman Ostrow School of Dentistry of USC, University of Southern California, Los Angeles, CA, USA. 925 W 34th Street, DEN 4365, Los Angeles, CA 90089-0641
Zavod za restaurativne znanosti, Stomatološki fakultet Herman Ostrow, University of Southern California, Los Angeles, CA, SAD.
[2] Advanced Education in Pediatric Dentistry. NYU Langone – CA South, 8110 Birmingham Way, San Diego, California 92123.
Izobrazba u dječjoj stomatologiji. NYU Langone – CA South, San Diego, California, SAD

Abstract

Objective. Polymerization of light-cured resin-based materials is well documented; however, the intensity of the activating light can be reduced by passage through air, dental structure, or restoration compromising the physical and mechnical properties of the restoration. The aim of this study was to evaluate the depth of cure of different light cured composite resins polymerized directly or transdental, through enamel and enamel/dentin tissues. **Material and methods.** Five composite resins were selected for this experiment: SureFil SDR, Dentsply (SDR), Filtek Supreme Plus, 3M ESPE (FSP), Aelite LS, Bisco (ALS), Filtek LS, 3M ESPE (FLS), and TPH, Dentsply (TPH). Thirty specimens of each material were prepared with 2- or 4-mm thickness. The specimens were light-cured (Elipar 2500, 3M ESPE) for 40 sec using three different protocols: direct or transdental, through a disc of enamel with 1 mm of thickness, and a disc of enamel and dentin with 2 mm of thickness. Eight Vickers microhardness (VH) measurements were taken from each specimen, four on top and four on bottom surface (Micromet, Buehler, 100 g per 15 sec). Data was analyzed with ANOVA three-way, Tukey HSD post-hoc ($\alpha = .05$). **Results.** Bottom surfaces of specimens exhibited statistically significant lower Vickers microhardness than the top surfaces for all composite resin evaluated, regardless of the curing conditions, except for the SDR when direct light-cured. Transdental light curing through enamel/dentin layer, significantly decreased VH ($P<0.05$) on the bottom surface of all composite groups. **Conclusion.** The results of this study showed that light-curing attenuation of dental structures negatively affect the micro-hardness of composite resins.

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Address for correspondence
Neimar Sartori, DDS, MS, PhD
University of Southern California
Herman Ostrow School of Dentistry
of USC
Norris Dental Science Center
925 W 34th Street, DEN 4365 | Los
Angeles, CA 90089-0641
Tel: 213 740 3762
Fax: 213 740 0174
sartori@usc.edu

Key words
Composite resins; Light curing; Vickers hardness; Trans-dental polymerization; Low-shrinkage composite; Flowable composite

Introduction

Light-cured composite resin materials are widely used in everyday clinical practice. Composite materials present several advantages, such as ease of handling, satisfactory physical and mechanical properties, and most importantly, excellent esthetic appearance. However, light-cured resin-based materials must be exposed to a sufficient amount of blue light energy to achieve satisfactory conversion of resin monomers into polymers (1).

Degree of polymerization of composite materials depends not only on their chemical composition but also on the properties of the light-curing unit. Improper curing of the composite materials would decrease their physical properties, leading to marginal leakage, secondary caries, higher wear, and poor esthetic appearance of the composite restoration (2, 3).

In order to enhance clinical success of composite resin restorations, dental manufacturers have focused on the de-

Uvod

Svjetlosno stvrdnjavajući kompozitni materijali već se dugo vremena svakodnevno upotrebljavaju u kliničkoj praksi. Naime, imaju nekoliko prednosti kao što su lakoća rukovanja, zadovoljavajuće fizičke i mehaničke značajke te izvrsna estetska svojstva. No svjetlosno stvrdnjavajući smolasti materijali moraju biti izloženi odgovarajućoj količini energije plavog svjetla kako bi se postigla zadovoljavajuća koverzija monomera u polimer (1).

Stupanj konverzije kompozitnih materijala ne ovisi samo o njihovu kemijskom sastavu nego i o svojstvima uređaja za polimerizaciju. Nedostatno stvrdnjavanje kompozitnih materijala utjecat će na smanjenje fizičkih svojstava kompozitnog ispuna, uzrokujući, između ostaloga, rubno propuštanje, sekundarni karijes, veće trošenje te loš estetski izgled kompozitne restauracije (2, 3).

Kako bi se postigao klinički uspjeh kompozitne restauracije, proizvođači dentalnih materijala usredotočili su se na ravelopment of new light curing units, as well as the improvement of composite material composition. The introduction of nanotechnology enabled the development of composite resins with higher filler content, decreased filler size, and enhanced composition in methacrylate-base organic matrix (4, 5). Changing the monomer structure of composite resins also led low-shrinkage and tooth-colored silorane-based resins, composed of siloxane and oxirane molecules (5-9). Due to the siloxane components, silorane materials have lower water sorption and solubility than conventional methacrylate-based composite materials (8, 9). The oxirane components provide lower polymerization shrinkage and higher strength through a cationic ring-opening mechanism and cationic polymerization of the composite resin (8, 10).

Another variable, which is important for durability of the light-curing composite resins is their limited depth of cure. In general, only increments up to 2 mm thick should be placed to ensure adequate light transmittance and composite resin polymerization. Recently, some bulk-fill based composite materials with low polymerization shrinkage and higher dissipation of induced energy, which increases the depth of cure, have been introduced to the market (11). Studies have shown that some bulk-fill materials can be cured adequately at depths up to 5 mm due to their increased light transmittance (12, 13). Controversially, other studies have shown significantly less depth of cure for the bulk-fill composite resins than claimed by manufacturers (14, 15).

However, regardless of the composite resin used, inadequate light-curing, especially in the deepest area of the composite restoration, remains an issue. In cavity preparation with deep undercut areas, it is impossible to place the tip of the light guide directly on the top of the light-cured composite resin (16-18). In such cases, enamel and dentin would attenuate intensity of the light delivered to the resin based composite material, depending on their optical properties like light transmittance and light diffusion (16-19).

Light transmittance through enamel and dentin is not well described in the literature so far. When the light irradiation is applied parallel to the dentine tubules the light is in that case scattered mainly from the dentine tubules while at the same time scattering pattern of obliterated dentine tubules will not be different from the scattering pattern of the regular structured dentine (20, 21). Some published studies described the effects of light irradiation through enamel on light-activated restorative materials and reported that the light-attenuation effect of enamel significantly diminished the depth of cure and hardness of the cured resin restoration (17, 19, 22, 23). However, it is still not clear if light-attenuation by enamel and enamel/dentin tissues affect the mechanical properties and degree of conversion of composite resin.

The degree of conversion of the resin monomer formulations is one of the most significant variables evaluated for assessing mechanical properties of polymerized composite resin materials. The degree of conversion of composite resin can be determined by direct and indirect methods. Direct methods for assessment the quality of polymerization of composite material are usually determinated using Fourier transform infrared spectroscopy (FTIR) or Raman Spec-

zvoj novih uređaja za polimerizaciju te na poboljšanje sastava kompozitnih materijala. Uvođenje nanotehnologije omogućilo je proizvodnju kompozitnih materijala s većim udjelom punila i manjim česticama, a poboljšan je i sastav organske komponente (4, 5). Mijenjanje strukture monomera kompozitnog materijala rezultiralo je uvođenjem niskoskupljajućih monomera i silorana proizvedenih na temelju siloranskih i oksiranskih molekula (5 – 9). Zbog siloranskih komponenti, silorani imaju nižu apsorpciju vode i nižu topljivost nego konvencionalni kompozitni materijali izrađeni na temelju metakrilata (8, 9). Oksiranske komponente osiguravaju manje polimerizacijsko skupljanje i veću snagu zahvaljujući kationskom postupku polimerizacije (8, 10).

