©Operative Dentistry, 2009, **34-4**, 408-414

Influence of Photoactivation Protocol and Light Guide Distance on Conversion and Microleakage of Composite Restorations

NRG Fróes-Salgado • CSC Pfeifer
CE Francci • Y Kawano

Clinical Relevance

In this study, soft-start photoactivation methods were demonstrated to be able to reduce microleakage with only a discrete reduction in the degree of conversion. This was achieved when this protocol was associated with a 7 mm distance from the light guide, which is common in deep preparations in clinical practice.

SUMMARY

Purpose: To evaluate the effect of light guide distance and the different photoactivation methods on the degree of conversion (DC) and microleakage of a composite. Methods and Materials: Three photoactivation protocols (600mW/cm² x 40 seconds; 400 mW/cm² x 60 seconds or 200 mW/cm² x 20 seconds, followed by 500 mW/cm² x 40 seconds) and three distances from the light source (0, 3 or 7 mm) were tested. Cylindrical specimens (5 mm diameter; 2 mm tall; n=3) were prepared for the DC test (FT-Raman). Class V cavities were made in 90 bovine incisors to conduct the microleakage test. The specimens were conditioned for 15 seconds with phosphoric acid (37%), followed by application of the adhesive system Prime & Bond NT (Dentsply/Caulk). The preparations were restored in bulk. The specimens were stored for 24 hours in distilled water (37°C) before being submitted to the silver-nitrate microleakage protocol. The restorations were sectioned and analyzed under 25x magnification. Results: Statistical analyses (two-way ANOVAs and Tukey test, α=0.05) found significance only for the factor distance (*p*=0.015) at the top of the composite for the DC test. Conversion

*Nívea Regina de Godoy Fróes-Salgado, DDS, MSD, PhD, Department of Biomaterials and Oral Biochemistry, School of Dentistry, University of São Paulo, São Paulo, Brazil

Carmem Silvia Costa Pfeifer, DDS, PhD, Department of Biomaterials and Oral Biochemistry, School of Dentistry, University of São Paulo, São Paulo, Brazil

Carlos Eduardo Francci, DDS, MSD, PhD, assistant professor, Department of Biomaterials and Oral Biochemistry, School of Dentistry, University of São Paulo, São Paulo, Brazil

Yoshio Kawano, MSD, PhD, professor, Department of Fundamental Chemistry, Institute of Chemistry, University of Sao Paulo, São Paulo, Brazil

*Reprint request: Av Prof Lineu Prestes, 2227, Sao Paulo, SP 05508-000 Brazil; e-mail: niveafroes@gmail.com

DOI: 10.2341/08-104

was statistically lower for the 7 mm groups compared to the 0 and 3 mm groups, which were equivalent to each other. At the bottom of the specimens, none of the factors or interactions was significant (*p*<0.05). The Kruskal-Wallis test showed that, in general, the soft-start method led to lower microleakage scores when compared to the continuous modes, mainly when associated with a distancing of 7 mm (*p*<0.01). With the exception of specimens irradiated with 400mW/cm^2 that did not demonstrate variations on scores for the distances tested, higher microleakage was observed for shorter distances from the light source. Conclusions: Soft-start methods may reduce microleakage when the light guide distancing provides a low level of irradiance, which also causes a discrete reduction in the DC.

INTRODUCTION

Although adhesive restorative techniques have evolved in the past few years, the polymerization shrinkage of resin composites still poses a challenge to the bonded interface. Because the reaction takes place under confinement, the shrinkage inherent to conversion transfers stress to the adhesive layer,[1] which may lead to cuspal deflection,[2] tooth fracture[3] or gap formation.[4] Moreover, once rigidity starts to build up within the material, the magnitude of such stresses increases exponentially.[5] Indeed, the correlation between the elastic modulus and polymerization stress has been well established.[6]

The reduction of the rate at which the reaction develops facilitates chain rearrangement due to flow before the material becomes a viscoelastic solid. Consequently, stress buildup within the composite will be lower, improving the marginal adaptation and longevity of the restoration. One way to obtain this effect in reaction kinetics is through the use of light attenuation, because the low photon flux will generate fewer polymerization growth centers.[7] This is the principle of alternative photoactivation protocols, generally referred to as "soft-start" methods, which consist of an initial low irradiance followed by a second exposure with higher output to complete the radiant exposure so that the conversion is not jeopardized.[8] Indeed, some studies have shown reduced marginal leakage with the use of ramp curing (150 to 800 mW/cm^2 in the first 15 seconds of a 40-second exposure[9]) or soft-start curing.[10] However, some authors reported that composites photoactivated with a pulse-delay method (five seconds at 150 mW/cm^2, followed by 19 seconds at 935 mW/cm^2) were more prone to degradation in ethanol when compared to the control specimens cured in continuous mode.[11] This was credited to reduced crosslink density,[12] which may negatively affect mechanical properties.[13] In some studies, the stress reduction achieved with these photoactivation methods was associated with a reduced degree of conversion.[14-15] On the other hand, stress reductions of up to 34% were reported with the use of pulse-delay methods[8,16] without compromising microhardness before and after immersion in ethanol.[16]

