Comparison Between Standard and Pulsed Coherent Light Polymerization

Usporedba standardne i pulsno-laserske polimerizacije kompozitnih materijala

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Summary

An ever growing amount of photo-curable materials is being used in different fields of dentistry. Standard photopolymerization devices produce about 60% of monomer conversion in composite resin fillings. In order to improve the quality of polymerization, a series of experiments was made using pulsed laser, because continuous coherent light leads to a higher polymerization shrinkage caused by a temperature rise in the material. Three different experiments were carried out with different shades of composite resins Helioprogress and Heliomolar (Vivadent, Liechtenstein). In the first experiment, the wavelength was changed from 465 to 495 nm in steps of 5 nm with 30s exposition time. In the second one, the wavelength was constant (470 nm) and the illumination time was changeable (10, 20, 30 and 40s). The cured part of the sample, situated in a specially prepared aluminum mould, was measured with Vernier micrometer. The best results were achieved at 470 nm regardless of the amount of filler and pigment. The results were compared with a commercial device (Heliomat). It is expected that pulsed laser polymerization will improve the degree of monomer conversion, decrease a temperature rise in the composite and in that way avoid wall-to-wall contraction.

Key words: *composite resins, polymerization, pulsed laser*

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Introduction

Photo-curable resins are widely used in different fields of dentistry, especially for composite materials. In contrast to the self-cured, light-cured resins have remarkable advantages: control of the setting time, homogeneity of the material and color stability (1). The setting of the material occurs through the influence of electromagnetic radiation in the blue part of the spectrum (440–500 nm). Visible-light-cured (VLC) resins contain camphorquinone (CQ) in combination with N,N-dimethylaminoethyl-methacrylate (DMAEMA) as photochemical initiator.

Standard photopolymerization device in clinical conditions is a halogen lamp with filters

which allow the emission of a particular part of the spectrum. However, this conventional way of polymerization has some important drawbacks such as relatively low depth of cure of the darker shades and about 55–70% degree of monomer conversion in composite resin fillings (2). The nature of the unpolymerized resin has a negative effect on the mechanical properties, dimensional stability of the restoration and inadequate biocompatibility (3). Therefore, some experiments with high pressure zincsodium and indium lamps whose emission lines correspond to camphorquinone absorption coefficient, were carried out (4,5). High power argon-ion laser (200 mW) leads to a higher polymerization shrinkage, as a result of a temperature rise in the sample (6), which limits the practical use of the method. Low power argon-ion laser (10 mW) in continuous regime ensures the same depths of cure as the standard photopolymerization device (7).

The aim of this investigation was to improve the quality of photopolymerization using pulsed laser, thus avoiding the disadvantages of other methods.

Material and Methods

The light source consisted of the pump excimer lase (XeCl Lambda Physik LPX 100) and the dye laser (Lambda Physik 3000) that allowed the variable wavelength ranging from 460–510 nm. The duration of the laser pulse was 20 ns, the number of the pulses was 300 and the energy of 0.6 mJ with repetition rate of 10 Jz. Exposition time was 30 seconds, which was checked with a stop-watch. Composite material was situated in a specially prepared aluminum mould with half oval cavity which was 5.0 mm wide and 2.5 mm deep (Figure 1). After laser illumination, the cured part of the sample was measured with Vernier micrometer (accuracy = = 0.02 mm). Standard deviations, for three repeated measurements, were calculated (Tables 1,2) (the Tables 1 and 2 for Helioprogress 20 and Heliomolar 20 are given; other results are presented in the figures).

Three different experiments were carried out. In the first experiment, three different shades of materials Helioprogress and Heliomolar (Vivadent, Liechtenstein) were used; 20 (white), 24 (brown) and 35 (yellow-gray). This

