ORIGINAL ARTICLE

Effect of Light Curing Mode and Type on Conversion of Resin Composites

C Kucukesmen[1], A Usumez[2], BC Uludag[3], B Gunduz[4], CH Kucukesmen[5], O Acar[6]

ABSTRACT

Objective: *To determine the efficacy of polymerization for two different curing units by examining the degree of conversion (DC) of seven different composite materials.*

Methods: *Conventional halogen light (40 seconds) and a light-emitting diode (LED) curing unit (20 seconds) were used to polymerize seven different composite brands. A total number of 70 specimens were evaluated (n = 5). To determine the DC, Fourier transformation infrared spectroscopy was used. For statistical analysis, two-way analysis of variance and Tukey's honestly significant difference post hoc test were applied (α = 0.05).*

Results: *Degree of conversion varied with both the light unit and type of composite, with significant interactions. Charisma (67.0 ± 6.0) and Z-250 (65.2 ± 3.3) showed the highest DC when cured using the LED, whereas Grandio (38.2 ± 3.5) showed the lowest when exposed to the conventional halogen light.*

Conclusion: *Degree of conversion was affected by the type of light curing units, and results varied greatly with respect to composite brand and type (nanofilled, macrofilled, hybrid, microhybrid and organically modified ceramics).*

Keywords: Composite, degree of conversion, light curing mode.

INTRODUCTION

Advances in adhesive materials lead a great increase in use of light-cured composite over their self-cured version (1). Freedom to time for the initiation of polymerization gives the opportunity to restore and shape with ease (2). There are several classifications according to filler content and particle size (3–5). Posterior-macrofilled composites have higher content of larger filler sizes (2–20 μm) (6). Although they are known as technique sensitive resulting from the need for incremental layering (7), some manufacturers propose bulk placement (8, 9). Microfilled composites have smaller filler sizes (0.01–0.1 μm) and good wear strength; however, their flexural and tensile bond strengths are lower than hybrid ones (10, 11).

For the synthesis of inorganic–organic copolymer organically modified ceramics (ormocer) composites, multifunctional urethane and thioether (meth) acrylate alkoxysilanes have been developed as sol–gel precursors (12). Ormocers that qualified with this new inorganic–organic copolymer formulation allows modification of mechanical parameters in a wide range depending on composition. These composites can be manipulated like the hybrid ones (12).

Hybrid-type composites contain different filler sizes (0.04–0.1 μm) (11). The advantages of having efficient and higher filler loading make hybrids—stronger, stiffer, harder and more wear resistant than microfilled products (13). Nonofiller composites have the smallest particle dimensions (75 nm) and high-filler proportions in volume. They have lower polymerization stress and provide good polished surfaces (11, 14).

For optimum physical properties and a favourable clinical performance, adequate polymerization is a key factor. Inadequate polymerization affects strength,

From: [1]Department of Paediatric Dentistry, Faculty of Dentistry, University of Suleyman Demirel, Isparta, Turkey, [2]Private Practice, Istanbul, Turkey, [3]Department of Prosthodontics, Faculty of Dentistry, University of Ankara, Ankara, Turkey, [4]Department of Chemistry, Faculty of Science, University of Selcuk, Konya, Turkey, [5]Department of Prosthodontics, Faculty of Dentistry, University of Suleyman Demirel, Isparta, Turkey and [6]Department of Prosthetics, Faculty of Dentistry, Baskent University, Ankara, Turkey.

Correspondence: Dr O Acar, Department of Prosthetics, Faculty of Dentistry, Baskent University, Ankara, Turkey.
Email: zlemacr@gmail.com

 DOI: 10.7727/wimj.2015.031

stiffness, water sorption and colour stability (15–18). Additionally, it may also cause the release of toxic substances. Ideally, the polymerization process should provide conversion of all monomers to polymers. In circumstances of conventional irradiations, degree of conversion (DC) may range 55%–75% (18, 19). Ambient conditions, including temperature, polymerization conditions, photoinitator concentration, dimethacrylate monomer's chemical structure and light intensity affect the final DC (18, 20).