Važan čimbenik za dugotrajnost kompozitnog ispuna jest ograničavajuća dubina stvrdnjavanja kompozitnog materijala tijekom polimerizacije. Općenito, trebali bi se postavljati samo slojevi do 2 mm debljine kako bi se osigurao odgovarajući prolazak svjetla i samim time zadovoljavajuća polimerizacija kompozitnog materijala. Nedavno su se na tržištu pojavili *bulk-fill* kompozitni materijali s niskim stupnjem polimerizacijskog skupljanja i većim rasipanjem energije, što povećava dubinu stvrdnjavanja (11). Neka ispitivanja pokazala su da se neki takvi materijali mogu uspješno polimerizirati i pri debljini sloja od 5 mm, zahvaljujući povećanoj transmisiji svjetla kroz takvu vrstu materijala (12, 13). Suprotno tomu, neka istraživanja pokazala su značajno manju dubinu stvrdnjavanja *bulk-fill* kompozitnih materijala nego što to navodi proizvođač (14, 15).

No bez obzira na to koja je vrsta kompozitnog materijala korištena, nedostatno osvjetljivanje, posebno u dubokim dijelovima kompozitne restauracije, još uvijek predstavlja znatan problem. U nekim kliničkim situacijama gotovo je nemoguće postaviti izvor svjetla izravno na površinu kompozitnog materijala, osobito u dubokim i podminiranim kavitetima (16 – 18). U tom slučaju caklina i dentin umanjuju intenzitet, odnosno energiju svjetla emitiranu iz uređaja za polimerizaciju, ovisno o transmisijskim i difuzijskim svojstvima cakline i dentina i kompozitnog materijala (16 – 19).

Transmisija svjetla za polimerizaciju kroz caklinu i dentin nije dovoljno opisana u stručnoj literaturi. Kada je svjetlo aplicirano paralelno s dentinskim tubulusima, raspršuje se uglavnom s dentinskih tubulusa. Istodobno, način raspršivanja svjetla na obliteriranim dentinskim tubulusima ne razlikuje se od onoga na regularno strukturiranom dentinu (20, 21). U nekim istraživanjima opisan je učinak osvjetljivanja kroz caklinu na svjetlosno stvrdnjavajuće restaurativne materijale pa autori zaključuju da raspršivanje svjetla kod cakline značajno smanjuje dubinu stvrdnjavanja i čvrstoću polimeriziranog kompozitnog materijala (17, 19, 22, 23). No još nije potpuno jasno utječu li disperzija svjetla kroz caklinu te caklina i dentin na mehanička svojstva i dubinu stvrdnjavanja kompozitnog materijala.

Stupanj konverzije smolastih materijala jedan je od značajnih parametara za procjenu mehaničkih svojstava polimeriziranog kompozitnog materijala. Može se odrediti direktnim ili indirektnim postupkom. Direktnim postupkom stupanj konverzije kompozitnog materijala obično se određuje uporabom *Fourier transform infrared* spektroskopije troscopy. Indirect methods for assessment of quality of polymerization of composite materials are Knoop and Vickers hardness (24, 25).

Therefore, the aim of this study was to evaluate the depth of cure of different composite resins cured directly and transdentally through enamel and enamel/dentin tissues. The null hypothesis assessed was that light-attenuation by dental tissues does not decrease the depth of cure or mechanical properties of light-cured composite resins used in this study.

Material and methods

In this in vitro study, five different composite resins were evaluated: two flowable [SureFil SDR (SDR), Filtek Supreme Plus Flowable (FSP),], two low-shrinkage [Aelite LS (ALS), Filtek LS (FLS)], and one microhybrid [TPH 3 Micro Matrix Restorative (TPH)]. The composition of composite resins used in this study is presented in Table 1, according to the manufacturer's information.

(FTIR) ili Ramanovom spektroskopijom. Najčešće korištena indirektna metoda u procjeni učinkovitosti polimerizacije kompozitnog materijala ili stupnja konverzije jest Knoopova i Vickersova čvrstoća (24, 25).

Svrha ovoga rada bila je odrediti dubinu stvrdnjavanja različitih kompozitnih materijala polimeriziranih izravnim postupkom te transdentalnom polimerizacijom preko cakline te cakline i dentina uporabom postupka Vickersove mikročvrstoće. U tu svrhu postavljena je nulta hipoteza da raspršenje svjetla uzrokovano zubnim tkivom ne utječe na smanjenje dubine stvrdnjavanja ni na mehanička svojstva svjetlosno polimerizirajućih kompozitnih materijala korištenih u ovom ispitivanju.

Materijali i postupci

U ovom ispitivanju *in vitro* korišteno je pet različitih kompozitnih materijala – dva tekuća [SureFil SDR, Dentsply (SDR), Filtek Supreme Plus Flowable, 3M ESPE (FSP),], dva niskoskupljajuća [Aelite LS, Bisco (ALS), Filtek LS, 3M ESPE (FLS)] i jedan mikrohibridni [TPH 3 Micro Matrix Restorative, Dentsply (TPH)].

Sastav kompozitnih materijala (prema podatcima proizvođača) korištenih u ovom ispitivanju prikazan je u tablici 1.

Table 1 Commercial name, chemical composition and batch number of the composite materials used in this study.
Tablica 1. Tvornički ime, kemijski sastav i serijski broj kompozitnih materijala korištenih u ispitivanju

Material (Manufacturer) • Materijal (proizvodjač)	Chemical Composition • Kemijski sastav	Batch # • Serijski broj
SureFil SDR (Dentsply, York, PA, USA) Bulk Fill Flowable • *Bulk Fill* tekući	Polymerizable dimethacrylate resins, polymerizable urethane dimethacrylates, barium boron fluoro-aluminosilicate glass, silicon dioxide, amorphous, strontium aluminosilicate glass, and titanium dioxide • Polimerizirajuće dimetakrilatne smole, polimerizirajući uretan dimetakrilati, barijevo boro fluoro-alumosilikatno staklo, silicijev dioksid, amorfno stroncijevo aluminosilikatno staklo, titanijev dioksid	091028
Filtek Supreme Plus (3M ESPE, St Paul, MN, USA) Flowable • Tekući	Silane treated ceramic, silane treated silica, bisphenol a polyethylene glycol diether dimethacrylate, diurethane dimethacrylate, bisphenol A diglycidyl ether methacrylate, triethylene glycol dimethacrylates, benzotriazol, ethyl 4-dimethyl aminobenzoate, diphenyliodonium hexafluorophosphate • Keramika tretirana silanom, silika tretirana silanom, bisfenol polietilen glikol dieter dimetakrilat, diuretan-dimetakrilat, bisfenol A diglicidil eter metakrilat, trietilen glikol dimetakrilat, benzotriazol, etil 4-dimetil aminobenzoat, difeniljod heksafluorofosfat	9JL
Aelite LS Posterior (Bisco, Schaumburg, Il, USA) Low shrinkage hybrid • Niskoskupljajući hibrid	Ethoxylated bisphenol A glycol dimethacrylate, bisphenol A glycol dimethacrylates, triethylene glycol dimethacrylates glass filler, and amorphous silica • Etoksilirani bisfenol A glikol dimetakrilat, bisfenol A glikol dimetakrilat, trietilen glikol dimetakrilatno stakleno punilo, amorfna silika	1000005228
Filtek LS (3M ESPE, St Paul, MN, USA) Low shrinkage silorane based • Niskoskupljajući temeljen na siloranima	Silane treated quartz, 3,4-epoxycyclohexylcyclopolymethylsiloxane, BIS-3,4-epoxycyclohexylethyl-phenyl-methylsilane, yttrium trifluoride, mixture of epoxy-monosilanole, mixture of epoxyfunctional di- and oligo-siloxane, mixture of alpha-substituted, tetrakis(pentafluorophenyl)-[4-(methylethyl)phenyl](4-methylphenyl)iodonium • Kvarc tretiran silanom, 3,4-epoksiklorheksiciklopolimetilsiloksan, BIS-3,4-epoksicikloheksetil-fenil-metilsilan, itrijev trifluorid, mješavina epoksi-mono-silanola, mješavina epoksi-funkcionalnih di- i oligo-siloksana, mješavina alfa-supstituta, tetra (pentafluorfenil-4-metiletil fenil 4-metilfenil jod.	N169991
TPH 3 Micro Matrix Restorative (Dentsply, York, PA, USA) Microhybrid • Mikrohibrid	Titanium dioxide, hydrophobic amorphous fumed silica, silica (amorphous), barium boron fluoro alumino silicate glass, urethane modified Bis-GMA dimethacrylates, polymerizable dimethacrylate resin, inorganic iron oxides • Titanijev dioksid, hidrofobna amorfna silika, amorfna silika, barij boro-fluoroalumosilikatno staklo, uretanom modificirani Bis-GMA dimetakrilati, polimerizirajuće dimetakrilatne smole, anorganski željezni oksidi	100310