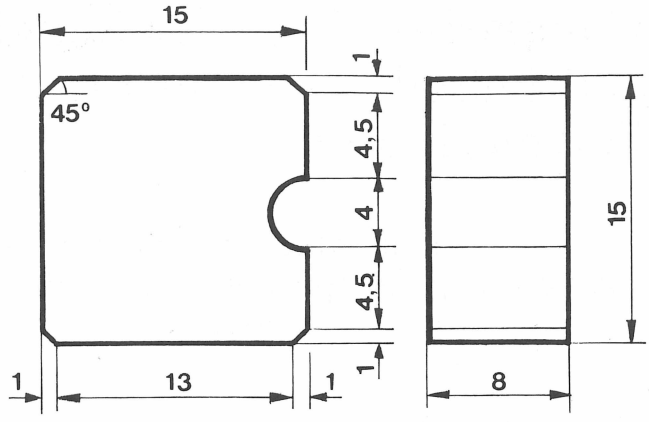

Figure 1. *Aluminum mould for composite resin samples (expressed in mm)*

Slika 1. *Aluminijski kalup za uzorak kompozitnog materijala (izraženo u mm)*

Table 1. *Curing depths, mean values and standard deviations for Helioprogress 20*

Tablica 1. *Dubine polimerizacije, srednje vrijednosti i standardne pogreške za Helioprogress 20*

λ/nm	T/s	γ/Hz	d/mm				
			1	2	3	x	ℭ
465	30	10	3,7	3,4	3,9	3,67	0,252
470	30	10	4,5	3,8	4,0	4,10	0,361
475	30	10	3,7	3,9	3,7	3,77	0,115
480	30	10	3,5	3,4	3,4	3,40	0,100
485	30	10	3,0	2,9	2,9	2,93	0,058
490	30	10	2,7	2,5	2,4	2,53	0,153
495	30	10	2,0	1,9	1,9	1,93	0,058

Table 2. *Curing depths, mean values and standard deviations for Heliomolar 20*

Tablica 2. *Dubine polimerizacije, srednje vrijednosti i standardne pogreške za Heliomolar 20*

λ/nm	T/s	γ/Hz	d/mm				
			1	2	3	x	ℭ
465	30	10	1,9	2,2	2,2	2,10	0,173
470	30	10	2,7	2,7	2,5	2,63	0,115
475	30	10	2,0	2,7	2,2	2,30	0,361
480	30	10	2,0	2,0	2,1	2,03	0,058
485	30	10	1,8	2,0	1,8	1,87	0,115
490	30	10	1,9	2,0	2,0	1,97	0,058
495	30	10	1,5	1,6	1,7	1,60	0,100

was done at different wavelengths: 465, 470, 475, 480, 485, 490 and 495 nm. In the second experiment the wavelength was constant (470 nm) and the illumination time was changeable (10, 20, 30 and 40s). Two different materials were used: Helioprogress 20 and Heliomolar 24. Frequency, laser pulse duration, moulds, the way of their filling with the material, exposition time, time measuring and curing depth were the same as in the previous experiment. The control measurements, with standard halogen lamp Heliomat (Vivadent, Liechtenstein), under the same conditions as those in former experiments, were also carried out.

Results

Figure 2 shows curing depth mean values for Helioprogress 20 and Heliomolar 20 at 30s illumination time and the wavelength ranging from 465 to 495 nm. The best curing depth was achieved at 470 nm, especially for Helioprogress 20. There was a marked difference in curing depth between the material with smaller and bigger amount of filler.

Figure 3 and 4 show the curing depth profiles for Helioprogress 24 and 35 and Heliomolar 24 and 35 under the same conditions as for Helioprogress and Heliomolar 20. The biggest polymerization depth was noticed again at 470 nm, which represents the peak of camphorquinone absorption curve. There was no great difference in curing depths between the darker shades of Helioprogress and Heliomolar compared with the light one.

Figure 5 and 6 show the curing depth for Helioprogress 20 and Heliomolar 24, where the wavelength was unchangeable at 470 nm and the illumination time changed from 10 to 40 s (in steps of 10s). Helioprogress reached its maximal curing depth already at 30s of illumination and resulted in saturation. Heliomolar showed the tendency toward the increase of curing depth by longer laser radiation.