Reductions in the irradiance reaching the composite were also observed in clinical practice for deep preparations, where the light guide is hardly ever in close contact with the first increment of the composite. As demonstrated by Hansen and Asmussen,[17] the distance between the light guide and composites can be greater than 7 mm. Indeed, in a study using FTIR, increasing the distance between the light guide and composite from 0 to 10 mm caused a 23% reduction in irradiance related to a significant decrease in conversion on the bottom of 2-mm thick composite specimens.[18] However, some authors did not find differences in conversion[19-20] or microhardness,[21] regardless of the distance between the light guide and composite.

In clinical practice, the soft-start methods are likely to be used to photoactivate composites in preparations with very distinct sizes and geometries. In the literature, however, the studies that analyzed low irradiance techniques generally performed light curing with the composite in direct contact with the photoactivator tip, ignoring the conjugated effect of these two light attenuating forms on the restorative cavity. For recent commercial composites in use, requiring a relatively low radiant exposure to reach a high degree of conversion, the association of soft-start methods and light distancing may reduce polymerization stress in a manner that these attenuating methods cannot promote separately, with a light dosage sufficiently low to modify reaction kinetics but enough to guarantee composite cure. Therefore, the current study evaluated the degree of conversion achieved with a micro-hybrid composite photoactivated using three different methods from three levels of distance. Since a correlation between polymerization stress and microleakage was established in some studies,[22-23] the current study evaluated microleakage in restorations with the same conditions applied to the degree of conversion test as an *in vitro* predictor of the effects of stress development on marginal integrity. The tested hypotheses were: 1) the photoactivation methods (continuous or stepped) do not affect the degree of conversion; 2) microleakage is lower for the stepped method and 3) increasing the distance between the light guide and composite reduces the degree of conversion and microleakage.

METHODS AND MATERIALS

In all tests, a micro-hybrid composite (Esthet-X; Dentsply Caulk, Milford, DE, USA; batch #0109266, shade A2) was used and photoactivated with a quartz-

Table 1: *Groups According to the Photoactivation Method*

Group	Light-tip Distance (mm)	Irradiance Provided by Device (mW/cm²)	Irradiance Received by Specimens (mW/cm²)	Irradiation Time(s)	Radiant Exposure Provided by Device (J/cm²)	Radiant Exposure Received by Specimens (J/cm²)
A0	0	600	600	40	24.0	24.0
A3	3	600	520	40	24.0	20.8
A7	7	600	350	40	24.0	14.0
M0	0	400	400	60	24.0	24.0
M3	3	400	340	60	24.0	20.4
M7	7	400	260	60	24.0	15.6
S0	0	Step 1: 200 Step 2: 500	Step 1: 200 Step 2: 500	Step 1: 20 Step 2: 40	24.0	24.0
S3	3	Step 1: 200 Step 2: 500	Step 1: 170 Step 2: 420	Step 1: 20 Step 2: 40	24.0	20.2
S7	7	Step 1: 200 Step 2: 500	Step 1: 130 Step 2: 300	Step 1: 20 Step 2: 40	24.0	14.6

tungsten-halogen light curing unit (VIP—variable intensity polymerizer; BISCO Inc, Schaumburg, IL, USA). Irradiance was checked daily with a built-in radiometer and with the Model 100 Optilux Radiometer (SDS Kerr, Danbury, CT, USA). The composites were photoactivated according to the protocols described in Table 1 at 0, 3 or 7 mm from the light guide. These distances were standardized with the use of opaque ring spacers placed between the light guide and the Mylar strip that covered the material.

Degree of Conversion Analysis

Cylindrical specimens (n=3) 2 mm tall and 5 mm in diameter were built in a Teflon mold sandwiched between Mylar strips. The specimens were stored dry for 24 hours at 37°C, then submitted to degree of conversion (DC) analysis using FT-Raman spectroscopy (RFS 100/S, Bruker Optics, Billerica, MA, USA). Both irradiated and non-irradiated surfaces of the composite were analyzed. The spectra were obtained by the co-addition of 64 scans at a resolution of 4cm^{-1}. The degree of conversion was obtained through standard baseline techniques.