Enamel and enamel/dentin discs preparation

An intact freshly extract, non-carious, non-restored human third molar was selected after the donors' informed consent was obtained under a protocol approved by the institutional review board of the University of Southern California. The tooth was scaled, cleaned, stored in 0.5% chloramine solution at 4° C to prevent bacteria growth and used within three months after extraction.

The tooth was sectioned in mesio-distal direction, parallel to its long axis using a diamond saw (Isomet 1000, Buehler Ltd., Lake Bluff, IL, USA) under distilled water-cooling to obtain a buccal and a lingual tooth slab. Both slabs were then further trimmed with a fine diamond bur in a high-speed hand piece under water cooling to obtain discs with a final diameter of 4 mm each. The discs were then polished using a waterproof 600-grit silicon carbide paper under running water to create a disc of enamel with a final thickness of 1 mm and another disc of enamel and dentin with a final thickness of 2 mm. Both discs were immersed in 0.5 M ethylenediaminetetraacetic acid (EDTA) solution for 2 min for cleaning and removal of the smear layer. The discs were then thoroughly rinsed with distilled water for 60 s and then stored in the same solution to avoid dehydration.

Depth of Cure by Vickers Microhardness

Opaque standardized polytetrafluoroethylene molds, with 2- and 4-mm thickness and an internal diameter of 2 mm, were used to fabricate the composite specimens. The molds were then placed on the top of a glass slide; the internal portion of the mold was filled in bulk with each composite resin and covered with another glass slide with a pressure of 1 kg for 30 sec. The composite resin specimen was then light-cured directly, through a disc of enamel with 1 mm of thickness, or through a disc of enamel/dentin with 2 mm of thickness. All specimens were light-cured for 40 sec with irradiance of 800mW/cm^2 (Elipar 2500, 3M ESPE, St Paul, MN, USA), keeping the tip of the light-curing unit in contact with the glass slide or the dental tissue disc (Figure 1).

After polymerization, each specimen was removed from the mold and stored in distilled water for 24 h at 37° C in a dark container. Subsequently, microhardness measurements were taken from the top and bottom surfaces of each specimen using a Vickers microhardness tester (Buehler MicroMet, Buehler Ltd., Lake Bluff, IL, USA). The micro indenter

Preparacija caklinskih i caklinsko/dentinskih diskova

Intaktni svježe ekstrahirani nekarijesni i nerestaurirani ljudski treći molar (kutnjak) izabran je nakon potpisivanja pristanka donora prema protokolu koji je odobrilo Etičko povjerenstvo Sveučilišta Južne Kalifornije (University of Southern California). Ostatak parodontnog tkiva poslije ekstrakcije uklonjen je skelerom nakon čega je zub temeljito očišćen te pohranjen u 0,5-postotnu otopinu kloramina na temperaturi od 4 °C kako bi se spriječio rast bakterija. Tako spremljeni zub korišten je unutar tri mjeseca poslije ekstrakcije.

Zub je prerezan dijamantnom pilom (Isomet 1000, Buehler LTd., Lake Bluff, IL, SAD) u mezio-distalnom smjeru, paralelno s uzdužnom osi, uz hlađenje destiliranom vodom kako bi se dobili bukalni i lingvalni uzorci zuba. Nakon toga uzorci su dalje rezani finim dijamantnim svrdlom postavljenim na električnu turbinu uz hlađenje vodom kako bi se dobili diskovi konačnog promjera od 4 mm. Diskovi su zatim polirani vodootpornim silikonskim karbidnim papirom (od 600 grita) pod mlazom vode kako bi se dobili diskovi cakline konačne debljine od 1 mm te disk od cakline s dentinom završne debljine od 2 mm. Oba diska uronjena su dvije minute u 0,5 M etilendiamintetraoctenu kiselinu (EDTA) zbog čišćenja i uklanjanja zaostatnog sloja. Nakon toga temeljito su ispirani destiliranom vodom 60 sekunda te pohranjeni u istu otopinu kako bi se izbjegla dehidracija.

Dubina stvrdnjavanja mjerena Vickersovim mjeračem mikročvrstoće

Opakni standardizirani politetrafluoroetilni kalup debljine 2 i 4 mm te unutarnjeg promjera od 2 mm, korišteni su za pripremu kompozitnih uzoraka. Kalupi su stavljeni na površinu pokrovnog stakalca – u unutarnji dio kalupa stavljen je u jednom komadu svaki ispitivani kompozitni materijal, a zatim je prekriven drugim pokrovnim stakalcem uz 30-sekundni pritisak od 1 kg. Kompozitni uzorci osvijetljeni su nakon toga direktnim postupkom, kroz disk od cakline debljine 1 mm, te kroz disk od cakline/dentina debljine 2 mm. Svi uzorci osvjetljavani su 40 sekunda intenzitetom od 800 mW/cm2 (Elipar 2500, 3M ESPE), pazeći pritom da je radni dio uređaja za polimerizaciju u kontaktu s pokrovnim stakalcem ili diskom od zubnog tkiva (slika 1.).

Nakon polimerizacije svaki je uzorak izvađen iz kalupa i spremljen u destiliranu vodu 24 sata na temperaturi od 37 °C u tamnom kontejneru. Nakon toga je mikročvrstoća izmjerena na površini i na dnu svakog uzorka uporabom Vickersova mjerača mikročvrstoće (Buehler MicroMet, Buehler Ltd.,

Polytetrafluoroethylene molds with 2 and 4 mm of thickness

Composite resin placement in one increment

Glass slide compression for 30 s before light-curing

Light-curing for 40 s

Samples with 4 mm of thickness

Figure 1 Working flow of the composite resin specimens' fabrication for the Vickers microhardness test.
Slika 1. Postupak pripreme uzoraka kompozitnih materijala za mjerenje Vickersove mikročvrstoće

was pressed to the composite specimen using a load of 100 g for 15 sec. Vickers microhardness was measured at four points of each surface (top and bottom) of the specimen to minimize measurement errors within a specimen.