Figure 7 shows the comparison between the curing depths achieved with pulsed laser and

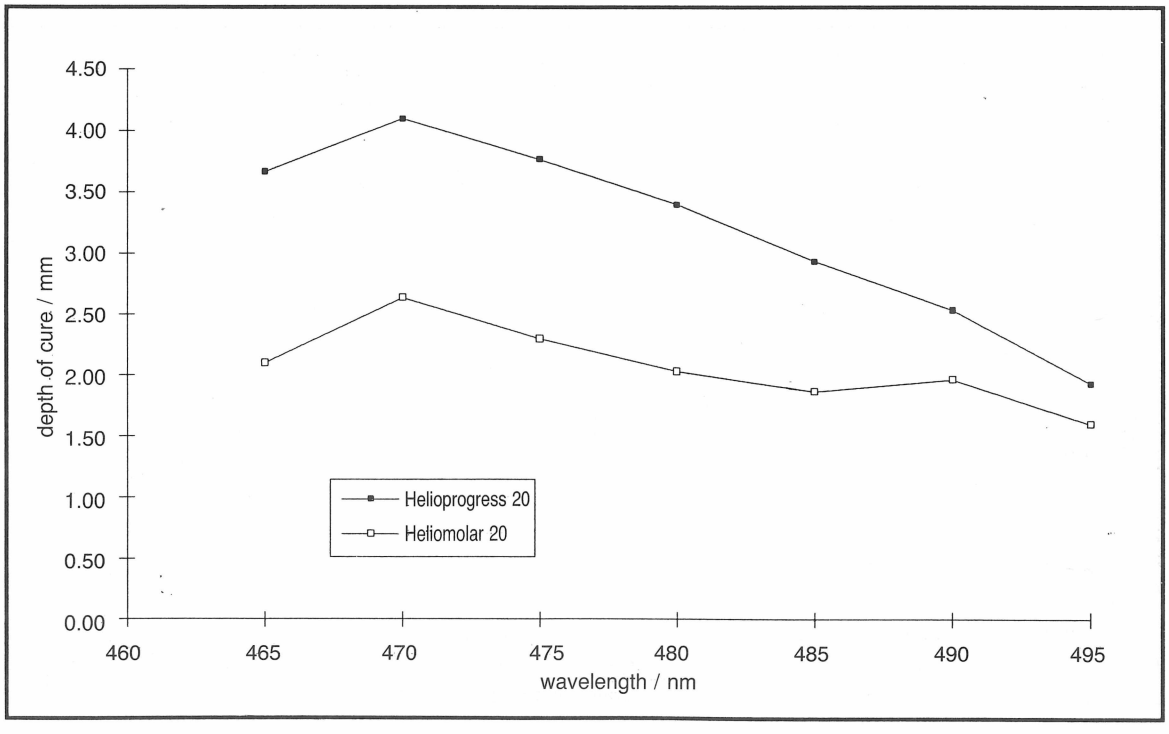

Figure 2. *Curing depths mean values for Helioprogress 20 and Heliomolar 20 at 30s exposition time and different wavelengths*

Slika 2. *Srednje vrijednosti dubine polimerizacije za Helioprogress 20 i Heliomolar 20 pri promjenljivim valnim duljinama uz vrijeme osvjetljavanja od 30s*