A visible light emitted from a halogen light source has been widely used. Their light intensity is usually between 400 and 800 mW/cm^2 and polymerize composite within 20–40 seconds at depths of up to 2 mm. However, deep restorations require incremental layering, which results in longer placement time (18, 21). The solid-state light-emitting diode (LED) that is the latest advancement in polymerizing technology overcomes the halogen visible light-polymerization units' shortcomings (22). This LED device polymerizes compatible materials faster than manufacturers' recommended irradiation times. The second generation of these types of light units has a power density of approximately 1000 mW/cm^2 (23–26). With a high-power light unit, more photons are available for absorption by photosensitizers (25, 27). The advantage of increased photon number is that more camphorquinone molecules are raised to the excited state to react with the amine and form free radicals for polymerization (28). However, this high light intensity produces higher contraction stresses, which may contribute to poor mechanical properties (24, 25). To solve this problem and improve marginal adaptation, "soft-start polymerization" was recommended (17, 18, 29–31). The aim of the present study was to evaluate the hypothesis that the DC of different composite materials cured with LED at ramping mode during 20 seconds is equivalent to a continuous 40 seconds exposure to a conventional halogen light.

MATERIALS AND METHODS

The composite materials used are presented in Table 1. Composite discs (A3) were prepared in a polytetrafluoroethylene mould (5 mm in diameter and 2 mm in height) using mylar strips to attain flat surfaces. A 2-mm-thick white silicone mould (Speedex; Coltène/Whaledent Inc, Cuyahoga Falls, OH, USA) was used to support the composite structure. To cure composite specimens, a conventional halogen light unit (450 mW/cm^2 × 40 s) and LED light with the ramp mode (The initial intensity was 150 mW/cm^2 for 10 seconds with incremental increases to 1130 mW/cm^2; the highest intensity was maintained for 10 seconds) were used (Table 2). Total estimated energy density was about 18 J/cm^2 in both polymerization procedures. A digital radiometer (Optilux 501; Kerr, Danbury, CT, USA) was used to calibrate the light output of the conventional halogen light unit. For each combination of exposure mode and composite material, five specimens were prepared. After polymerization, they were stored in light-proof boxes for 24 hours to avoid further light exposure. Five milligrams of KBr powder was mixed with 55 µg of the ground powder (Carlo-Erba Reagenti, Milan, Italy), and the infrared spectrum was obtained in absorbance using a diffuse-reflection attachment in a Fourier transform infrared spectrometer (FTIR) (1600 Series; PerkinElmer, Wellesley, MA, USA) (17). Spectra were also gained from unpolymerized adhesives, while unpolymerized pastes were smeared onto thin KBr discs. The amount of double vinyl bonds remaining in the specimen exposed to irraddiation is shown by the intensity of the peak at 1637 cm^{-1} referring to the C=C stretching of the vinyl group. The DC was calculated as follows: (17, 32) $DC = ([A_0 - A_t]/A_0) \times 100$ A_0: absorption of the peak at 1637 cm^{-1} when time is equal to 0, where A_t: absorption at time. For statistical analysis, two-way analysis of variance (factors: type of polymerizing units,

Table 1: Brands and types of composite materials and manufacturers

Brands	Type of resin	Manufacturers	Batch number
Grandio p	Nonohybrid	Voco, Cuxhaven, Germany	#381395
Filtek Supreme	Nonofiller	3M ESPE, St. Paul, MN, USA	1AN
Z-250	Hybrid	3M ESPE, St. Paul, MN, USA	3MM
Solitáire 2	Packable, macrofiller	Heraeus Kulzer, Dormagen, Germany	#020226
Clearfil Photo Posterior	Posterior, macrofiller	Kuraray, Okayama, Japan	00152A
Charisma	Microhybrid	Heraeus Kulzer, Hanau, Germany	#010074
Admira	Ormocer	Voco, Cuxhaven, Germany	#22789