Statistical Analysis

The Vickers hardness values were analyzed using a statistical software package (SPSS 17, SPSS Inc., Chicago, IL, USA). The data was first analyzed for normality with the Shapiro-Wilk test. Since all groups showed a normal distribution, the differences in the microhardness between the composite resins, light-curing procedure (direct, transdental through enamel or enamel and dentin) and depth of cure (top and bottom surfaces) were statistically analyzed using 3-way ANOVA. To isolate statistical significance among the groups, the data was submitted to Tukey HSD post-hoc test at a confidence level of 95 %.

Results

Results of the VH measurements for all composite resin, light-curing protocol and surfaces were presented in Table 2. The VH of the top surface of the composite resins revealed that the highest values of microhardness were observed with the low shrinkage hybrid resin (ALS), regardless of the curing procedure (directly, through enamel or enamel/dentin discs). Both flowable composite resins, SDR and FSP, show the lowest values of VH on the top surface, regardless of the light-curing modes. No statistically significant difference was observed between two flowable composites, regardless of the light-curing procedure except when curing through 4 mm sample (P>0.05). At the bottom surface of the

Lake Bluff, IL, SAD). Mikromjerač je pritisnut na kompozitni uzorak uporabom opterećenja od 100 g tijekom 15 sekunda. Vickersova mikročvrstoća mjerena je na četiri mjesta na svakoj površini uzorka (gornja površina uzorka i dno uzorka) kako bi se minimizirale pogreške pri mjerenju.

Statistička analiza

Vrijednosti Vickersove čvrstoće analizirane su statističkom paketom softvera (SPSS 17, SPSS Inc., Chicago, IL, SAD). Podatci su najprije analizirani za normalne vrijednosti uporabom Shapiro-Wilkova testa. Budući da sve grupe pokazuju normalnu distribuciju, razlika u mikročvrstoći između kompozitnih materijala, postupka polimerizacije (direktna, transdentalna kroz caklinu ili caklinu/dentin) i dubina stvrdnjavanja (površina ili dno uzorka), statistički su analizirani programom trosmjerne ANOVA- e. Da bi se utvrdila statistička značajnost između grupa, podatci su analizirani Tukeyevim post-hoc HSD testom s razinom pouzdanosti od 95 %.

Rezultati

Rezultati VH mjerenja za svaki kompozitni materijal na površini i na dnu uzorka pri osvjetljavanju direktnim postupkom te preko cakline i caklinsko/dentinskih diskova za uzorak debljine od 2 i 4 mm prikazani su u tablici 2.

VH površine uzorka kompozitnih materijala pokazao je da je najveća vrijednost mikročvrstoće zapažena za niskoskupljajući hibridni kompozitni materijal ALS, bez obzira na postupak osvjetljavanja (direktna polimerizacija, polimerizacija preko caklinskih ili caklinsko/dentinskih diskova). Oba tekuća kompozitna materijala – SDR i FSP, pokazala su najniže vrijednosti VH-a na površini uzorka ne uzimajući u obzir postupak polimerizacije. Nije uočena statistički značajna ra-

Table 2 Mean microhardness values and statistical results of the composite resins evaluated on the top and bottom surfaces of the specimens.

Tablica 2. Srednje vrijednosti mikročvrstoće i statistički rezultati uzoraka kompozitnih materijala s površine i dna uzorka

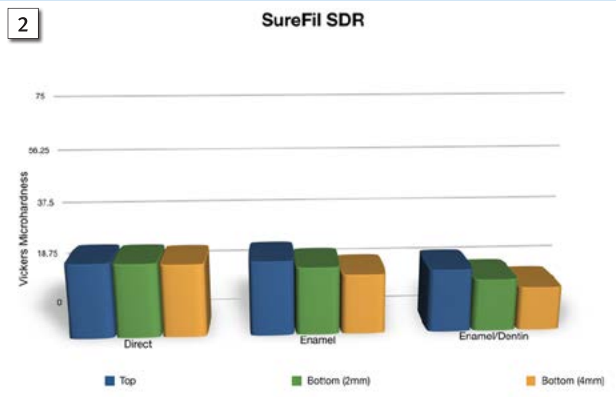
Curing protocol • Postupak osvjetljavanja		SDR	FSP	ALS	FLS	TPH
Direct • Direktni	Top • Površina	25.72^{aA}	29.50^{aA}	75.97^{aC}	48.64^{aB}	47.80^{aB}
Enamel • Caklina		25.68^{aA}	25.08^{aA}	58.83^{bC}	42.87^{bB}	48.98^{aB}
Enamel/Dentin • Caklina/Dentin		21.74^{aA}	26.04^{aA}	49.87^{cC}	40.66^{bD}	47.22^{aC}
Direct • Direktni	Bottom • Dno (2 mm)	$25.46^{aA\alpha}$	$28.78^{aA\alpha}$	$43.33^{aB*\alpha}$	$40.70^{aB*\alpha}$	$46.70^{aB\alpha}$
Enamel • Caklina		$23.26^{aA\beta}$	$19.18^{bA*\beta}$	$36.00^{bB*\beta}$	$32.90^{bB*\beta}$	$42.20^{aC*\beta}$
Enamel/Dentin • Caklina/Dentin		$18.02^{bA*\delta}$	$18.62^{bA*\delta}$	$34.42^{bC*\delta}$	$27.60^{cB*\delta}$	$35.07^{bC*\delta}$
Direct • Direktni	Bottom • Dno (4 mm)	$25.00^{aA\alpha}$	$22.14^{aB*\varepsilon}$	$36.35^{aD*\varepsilon}$	$24.92^{aA*\varepsilon}$	$39.64^{aE*\varepsilon}$
Enamel • Caklina		$20.54^{bA*\lambda}$	$14.72^{bB*\lambda}$	$34.17^{aD*\beta}$	$16.28^{bB*\lambda}$	$31.20^{bC*\lambda}$
Enamel/Dentin • Caklina/Dentin		$15.00^{cA*\tau}$	$12.32^{bB*\tau}$	$29.86^{bD*\tau}$	$9.82^{cE*\tau}$	$27.20^{cD*\tau}$

Means with the same superscript lower-case letters, within the same column for each surface (comparing the curing protocols) are not statistically different (P>0.05). • Srednje vrijednosti s istim u superskriptu malim slovom, u istoj koloni za svaku površinu (uspoređujući postupak osvjetljavanja) nisu statistički različite (P > 0,05).

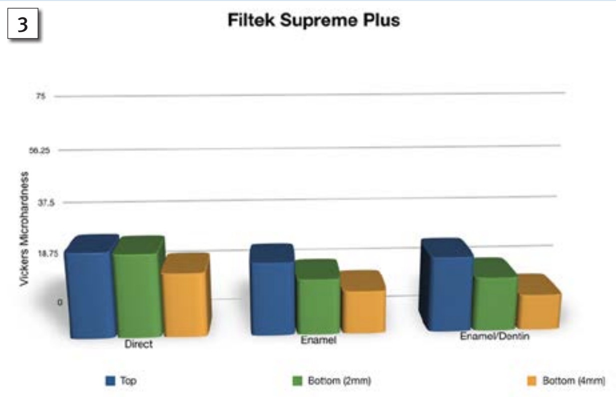
Means with the same superscript upper-case letter, within the same row (comparing the composite resins), are not statistically different (P>0.05). • Srednje vrijednosti s istim u superskriptu velikim slovom, u istom retku (uspoređujući kompozitne materijale), nisu statistički značajne (P > 0,05).