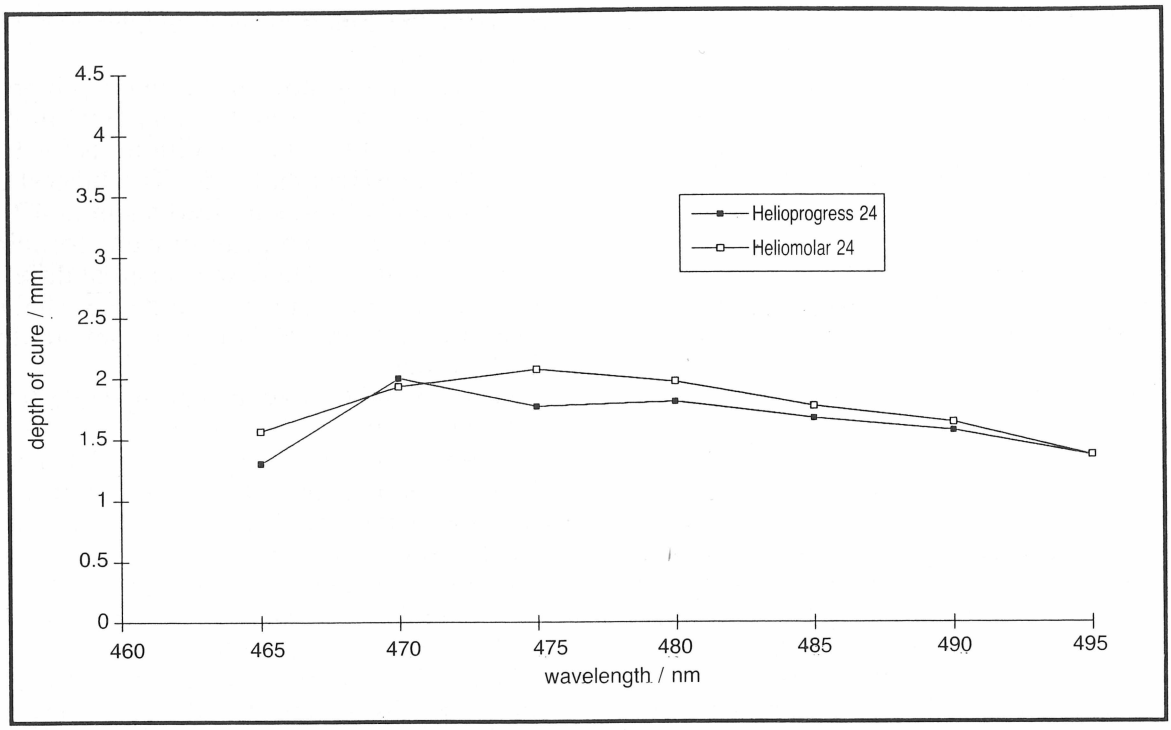

Figure 3. *Curing depths mean values for Helioprogress 24 and Heliomolar 24 at 30s exposition time*

Slika 3. *Srednje vrijednosti dubine polimerizacije za Helioprogress 24 i Heliomolar 24 uz vrijeme osvjetljavanja od 30s*