Table 2: Classification, power density, exposure duration and manufacturer information for curing lights used

Light units	Unit classification	Exposure duration (seconds)	Power density (mW/cm^2)	Manufacturer
Hilux 550	Conventional halogen	40	450	First Medica, Greensboro, NC, USA
MiniLED	LED	20	1100	Satelec, Merignac, France

type of composite materials) was applied. Tukey's honestly significant difference post hoc test was applied for pairwise means comparisons ($\alpha = 0.05$).

RESULTS

Tables 3 and 4 show conversion values. Significant variation was found within each of the major factors, and also within the interaction term. The conversion values varied with the light units ($p < 0.05$) and among composite types ($p < 0.05$). Between the light unit types, the rank order of conversion values was differed with respect to composite type ($p < 0.05$). Charisma (67.0 ± 6.0) and Z-250 (65.2 ± 3.3) showed the highest conversion values when cured with LED unit, whereas the Grandio (38.2 ± 3.5) showed the lowest when cured with conventional halogen light ($p < 0.05$).

Table 3: Degree of conversion values (%) of a wide variety of composite types using two different curing units

	Conventional halogen Mean ± SD	LED unit Mean ± SD
Grandio	38.2 ± 3.5^{a}	45.8 ± 2.7^{b}
Filtek Supreme	52.7 ± 2.0^{bcd}	56.4 ± 5.1^{cd}
Z-250	49.2 ± 2.9^{bc}	65.2 ± 3.3^{e}
Solitáire 2	47.7 ± 4.0^{b}	52.1 ± 5.0^{bcd}
Clearfil Photo Posterior	47.0 ± 3.4^{b}	46.9 ± 1.3^{b}
Charisma	52.9 ± 4.3^{bcd}	67.0 ± 6.0^{e}
Admira	44.9 ± 4.8^{ab}	59.8 ± 3.7^{de}

Groups with different letters are statistically different.

Table 4: Two-way analyses of variance

Unit	*df*	MS	F	*p*
Light unit	1	1308.7	85.6	0.000
Types of composites	6	378	24.7	0.000
Light unit × Types of composites	6	100.9	6.6	0.000

DISCUSSION

The hypothesis that conversion of composites cured with LED unit is equivalent to that of conventional halogen unit exposure was rejected. The differences between curing unit groups and the differences among composite types are significant for DC values.

The polymerization of microhybrid composite (Charisma) was greater than the others for both polymerizing units. Nanofilled (Filtek Supreme; 3M ESPE, St. Paul, MN, USA) and hybrid (Z-250; 3M ESPE, St. Paul, MN, USA) composites also showed high conversion values with both polymerizing units, and Ormocer-type (Admira; Voco, Cuxhaven, Germany) composite material achieved a high conversion level with the LED unit.

Two 'macrofilled' products (Solitáire 2; Heraeus Kulzer, Dormagen, Germany, Clearfil Photo Posterior; Kuraray, Okayama, Japan) demonstrated lower mean polymerization values than the others. Interestingly, another nanohybrid composite (Grandio) showed the lowest DC values with both polymerizing units. This may be due to the contents or manufacturing properties of this resin.

Other factors affecting the polymerization of light-activated composites may have overshadowed the composite resin's light transmission coefficient, shade and thickness of the material, light intensity and exposure time (1, 5). Light shades have more light transmission and easy polymerization (1, 5). In the current study, the light shades of specimens were similar in all composite groups.