Means of the bottom surface with asterisk differ from top value when light-cured using the same protocol (P<0.05). For the bottom surfaces, means with the same superscript Greek letter, within the same column, are not statistically different (P>0.05). • Srednje vrijednosti dna uzorka sa zvjezdicom različitom od vrijednosti izmjerene na površini uzorka pri istom protokolu osvjetljavanja (P < 0,05); za dno uzorka, srednje vrijednosti s istim grčkim slovom u superskriptu, u istoj koloni, nisu statistički značajne (P >,05).

2



3



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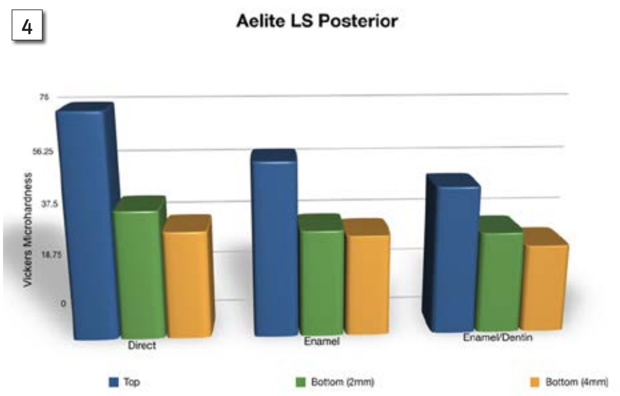

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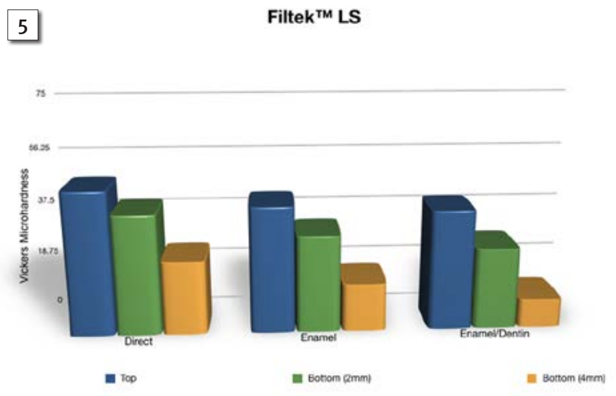

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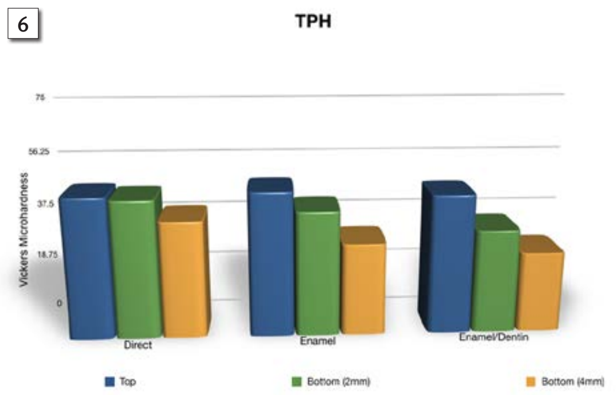

Figure 2 Graphical representation of the microhardness means (in Vickers) of the flowable composite resin SureFil SDR on top and bottom surfaces.

Slika 2. Grafički prikaz srednjih vrijednosti mikročvrstoće (Vickersove) tekućeg kompozitnog materijala SureFil SDR na površini i na dnu uzorka

Figure 3 Graphical representation of the microhardness means (in Vickers) of the flowable composite resin Filtek Supreme Plus on top and bottom surfaces.

Slika 3. Grafički prikaz srednjih vrijednosti mikročvrstoće (Vickersove) tekućeg kompozitnog materijala Filtek Supreme Plus na površini i na dnu uzorka

Figure 4 Graphical representation of the microhardness means (in Vickers) of the low-shrinkage composite resin Aelite LS Posterior on top and bottom surfaces.

Slika 4. Grafički prikaz srednjih vrijednosti mikročvrstoće (Vickersove) niskoskupljajućeg kompozitnog materijala Aelite LS Posterior na površini i na dnu uzorka

Figure 5 Graphical representation of the microhardness means (in Vickers) of the low-shrinkage composite resin Filtek™ LS on top and bottom surfaces.

Slika 5. Grafički prikaz srednjih vrijednosti mikročvrstoće (Vickersove) niskoskupljajućeg kompozitnog materijala Filtek LS na površini i na dnu uzorka

Figure 6 Graphical representation of the microhardness means (in Vickers) of the microhybrid composite resin TPH on top and bottom surfaces.

Slika 6. Grafički prikaz srednjih vrijednosti mikročvrstoće (Vickersove) mikrohibridnog kompozitnog materijala TPH na površini i na dnu uzorka

4-mm thick sample, the lowest VH values were observed for the groups SDR, FSP and FLS for all curing procedures. The highest values at bottom surface of the 4 mm thick sample were observed for the composites ALS and THP.

For the composite SDR, the VH on the top surfaces was not affected by the curing procedure (Figure 2). There was no statistically significant difference between the VH values of the surfaces evaluated (top and 4-mm bottom) when the light was applied directly on the composite resin ($P>0.05$). However, the interposition of a disc of 2-mm enamel and dentin significantly reduced VH on the bottom surface of

zlika između dvaju tekućih kompozitnih materijala, bez obzira na postupak osvjetljavanja, osim u slučaju osvjetljavanja kroz uzorke debljine 4 mm ($P > 0,05$). Na dnu uzorka od 4 mm debljine, najniži VH-i zabilježeni su za grupe SDR, FSP i FSL za sve postupke osvjetljavanja. Najviše vrijednosti na dnu površine uzorka debljine 4 mm zabilježene su za kompozitne materijale ALS i THP.

Kad je riječ o kompozitnom materijalu SDR, postupak polimerizacje nije utjecao na VH na površini uzorka (slika 2.). Nije utvrđena statistički značajna razlika između VH vrijednosti na površini i na dnu uzorka debljine 4 mm kaspecimens with 2-mm of thickness. There were statistically significant difference between the VH of bottom surfaces of 2- and 4-mm SDR specimens when transdental polymerization was used (P<0.05).

For the composite FSP, the curing procedure did not affect the VH top surface (Figure 3). There was, however, a significant reduction in the VH at the bottom surface of specimens with 4-mm, even when the light was applied directly on the composite resin (P<0.05). The presence of dental tissue discs significantly reduced the VH on the bottom surfaces, regardless of the specimen thickness.

For the composite ALS, the curing procedures significantly reduced the VH on top and both bottom surfaces of the composite resin (Figure 4). There is a significant reduction on the microhardness at the bottom surfaces (2- and 4-mm) regardless of the light-curing procedure.

For the composite FLS, the presence of a disc of 1 mm of enamel or 2 mm of enamel and dentin affect the top and bottom (2- and 4-mm) surfaces VH (P>0.05) (Figure 5). The lowest values of VH were observed at the bottom surface with 4 mm of thickness for when polymerized through the enamel and dentin disc (9.82 VH).

For the composite TPH, the curing mode did not affect the top surface polymerization (Figure 6). There was a significant reduction on the microhardness at the bottom surface (4-mm) even when the light was applied directly on the resin specimen. The presence of a dental tissue disc significantly reduced the VH on the bottom surfaces of specimens with 2- and 4-mm thickness (P<0.05).