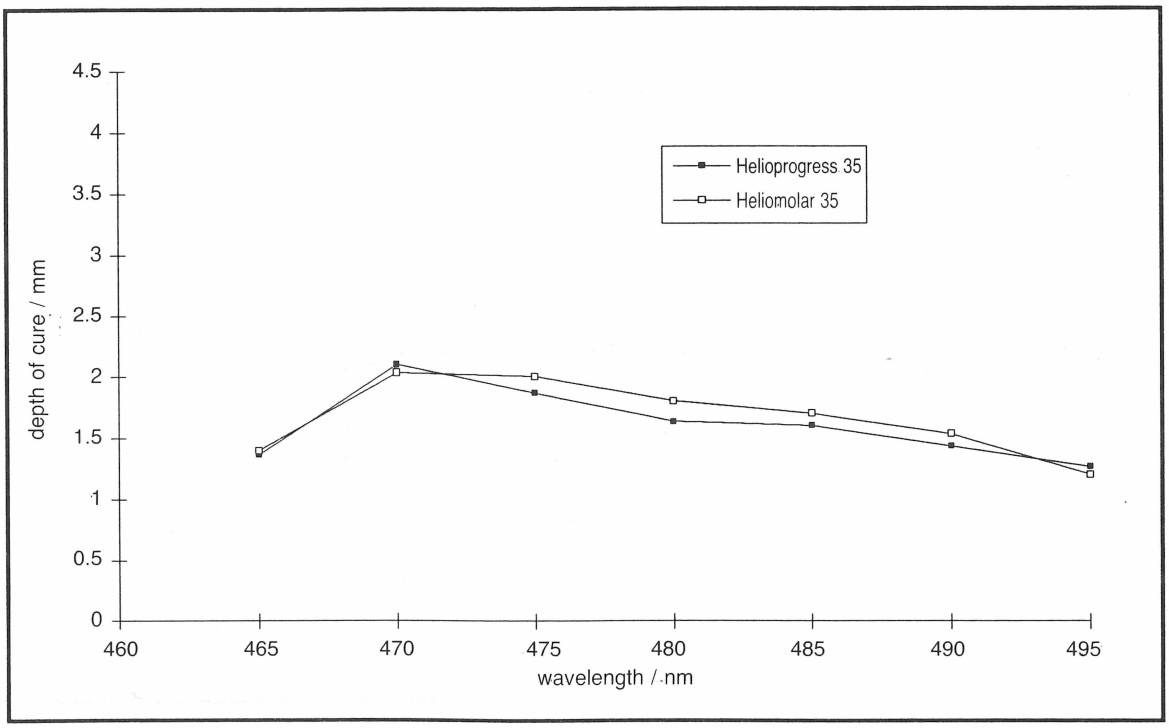

Figure 4. *Curing depths mean values for Helioprogress 35 and Heliomolar 35 at 30s exposition time and different wavelengths*

Slika 4. *Srednje vrijednosti dubine polimerizacije za Helioprogress 35 i Heliomolar 35 pri promjenljivim valnim duljinama uz vrijeme osvjetljavanja od 30s*

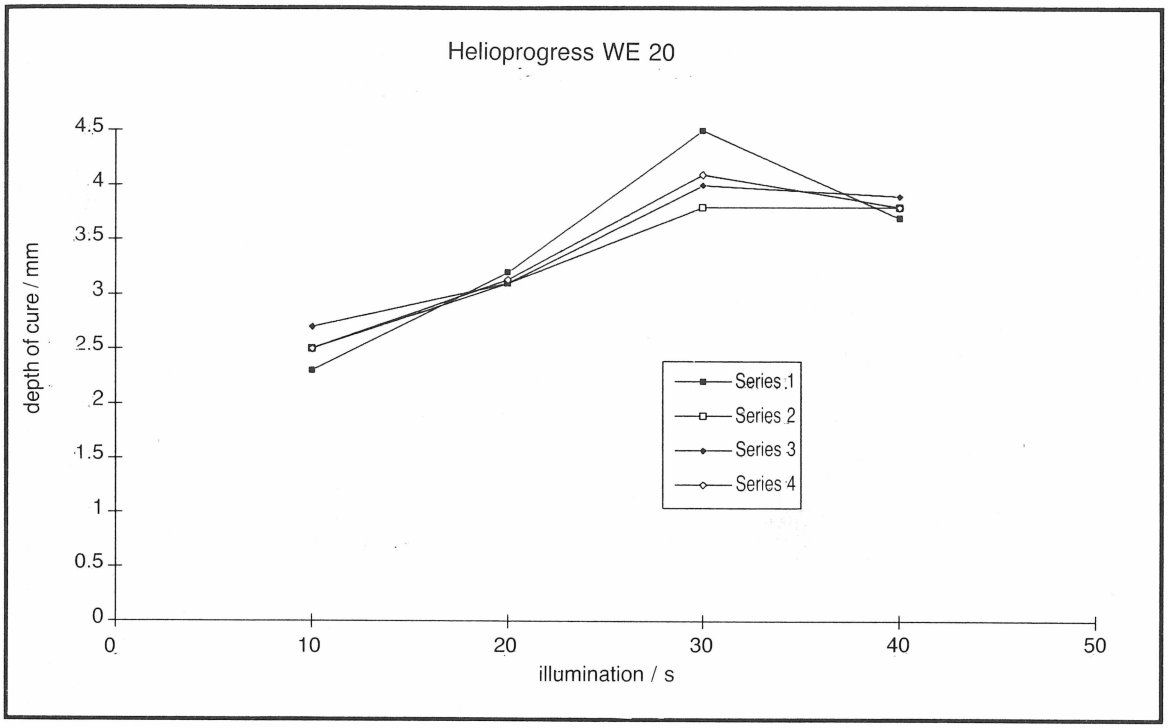

Figure 5. *Curing depths mean values for Helioprogress 20 at 470 nm wavelength and changeable exposition time*

Slika 5. *Srednje vrijednosti dubine polimerizacije za Helioprogress 20 pri valnoj duljini od 470 nm i promjenljivom vremenu osvjetljavanja*