The polymerization process induces strain in restorations, but high conversion values result in elevated levels of hardness and strength (30). Therefore, to obtain a desirable polymerization, a reduction in remaining double bonds to the lowest possible level is essential. Energy density applied during the exposure influences the conversion of composite material (18, 33). Recent studies showed that composite can be irradiated at a significantly higher light intensity for about 20 seconds (26). Generally, the light intensity recommended is about 250 mW/cm^2. Recent recommendations suggest that the light intensity should range approximately from 650 to 1000 mW/cm^2 (30). Some of the current light units provide two distinct modes of radiation: producing a lower level of light followed by a gradual increase (or ramping) to a higher level of intensity, and this polymerization technique was termed soft-start polymerization (31). Studies reported that soft-start polymerization techniques significantly reduce polymerization strains and improve material properties as well (25, 29).

Soft-start polymerization (150–1100 mW/cm^2) for 20 seconds by using LED unit and conventional polymerization (450 mW/cm^2) by using a continuous light application for 40 seconds were compared in the present study. The total estimated energy density was about 18 J/cm^2 in both polymerization procedures; however, the conversion efficiency of LED curing light was better in almost all composite brands. This may be due to the narrow emission spectrum of LED.

In the present study, FTIR was used to determine DC; however, there are some limitations. This method only provides a general, average bulk value of the extent of conversion because the entire 2-mm-thick specimen was ground to provide the infrared specimen. Thus,

differences in conversion values at the top, irradiated surface and at 2-mm depth are not determined, but instead were averaged with those of all materials between them.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1. The DC values varied according to the type of resin (nanofilled, macrofilled, hybrid, microhybrid, and ormocer), brand and light polymerizing unit. The highest DC values were achieved with soft-start polymerization by LED unit in microhybrid type (67.0 ± 6.0%) and hybrid (65.2 ± 3.3%) composite materials.
2. The rank order for conversion using the halogen light was: Charisma, Filtek, Z250, Solitare, Clearfil, Admire, and Grandio. For the LED unit, it was Charisma, Z250, Admira, Filtek, Solitare, Clearfil, and Grandio. The only two materials that have no similar rankings were Charisma and Grandio for all others, even though the LED light may have provided equivalent or better conversion; the rank orders were different. This finding supports the concept that the choice of composite itself is just as important as selecting a curing light.