Discussion

There are many published studies analyzing transmission of the blue light through different composite materials, however, there is a lack of data about transmission of the blue light through hard tooth structure, dentin and enamel, and how that will impact curing of composite materials (26, 27). Manufactures try to optimize and improve light transmittance through composite resin by changing and modifying organic matrix chemistry and morphological properties of fillers (26). As the dental composites are heterogeneous substances, the passing light is scattered at the resin-filler interface due to the differences in the refractive indices of the individual compounds (28, 29).

Uusitalo et al. (20) conducted a study where authors tested light transmittance through differently treated dentin and enamel surface. They concluded that light transmission through dentin was less than light transmission through enamel. Further, they found that the light is transmitted better through wet dentin and enamel than through dry substrate. Also, the exposed dentin tubules enhanced light transmission through the dentin surface (20). In our study, light irradiation through dental tissue significantly reduced the depth of cure of all composite resins evaluated, including the low-shrinkage and bulk-fill composites. Therefore, the null hypothesis stating that light-attenuation by dental tissues does not decrease the mechanical properties or the depth of cure of composite resin was rejected.

da je svjetlo aplicirano direktno na kompozitni materijal (P > 0,05). Međutim, osvjetljavanje preko diska cakline/dentina debljine 2 mm značajno je utjecalo na smanjenje VH vrijednosti na dnu površine uzoraka debljine 2 mm. Uočena je također statistički značajna razlika između VH-a na dnu uzoraka debljine 2 i 4 mm SDR uzoraka u slučaju postupka transdentalne polimerizacije (P < 0,05).

Pri korištenju kompozitnog materijala FSP, postupak osvjetljavanja nije utjecao na VH na površini uzorka (slika 3.). No zabilježeno je značajno smanjenje VH-a na dnu uzorka debljine 4 mm čak i u slučaju direktnog osvjetljavanja (P < 0,05). Diskovi zubnog tkiva značajno smanjuju VH na dnu uzorka, bez obzira na debljinu uzorka.

Pri upotrebi kompozitnog materijala ALS, postupak osvjetljavanja značajno smanjuje VH na površini i na dnu uzoraka debljine 2 i 4 mm (slika 4.). Uočeno je značajno smanjenje mikročvrstoće na dnu uzoraka (2 i 4 mm), bez obzira na postupak polimerizacije.

Pri korištenju kompozitnog materijala FLS, diskovi cakline debljine 1 mm te cakline/dentina debljine 2 mm utjecali su na VH i na površini i na dnu uzorka (P > 0,05) (slika 5.). Najniža vrijednost VH-a zapažena je na dnu uzorka debljine 4 mm pri polimerizaciji kroz diskove cakline i dentina (9,82 VH).

Kad je riječ o kompozitnom materijalu TPH, postupak polimerizacije nije utjecao na površinu uzorka (slika 6.). No uočeno je značajno smanjenje mikročvrstoće na dnu uzorka (4 mm) čak i kada je uzorak bio izložen direktnoj polimerizaciji. Diskovi zubnog tkiva značajno su utjecali na smanjenje VH-a na dnu uzoraka debljine 2 i 4 mm (P < 0,05).

Rasprava

U stručnoj literaturi objavljeno je više studija koje se bave proučavanjem prolaska plavog svjetla kroz različite kompozitne materijale, ali nema dovoljno podataka o njegovu prolasku kroz tvrdo zubno tkivo, dentin i caklinu, te kako to utječe na polimerizaciju kompozitnih materijala (26, 27). Proizvođači nastoje optimizirati i poboljšati prolazak svjetla kroz kompozitni materijal mijenjanjem ili modificiranjem kemijskog sastava organske matrice te morfoloških svojstava punila (26). Budući da su dentalni kompozitni materijali heterogene supstancije, tijekom prolaska kroz takav supstrat svjetlo se raspršuje na spoju organske matrice i punila zbog razlike u refraktivnom indeksu pojedinačnih komponenti (28, 29).

Uusitalo i suradnici (20) ispitivali su transmisiju svjetla kroz različito tretiranu dentinsku i caklinsku površinu. Zaključili su da je transmisija svjetla kroz dentin manja negoli kroz caklinu. Također su ustanovili da je bolja transmisija svjetla kroz vlažni dentin i caklinu negoli kroz suhi supstrat, te da eksponirani dentinski tubulusi poboljšavaju transmisiju svjetla kroz dentinsku površinu (20). U našem istraživanju osvjetljavanje kroz dentinsko tkivo značajno smanjuje dubinu stvrdnjavanja svih ispitivanih kompozitnih materijala, uključujući niskoskupljajuće i *bulk-fill* kompozite. Zato je odbijena nulta hipoteza da gubitak svjetla kroz zubno tkivo ne utječe na smanjenje mehaničkih svojstava ili dubinu stvrdnjavanja kompozitnih materijala.

A standardized test for depth of cure, ISO 4049 test, is mandatory for manufacturers to certify their resin-based composites and to set its curing time and increment thickness (3, 30). This test advocates scraping off the unset materials immediately after irradiation and measuring the length of the remaining specimen, which is then divided by two (12, 31).

Surface hardness tests (Knoop or Vickers) have been used most often to characterize the depth of cure and mechanical properties of visible light-cured resin based composite materials (31, 32). Uhl et al (33) showed that the degree of polymerization of composite materials could be better evaluated with Knoop or Vickers hardness than with depth of cure tests using a penetrometer. However, data obtained from different studies is difficult to compare mainly due to the different molding methods used. Black molds produce shorter depths of cure than a stainless-steel molds (34). White molds, generally made of Teflon or other translucent material, may allow more of the curing light to pass through the mold than through the composite resin (5, 35). Consequently, this may result in exaggerated depths of cure. Human tooth molds have also been used but they have varied size and have not been compared with a 4 mm diameter stainless steel mold, as specified in the ISO test to determine the depths of cure (12, 17, 36, 37).

Variations in the depth of cure between different composite materials may be ascribed initially to light scattering at particle interfaces and light absorbance by photoinitiators and pigments present in light-cured resin-based material. Both, light scattering, and light absorbance reduces the light penetration through the composite resin sample and therefore a reduced degree of conversion or degree of cure (12, 38, 39). Ilie et al (40) tested the correlation between the Vicker Hardness and filler loading in composite materials and concluded that increased filler loading reduces the volume of resin matrix for polymerization and intrinsically increases hardness (12, 38). Furthermore, the study stated that satisfactory degree of conversion might be due to the refractive index matching between the resin and filler, which enhances light transmission through the composite resin sample (40). Reduction in refractive index differences between resin and filler improved the degree of conversion and increased depth of cure as well as color shade matching (12, 28, 41). Uhl et al (37, 42) explained in their study that the influence of co-initiators in a composite on the Knoop hardness was less important in the depth of a composite. This was explained by the fact that the light transmittance in dental composites is higher for longer wavelengths than for shorter wavelengths. Therefore, it can be concluded that a high percentage of the shorter wavelengths is absorbed near the surface of the composite and cannot excite co-initiators in a deeper portion of the composite filling. Another study compared light penetration in bulk filled flowable and packable composites in comparison to regular flowable and conventional composites. The authors confirmed that amount of light transmitted through composite was dependent on the amount of scattered and absorbed light (13).

Light transmittance in the dental composite materials was shown to decrease with increased filler content and for

Standardizirani test za dubinu stvrdnjavanja – ISO 4049 test, obvezan je za proizvođače kompozitnih materijala kako bi im se pravilno odredilo vrijeme stvrdnjavanja i debljina slojeva pri postavljanju u kavitet (3,30). Taj test sastoji se u struganju nestvrdnutog materijala s površine uzorka neposredno nakon osvjetljavanja te mjerenja debljine zaostatnog uzorka čija se dobivena vrijednost zatim dijeli s dva (12, 31).