Microleakage Test

Ninety sound bovine incisors were stored in 0.5% choramine solution for no longer than three months after extraction. The teeth were randomly assigned to one of nine experimental groups (n=10). Class V preparations (4 x 2 mm and 2 mm deep) with enamel margins were made with customized cylindrical diamond tips (ref 2094, KG Sorensen, Barueri, Brazil), with the burs being replaced after every five preparations. The preparations were acid etched (37% phosphoric acid) for 15 seconds, washed and gently dried. The Prime & Bond NT adhesive system (Caulk/Dentsply, Milford, DE, USA; batch #0509001919) was applied in one layer and light-cured at 600 mW/cm² for 10 seconds. The composite was placed in bulk. Finishing (600 grit sandpaper) was carried out after 24-hour storage in distilled water at 37°C. The teeth were then isolated with two coats of nail polish, except for 1 mm around the restoration, then immersed in 50% silver nitrate for two hours. Subsequently, the teeth were thoroughly washed with tap water before being immersed in developer solution for six hours and again thoroughly rinsed in tap water.

The restorations were sectioned twice in the labial-lingual direction, resulting in three fragments and four surfaces for analysis. Scores were used to rank the microleakage as follows: 0=no dye penetration; 1=dye penetration up to 1/2 of the cavity depth; 2=dye penetration greater than 1/2 of the cavity depth; 3=dye penetration extending along the axial walls. Each section was analyzed under 25x magnification in a stereomicroscope (Bausch & Lomb, Bern, Switzerland).

Statistical Analysis

For the degree of conversion, data was submitted to three-way ANOVA (photoactivation protocol x light-tip distance, with surface [top or bottom—split-plot] as the vinculated factor). Further analyses with two-way ANOVA were performed for top or bottom results (factors: photoactivation protocol x light-tip distance) so that some of the interactions could be better assessed. Pair-wise comparisons were carried out with the Tukey's test or Student's *t*-test (comparisons between means at the top and bottom). For microleakage results, data were analyzed with the Kruskal Wallis test. In all cases, 5% was the accepted global level of significance. Correlation plots were performed between the degree of conversion and microleakage results.

Table 2: *Degree of Conversion (mean and standard deviation in %) for All Experimental Groups Assessed at the Top of the Specimen*

Photoactivation Protocols	Distance From the Light Guide (mm)			*Pooled Average*
	0	*3*	*7*	
600 mW/cm² x 40 seconds	61.8 (1.4)a	58.4 (3.2)a	55.8 (0.4)a	58.7 (3.1)A
400 mW/cm² x 60 seconds	59.7 (1.2)a	61.1 (3.7)a	57.4 (2.2)a	59.4 (2.8)A
200 mW/cm² x 20 seconds+ 500 mW/cm² x 40 seconds	57.1 (0.6)a	60.5 (1.4)a	56.5 (4.3)a	58.4 (2.9)A
Pooled Average	59.5 (2.3)A	60.0 (2.8)A	56.6 (2.5)B	

*Values followed by the same superscript are equivalent (*p*<0.05).*
Two-way ANOVA: protocol: p*=0.483; distance:* p*=0.015; interaction:* p*=0.180.*

Table 3: *Degree of Conversion (mean and standard deviation in %) for All Experimental Groups Assessed at the Bottom*

Photoactivation Protocols	Distance From the Light Guide (mm)			*Pooled Average*
	0	*3*	*7*	
600 mW/cm² x 40 seconds	59.7 (3.9)a	58.3 (1.2)a	55.8 (1.0)a	57.9 (2.7)A
400 mW/cm² x 60 seconds	58.6 (1.0)a	54.9 (3.5)a	56.3 (1.2)a	56.6 (2.5)A
200 mW/cm² x 20 seconds+ 500 mW/cm² x 40 seconds	58.0 (2.3)a	58.6 (2.5)a	59.4 (1.7)a	58.6 (2.0)A
Pooled Average	58.7 (2.5)A	57.3 (2.9)A	57.2 (2.0)A	

*Values followed by the same superscript are equivalent (*p*<0.05).*
Two-way ANOVA: protocol: p*=0.176; distance:* p*=0.278; interaction:* p*=0.219.*

RESULTS

Results for the degree of conversion tests are shown in Tables 2 and 3. Two-way ANOVAs were performed for data obtained from the top and bottom surfaces. For data collected at the top of the specimen, only the pooled average of 7 mm distance was significant (p=0.015). When data was pooled for this factor, the degree of conversion was statistically lower for the 7 mm groups compared to the 0 and 3 mm groups (Table 2), which were equivalent to each other. For data collected at the bottom of the specimen (Table 3), none of the factors or the interactions was significant (p>0.05). T-tests performed for degree of conversion achieved in analogous groups at the top or bottom of the specimen were not able to find significant differences (p>0.05).