REFERENCES

1. Bayne S, Heymann H, Swift E. Update on dental composite restorations. J Am Dent Assoc 1994; **125:** 687–701.
2. Mc Cabe JF. Cure performance of light activated composites by differential thermal analysis (DTA). Dent Mater 1985; **1:** 231–4.
3. American Dental Association Council on Dental Materials. Specification No. 27 for direct filling materials. J Am Dent Assoc 1977; **94:** 1191.
4. Willems G, Lambrechts P, Braem M, Vanherle G. Composite resins in the 21st century. Quintessence Int 1993; **24:** 641–58.
5. Li Y, Swartz ML, Phillips RW, Moore BK and Roberts TA. Effect of filler content and size on properties of composites. J Dent Res 1985; **64:** 1396–401.
6. Council on Dental Materials, Instruments and Equipment. Posterior composite resins. J Am Dent Assoc 1986; **112:** 707–9
7. Leinfelder KF. Posterior composite resins: the materials and their clinical performance. J Am Dent Assoc 1995; **126:** 663–76.
8. Kawaguchi M, Fukushima T, Horibe T. Effect of monomer structure on the mechanical properties of light-cured composite resins. Dent Mater 1989; **8:** 40–5.
9. Peutzfeld A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci 1997; **105:** 97–116.
10. Tyas MJ, Jones DW, Rizkalla AS. The evaluation of resin composite consistency. Dent Mater 1998; **14:** 424–8.
11. Willems G, Lambrechts P, Braem M, Celis JP, Vanherle G. A classification of dental composites according to their morphological and mechanical characteristics. Dent Mater 1992; **8:** 310–9.
12. Hickel R, Dasch W, Janda R, Tyas M, Anusavice K. New direct restorative materials. Int Dent J 1998; **48:** 3–16.
13. Lambrechts P, Vanherle G, Vuilsteke M, Davidson CL. Quantitative evaluation of the wear resistance of posterior dental restorations: A new three-dimensional measuring technique. J Dent 1984; **12:** 252–67.
14. Condon JR, Ferracane JL. Reduced polymerization stress through non-bonded nanofiller particles. Biomaterials 2002; **23:** 3807–15.
15. Pires JAF, Cvitko E, Denehy GE, Swift EJ. Effects of curing tip distance on the light intensity and composite resin microhardness. Quintessence Int 1993; **24:** 517–21.
16. Usumez A, Ozturk AN, Usumez S, Ozturk B. The efficiency of different light units to polymerize resin cement beneath porcelain laminate veneers. J Oral Rehabil 2004; **31:** 160–5.
17. Oberländer H, Friedl KH, Schmalz G, Hiller KA, Kopp A. Clinical performance of polyacid-modified resin restoration using "soft-start polymerization". Clin Oral Invest 1999; **3:** 55–61.
18. Ozyesil AG, Usumez A, Gunduz B. The efficiency of different light sources to polymerize composite beneath a simulated ceramic restoration. J Prosthet Dent 2004; **91:** 151–7.
19. Silikas N, Eliades G, Watts DC. Ligth intensity effects on resin-composite degree of conversion and shrinkage strain. Dent Mater 2000; **16:** 292–6.
20. Sideridou I, Tserki V, Papanastasiou G. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. Biomaterials 2002; **23:** 1819–29.
21. Munksgaard EC, Peutzfeld A, Asmussan E. Elution of TED-DMA and BIS-GMA from a resin and a resin composite cured with halogen or plasma light. Eur J Oral Sci 2000; **108:** 341.
22. Mills RW, Jandt KD, Ashworth SH. Dental composite depth of cure with halogen and blue light emitting diode technology. Br Dent J 1999; **186:** 388–91.
23. Yoshikawa T, Burrow MF, Tagami JA. A light curing method for improving marginal sealing and cavity wall adaptation of resin composite restorations. Dent Mater 2001; **17:** 359–66.
24. Oberholzer TG, Pameijer CH, Grobler SR, Rossouw RJ. Effect of power density on shrinkage of dental resin materials. Oper Dent 2003; **28:** 622–7.
25. Turkkahraman H, Kucukesmen HC. Orthodontic bracket shear bond strengths produced by two high-power light-emitting diode modes and halogen light. Angle Orthod 2005; **75:** 854–7.
26. Usumez S, Buyukyılmaz T, Karaman AI. Effect of light-emitting diode on bond strength of orthodontic brackets. Angle Orthod 2004; **74:** 259–63.
27. Moon HJ, Lee YK, Lim BS, Kim CW. Effect of various light curing methods on the leachability of uncured substances and hardness of a composite resin. J Oral Rehabil 2004; **31:** 258–64.
28. Vandewalle KS, Ferracane JL, Hilton TJ, Erickson RL, Sakaguchi RL. Effect of energy density on properties and marginal integrity of posterior resin composite restorations. Dent Mater 2004; **20:** 96–106.
29. Deb S, Sehmi H. A comparative study of the properties of dental resin composites polymerized with plasma and halogen light. Dent Mater 2003; **19:** 517–22.
30. Mehl A, Hickel R and Kunzelmann KH. Physical properties and gap formation of light-cured composites with and without "soft-start polymerization". J Dent 1997; **25:** 321–30.
31. Goracci G, Mori G and Casa de' Martinis L. Curing light intensity and marginal leakage of resin composite restorations. Quintessence Int 1996; **27:** 355–62.
32. Decker C. Kinetic analysis and performance of UV-curable coatings. In: Pappas SP, ed. Radiation curing, science and technology. New York: Plenum Press; 1992: 135–79.
33. Peutzfeldt A, Sahafi A, Asmussen E. Characterization of resin composites polymerized with plasma arc curing units. Dent Mater 2000; **16:** 330–6.