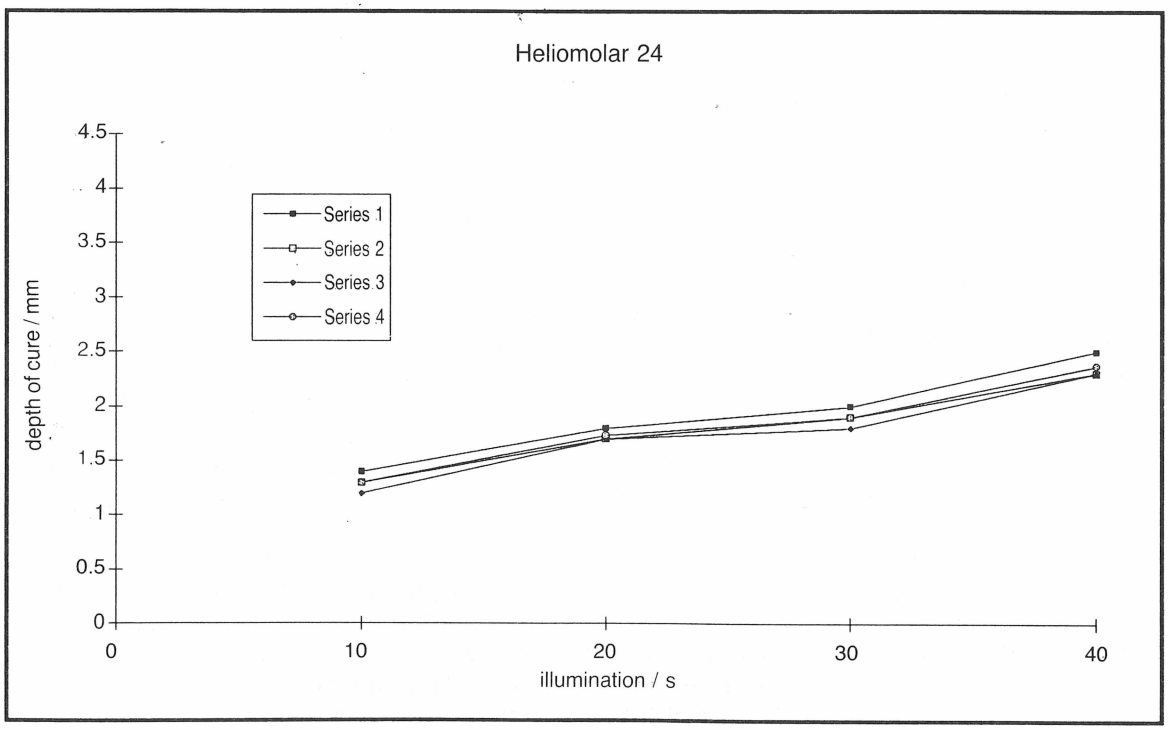

Figure 6. *Curing depths mean values for Heliomolar 24 at 470 nm wavelength and changeable exposition time*

Slika 6. *Srednje vrijednosti dubine polimerizacije za Heliomolar 24 pri valnoj duljini od 470 nm i promjenljivom vremenu osvjetljavanja*