Test površinske čvrstoće (Knoopov ili Vickersov) najčešće su korišteni za određivanje dubine stvrdnjavanja i mehaničkih svojstava svjetlosno polimerizirajućih kompozitnih materijala (31, 32). Uhl i suradnici (33) pokazali su da se stupanj konverzije ili polimerizacije kompozitnih materijala može bolje odrediti Knoopovom ili Vickersovom čvrstoćom negoli testom dubine stvrdnjavanja uporabom penetrometra. No podatke dobivene u različitim istraživanjima teško je uspoređivati, uglavnom zbog različitih metoda u obavljanju eksperimenta i različitih kalupa. Crni kalupi uzrokuju manju dubinu stvrdnjavanja negoli oni od plemenitog čelika (34). Bijeli kalupi, uglavnom od teflona ili nekog drugog translucentnog materijala, mogu propuštati veću količinu svjetla kroz kalup negoli kroz kompozitni materijal (5, 35). Posljedično, to može rezultirati pogrešnim (višim) rezultatima dubine stvrdnjavanja. Kalupi izrađeni od zubnog tkiva također se spominju u literaturi, no različitih su veličina te nisu uspoređivani s kalupom od plemenitog čelika promjera 4 mm koji se navodi u ISO testu kao obvezan za određivanje dubine stvrdnjavanja (12, 17, 36, 37).

Varijacije u dubini stvrdnjavanja između različitih kompozitnih materijala mogu biti povezane s raspršivanjem svjetla na površini čestica punila te apsorpcijom svjetla u fotoinicijatoru i pigmenatima u kompozitnom materijalu. I raspršivanje i apsorpcija svjetla smanjuju prodiranje svjetla kroz uzorak kompozitnog materijala i tako smanjuju stupanj konverzije ili dubinu stvrdnjavanja (12, 38, 39). Ilie i suradnici (40) ispitivali su povezanost između Vickersove čvrstoće i udjela punila u kompozitnim materijalima te zaključili da porast udjela punila smanjuje volumen organske komponente za polimerizaciju te povećava unutarnju čvrstoću (12, 38). Uz to, u istoj se studiji ističe da zadovoljavajući stupanj konverzije može biti zbog podudaranja refraktivnog indeksa smole i punila, što poboljšava transmisiju svjetla kroz uzorak kompozitnog materijala (40). Smanjenje razlike u refraktivnom indeksu između smole i punila poboljšava stupanj konverzije i povećava dubinu stvrdnjavanja te bolje podudaranje boje kompozitnog materijala (12, 28, 41). Uhl i suradnici (37, 42) objasnili su u svojem istraživanju da je utjecaj koinicijatora u kompozitnim materijalima na Knoopovu čvrstoću manje važan u dubljim dijelovima kompozitnog uzorka. To je objašnjeno činjenicom da je transmisija svjetla u kompozitnim materijalima veća za duže valne duljine negoli za kraće. Zato se može zaključiti da se visok postotak kratkih valnih duljina apsorbira bliže površini kompozitnog uzorka i ne može ekscitirati koinicijatore u dubljim dijelovima kompozitnog uzorka. Druga skupina autora uspoređivala je prodor svjetla pri uporabi *bulk* tekućih kompozitnih materijala i kondenzirajućih kompozita u usporedbi s regularnim tekućim i konvencionalnim kompozitnim materijalima, te su zaključili da količina svjetla koja irregular filler shape, which is due to the increase of specific surface between fillers and resin (13, 39, 43-45). A further important fact in light transmission through composite is the treatment of fillers. Silane-coated fillers were shown to enhance, while uncoated fillers were shown to decrease light transmission (36). In our study FSP composite was used which has silane treated ceramic (52-60%) and silane treated silica (<11%) as stated in the manufacturer instructions. Also, FLS, low-shrinkage composite, has silane treated quartz, 60-70% wt. according to the manufacturer. However, in this study neither FLS nor FSP has shown superior Vicker's micro-hardness in comparison to other tested flowable or low-shrinkage composite.

The curing light in this study was halogen-curing unit with broad spectral emission. Arikawa et al (19) discussed in their study that amount of light transmitted through 1 mm thick enamel was only about 35% of the original light in the overall wavelength from 400-600 nm. Furthermore, the light transmission of dental enamel and dentin increased with increasing wavelength (17-20). In their study Arikawa et al (19) used an enamel filter made of a mixture of composite materials, while in our study natural enamel and enamel/dentin were used. In this recent study, the enamel and enamel/dentin samples were collected from the same tooth to avoid any difference in enamel and dentin composition with taking samples from different tooth. The enamel and dentin samples were also maintained in distilled water and used immediately to avoid any dehydration, which can have influence on the final results of light transmission. Regardless of composite materials used, higher Vickers microhardness values were observed when they were cured through enamel disc than enamel/dentin disc. Arikawa et al (17) showed in their study that dentin had strong light diffusion characteristics which would encourage the light-attenuating effect of the hard tissue. It is well established that light intensity drops with distance regardless of curing unit or composite materials used (46, 47). It was confirmed that the light intensity used to irradiate the composite material through 0.5 mm of enamel is almost half of the direct irradiation, while the light intensity attenuation through 1.5 mm enamel was almost 80% of the original light intensity (48).

From the table 2 it is visible that only for SDR bulk fill flowable composite material there is no difference between VH on the top (25.72) and on the bottom – 2 mm (25.46) and bottom – 4 mm (25.00) when using direct curing protocol. For all other materials there is a drop in the VH value when compared the top and bottom 2 and 4 mm in case of direct curing protocol. The highest drop was noticed in case of ALS low shrinkage hybrid composite: 75.97 on the top, 44.33 on 2 mm bottom and 36,35 on 4 mm bottom when direct curing protocol was used.

In clinical setting, when composite material needs to be cured through tooth structure, special care should be employed to minimize the reduction of restoration's mechanical properties. Prolonging irradiation time could compensate the light-attenuating effect of enamel and dentin. However, prolonging irradiation time also can raise the temperature in the composite resin itself, hard dental tissues and the pulp

prolazi kroz kompozitni materijal ovisi o količini raspršenog i apsorbiranog svjetla (13).

Pokazalo se da transmisija svjetla u dentalnim kompozitnim materijalima pada s porastom udjela punila za iregularni oblik čestica punila, što se povezuje s porastom specifične površine između punila i smole (13, 39, 43 – 45). Nadalje, vrsta tretmana čestica punila također je jedan od važnih čimbenika koji utječe na transmisiju svjetla kroz kompozitni uzorak. Kod kompozitnih materijala kojima su čestice presvučene silanom uočeno je poboljšanje transmisije svjetla, a one koje nisu presvučene pokazuju smanjenje transmisije svjetla (36). U našoj studiji korišten je kompozitni materijal FSP koji, prema podatcima proizvođača, sadržava čestice keramike (52 – 60 %) i silike (< 11 %) tretirane silanom. Niskoskupljajući kompozitni materijal FLS, prema podatcima proizvođača, sadržava i kvarc tretiran silanom (60 – 70 % težinskog udjela). No u ovoj studiji ni FLS ni FSP nisu pokazali bolju Vickersovu mikročvrstoću u odnosu prema ostalim ispitivanim tekućim ili niskoskupljajućim kompozitima.