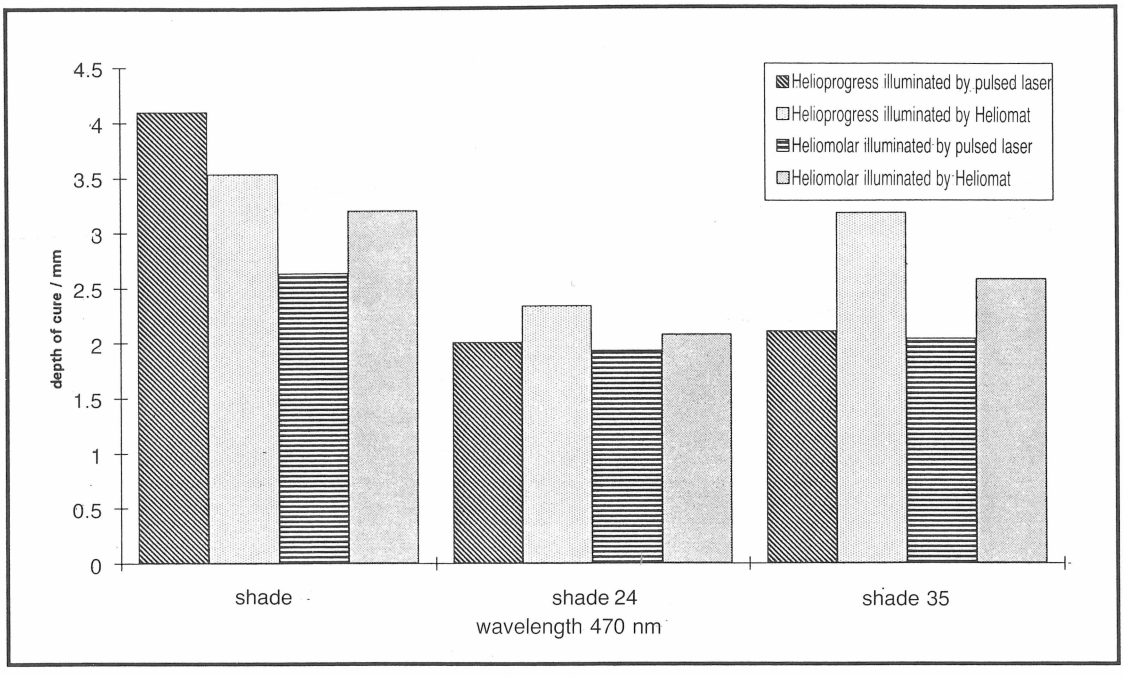

Figure 7. *The comparison between pulsed laser and Heliomat polimerization for Helioprogress 20, 24 and 35 and Heliomolar 20, 24 and 35 at 30s illumination time*

Slika 7. *Usporedba dubine polimerizacije postignute pulsnim laserom i Heliomatom za Helioprogress 20, 24 i 35 te Heliomolar 20, 24 i 35 pri 30s osvjetljavanja*

Heliomat. The values were similar in both cases, except noticeable big curing depth of Helioprogress 20 treated with pulsed laser at 470 nm.

Discussion

From previous experiments and in the comparison with the results achieved by a standard halogen lamp Heliomat and argon-ion laser, it is apparent that light-cured composite materials ensure the best curing depth at 470 nm regardless of the amount of filler and pigment. However, it has been noticed that a dependance exists on the amount of the filler (materials with a smaller amount of filler manage to reach a better curing depth) and on the pigment (lighter shades of the material ensure better polymerization depth, because of better transmission of the visible light through the material). Polymerization shrinkage is a consequence of photopolymerization with standard light source and especially with high power argon-ion laser because of the great thermodynamic reaction at the absorption spot. The percent of polymerization shrinkage is related to the filler loading, the amount of monomer, the type of monomer and the degree of cure (8). It ranges from 0.65% for the impression material to 7.9% for the unfilled resins (9). Posterior composite resin volumetric contraction ranges from 1.67 to 5.68% according to Seguera (10) and 2.5–5.5% according to Feilzer (11). 65–75% of this shrinkage occurs within the first 10 min of placement. It leads to the gap formation around the margins of a cavity, resulting in microleakage and its possible sequelae of pulpal irritation, thermal sensitivity and secondary caries (12).

This is the first attempt of photopolymerization of composite resins using pulsed laser. It is expected that photopolymerization in the pulsed regime will improve the degree of conversion, decrease a temperature rise (allowing »cooling« of the material) and in that way avoid wall-to-wall contraction. For better understanding the nature of photochemical reaction initiated in this manner, it is necessary to check accurately physical and chemical characteristics of the cured composite resin sample. The conversion rate is currently performed by means of free radicals detection using EPR (volumetric) measurements (13) and by using Raman spectroscopy (surface) measurements (14,15).