U ovom radu korišten je halogenski uređaj za polimerizaciju koji emitira svjetlo širokog spektra. Arikawa i suradnici (19) pokazali su u svojom radu da transmisija svjetla kroz uzorak cakline debljine 1 mm iznosi oko 35 % ukupno emitiranog svjetla iz uređaja za polimerizaciju pri valnim duljinama od 400 do 600 nm. Istaknimo da transmisija svjetla kroz caklinu i dentin raste i s porastom valnih duljina (17 – 20). Arikawa i suradnici (19) koristili su se caklinskim filtrom napravljenim od mješavine kompozitnih materijala, a u našoj studiji korišteni su prirodna caklina i dentin. U ovoj studiji caklina i dentin uzeti su s istog zuba kako bi se izbjegle bilo kakve razlike u sastavu cakline i dentina ako bi se uzorci uzimali s različitih zuba. Uzorci cakline i dentina čuvani su u destiliranoj vodi i korišteni su neposredno da bi se izbjegla bilo kakva dehidracija koja bi mogla utjecati na rezultate transmisije svjetla. Bez obzira na vrstu korištenog kompozitnog materijala u eksperimentu, ako se izuzmu rezultati s površine, veća Vickersova mikročvrstoća zabilježena je kad su uzorci bili osvjetljeni preko diska od cakline negoli preko diska caklina/dentin. Arikawa i suradnici (17) pokazali su u svojem istraživanju da dentin ima izrazito svojstvo difuzije, što bi trebalo potaknuti prodor svjetla u slučaju tvrdoga zubnog tkiva. Dobro je poznato da intenzitet svjetla opada s udaljenošću od izvora svjetla, bez obzira na to koja se vrsta uređaja za polimerizaciju ili kompozitnog materijala rabi (46, 47). Potvrđeno je da je intenzitet svjetla pri osvjetljavanju kompozitnog materijala preko cakline debljine 0,5 mm gotovo pola količine direktnog osvjetljavanja, a intenzitet svjetla koje prođe kroz caklinu debljine 1,5 mm gotovo je 80 % direktnog izvora svjetla (48).

U tablici 2. vidi se da samo za *bulk fill* kompozit SDR nije zabilježena razlika između VH-a na površini (25.72), na dnu uzorka od 2 mm debljine (25,46) i na dnu uzorka od 4 mm (25,00) pri direktnom postupku osvjetljavanja. Kod svih ostalih materijala uočen je pad mikročvrstoće pri usporedbi površine i dna uzorka debljine 2 i 4 mm u slučaju direktnog osvjetljivanja. Najveći pad vrijednosti VH-a zabilježen je kod niskoskupljajućeg hibridnog kompozita ALS – 75,97 na površini, 43,33 na dnu kod uzorka debljine 2 mm te 36,35 na

(49). Further studies are needed to explore alternatives for adequate polymerization of composite resins under hard dental tissues and restorative materials, as well as, to evaluate the response of pulpal cell to prolonged light irradiation.

Conclusion

The results of this study showed that light-curing attenuation of dental structures negatively affect the micro-hardness of all composite resins at the bottom surface. Bulk fill flowable composite SDR and flowable FSP composite have lower VH on the top surface. Flowable (SDR and FSP) and microhybrid (TPH) composite resins can be properly polymerized by direct light irradiation on increments with a thickness up to 2 mm. To achieve better clinical results for Bulk fill composite polymerization it can be suggested to decrease incremental thickness and/or to extend the curing time.

Conflict of interest

The authors report no conflict of interest.

dnu uzorka debljine 4 mm kod direktnog postupka osvjetljavanja.

U kliničkim uvjetima, kada se kompozitni materijal treba osvijetliti preko zubne strukture, treba biti maksimalno oprezan kako se ne bi narušila mehanička svojstva budućeg kompozitnog ispuna. Produženje osvjetljavanja može kompenzirati prigušenje svjetla pri prolasku kroz caklinu i dentin, no to može uzrokovati porast temperature kako u samom kompozitu, tako i u dentinskom i pulpnom tkivu (49). Potrebna su dodatna istraživanja kako bi se ustanovili najpogodniji postupci polimerizacije kompozitnih materijala u slučaju osvjetljivanja preko zubne strukture ili druge vrste restaurativnog materijala te evaluirati odgovor pulpnih stanica na produljeno osvjetljivanje.

Zaključak

Rezultati ovog ispitivanja pokazali su da prigušenje svjetla pri prolasku kroz zubnu strukturu negativno utječe na mikročvrstoću na dnu uzorka kod svih kompozitnih materijala korištenih u ovom eksperimentu. *Bulk fill* (SDR) i tekući (FSP) kompoziti imaju nižu Vickersovu čvrstoću na površini uzorka. Tekući (SDR i FSP) te mikrohibridni (TPH) kompozitni materijali mogu se dostatno polimerizirati direktnim postupkom osvjetljivanja pri postavljanju slojeva do 2 mm debljine. Kako bi se ostvarila bolja polimerizacija *bulk-fill* kompozitnih materijala, preporučuje se postavljati ih u tanjim slojevima u kavitet ili produžiti vrijeme osvjetljavanja.

Sukob interesa

Autori nisu bili u sukobu interesa.

Sažetak
Svrha rada: Polimerizacija svjetlosno stvrdnjavajućih materijala vrlo je čest predmet istraživanja. Naime, intenzitet svjetla pada prolaskom kroz zubnu strukturu ili kompozitni materijal te tako utječe na fizička i mehanička svojstva završne restauracije. Svrha ovoga rada bila je odrediti dubinu stvrdnjavanja različitih kompozitnih materijala polimeriziranih izravno ili transdentalnom polimerizacijom preko diskova izrađenih od cakline odnosno cakline/dentina. **Materijali i postupci:** U eksperimentu je korišteno pet kompozitnih materijala – SureFil SDR, Dentsply (SDR), Filtek Supreme Plus, 3M ESPE (FSP), Aelite LS, Bisco (ALS), Filtek LS, 3M ESPE (FLS) i TPH, Dentsply (TPH). Za svaki materijal pripremljeno je 30 uzoraka debljine 2 i 4 mm. Uzorci su osvijetljeni (Elipar 2500 3M ESPE) uređajem za polimerizaciju 40 sekunda na tri različita načina: izravnom polimerizacijom ili transdentalno, preko diskova cakline debljine 1 mm te diskova cakline i dentina od 2 mm. Ukupno je za svaki uzorak učinjeno osam mjerenja Vickersove mikročvrstoće (VH) – četiri na vrhu i četiri na dnu površine uzorka (Micromet, Buehler, 100 g/15 s). Podatci su analizirani statističkim programom ANOVA-e te Tukeyevim post-hoc testom HSD ($\alpha = .05$). **Rezultati:** Dno uzoraka pokazalo je nižu mikročvrstoću negoli njegova površina za sve ispitivane kompozitne materijale, bez obzira na uvjete osvjetljivanja, osim za kompozit SDR u slučaju izravne polimerizacije. Transdentalna polimerizacija kroz caklinsko/dentinski sloj značajno smanjuje mikročvrstoću na dnu uzorka kod svih ispitivanih kompozitnih materijala ($P < 0,05$). **Zaključak:** Rezultati ovog istraživanja pokazali su da transdentalna polimerizacija kroz caklinu i dentin negativno utječe na mikročvrstoću kompozitnog materijala te kompromitira mikročvrstoću konačne kompozitne restauracije.

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Adresa za dopisivanje
Neimar Sartori, DDS, MS, PhD
University of Southern California
Herman Ostrow School of Dentistry
of USC
Norris Dental Science Center
925 W 34th Street, DEN 4365, Los
Angeles, CA 90089-0641
tel: 213 740 3762
faks: 213 740 0174
sartori@usc.edu

Ključne riječi
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