USPOREDBA STANDARDNE I PULSNO-LASERSKE POLIMERIZACIJE KOMPOZITNIH MATERIJALA

Sažetak

Zbog širokog uporabnog spektra, jednokomponentni smolasti materijali postali su gotovo nezamjenjivi u raznim stomatološkim disciplinama. Standardni polimerizacijski uređaji osiguravaju svega 60%-tnu konverziju monomera, dok argonski laser uzrokuje veći stupanj polimerizacijskog skvrčavanja kao rezultat povišenja temperature na mjestu apsorpcije. Stoga su, prvi put, izvedeni pokusi polimerizacije kompozita pulsnim laserom (XeCl Lambda-Physik LPX 100). Korištene su različite boje kompozitnih materijala Helioprogress i Heliomolar (Vivadent, Liechtenstein). U prvom pokusu, eksperimentirano je sa sedam valnih duljina u rasponu od 465–495 nm pri ekspoziciji od 30s, dok je u drugom valna duljina bila nepromjenljiva (470nm) uz različito vrijeme osvjetljavanja od 10, 20, 30 i 40 s. Polimerizirani dio uzorka, smješten u posebno pripremljenom aluminijskom kalupu, mjeren je pomičnim mjerilom, nakon temeljitog odstranjenja mekog dijela kompozita. Zamjetna je najveća dubina polimerizacije u području oko 470 nm bez obzira na količinu punila i pigmenta. Dobiveni rezultati uspoređeni su s kontrolnim mjerenjima izvedenim halogenom žaruljom (Heliomat). Rad u pulsnom režimu pri određenoj valnoj duljini, mogao bi znatno poboljšati stupanj konverzije monomera, smanjiti temperaturni porast u materijalu i na taj način reducirati polimerizacijsko skvrčavanje.

Ključne riječi: *kompozitni materijali, polimerizacija, pulsni laser*

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Literature

1. UNO S, ASMUSSEN E. Variables in bonding to dentin. Scand J Dent Res 1992; 100:130–2.
2. OSAKABE T, NARUSAWA H, SHIMOURA H, HISAMITSU H, WAKUMOTO S. Laser Raman spectroscopy of visible light curing resins. J Dent Res 1991; (special issue A): 70: Abst No 2082.
3. COX C F, KEALL C L, KEALL H J, OSTRO E, BERGENHOLTZ G. J Prosthet Dent 1987; 57: 1–8.
4. MENIGA A, ŠUTALO J, RUKAVINA J, AZINOVIĆ D, PICHLER G. Zinc and sodium high pressure lamps for curing composite resins. Acta Stomatol Croat 1990; 24:233–40.
5. ŠUTALO J, MENIGA A, RUKAVINA J, AZINOVIĆ D, PICHLER G. Indium light sources for curing composite resins. Acta Stomatol Croat 1991; 25:77–82.
6. BURTSCHER P. Curing of composites with an argon ion laser. J Dent Res 1991; (special issue A): 70: Abst No 2080.
7. MENIGA A, ŠUTALO J, HORVATIĆ V, PICHLER G. Low power laser for curing of composite resins. J Dent Res 1991; (special issue): 72: Abst No 1635.
8. PUCKETT A D, SMITH R. Method to measure polymerization shrinkage of lightcured composites. J Prosthet Dent 1992; 68:56–8.
9. WATTS D C, CASH A J. Determination of polymerization shrinkage kinetics in visible light cured materials: methods development. Dent Mater 1991; 7: 281–287.
10. SEGUERA A, DONLY K J, CROLL T P. The effect of polymerization shrinkage during veneer placement. Quintessence Int 1992; 23:629–632.

11. FEILZER A J, DE GEE A J, DAVIDSON C L. Increased wall-to-wall curing contraction in thin bonded resin layers. J Dent Res 1989; 68:48–50.

12. REES J S, JAKOBSEN P H. The polymerization shrinkage of composite resins. Dent Mater 1989; 5:41–44.

13. OTTAVIANI M F, FIORINI A, MASON P N, CORVAJA C. Electron Spin Resonance studies of dental composites: effects of irradiation time, decay over time, pulverization, and temperature variations. Dent Mater 1992; 8: 118–124.

14. LOUDEN J D, ROBERTS T A. Cure profiles of light-cured dental composites by Raman spectroscopy. Journal of Raman Spectroscopy 1987; 8:365–366.

15. SUZUKI M, KATO H, WAKUMOTO S, KATAGIRI G, ISHITANI A. Spectroscopic evidence for resin--reinforced dentine by a Raman microprobe technique. 1987; 18:315–316.