Figure 1 illustrates microleakage scores for the nine experimental groups. The Kruskal-Wallis test was able to detect statistical differences among the groups at a global level of significance of 1%. For the highest irradiance (600mW/cm²), a significant reduction in microleakage was observed when the distance from the light guide increased to 3 mm (p<0.05), which was statistically similar to the results observed at 7 mm. For the intermediate irradiance (400 mW/cm²), the microleakage was similar for all light guide distances (p>0.05). When the soft-start method was used, no statistical difference was observed between the groups irradiated at 0 and 3 mm and both presented higher scores than the group irradiated at 7 mm (p<0.01). Comparing exposure protocols within the same irradiation distance, no statistical differences were observed among groups at 3 mm (p>0.05). When the 0 mm groups were considered, soft-start irradiation caused a decrease in microleakage scores when compared to the continuous high irradiance mode (p<0.05). The 400 mW/cm² irradiance showed results similar to both. At 7 mm, a significant reduction in microleakage scores was only observed with the soft-start method (p<0.01).

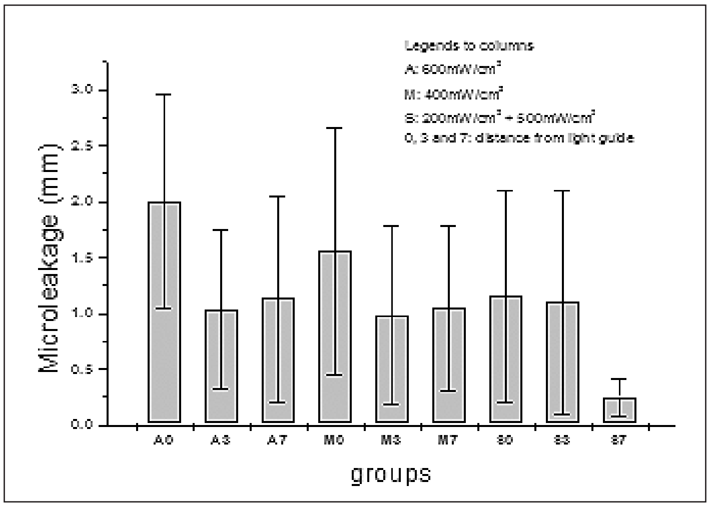

Figure 1. *Microleakage scores for all experimental groups.*

Figure 2 shows that microleakage and degree of conversion at the top of the specimen presented a positive linear correlation (r^2=0.5884), while the correlation with the bottom results was only poor (r^2=0.1713).

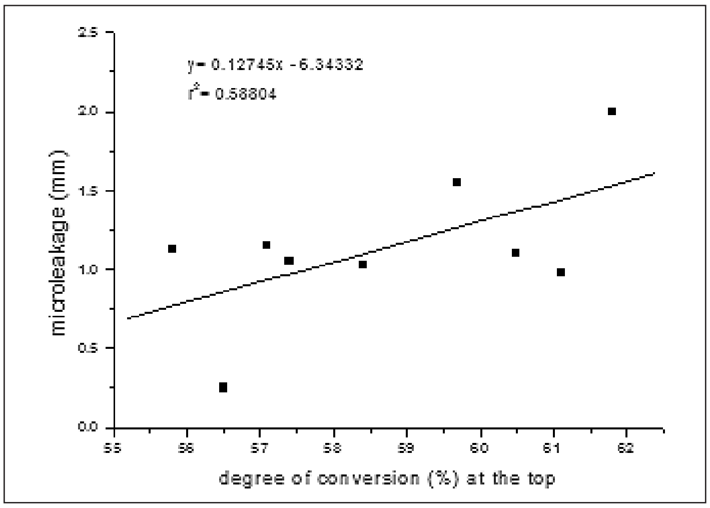

Figure 2. *Correlation plots between the degree of conversion and microleakage at the top and bottom of the specimen.*

DISCUSSION

As the distance between composite and light guide increases, severe light attenuation is observed,[24] which may jeopardize the extent of polymerization.[18] A number of studies have indirectly analyzed the effect of light guide distance on marginal integrity through the observation of microleakage at the cavosurface margin in the proximal box of Class II restorations.[25-26] However, direct attempts to correlate this important clinical aspect to the degree of conversion have not yet been made. The current study proposes a systematic approach to verify how a controlled increase in this distance influences the degree of conversion and microleakage in a composite restoration material. Moreover, the influence of different photoactivation protocols in relation to the increase in light guide distance was also evaluated, both on the top and bottom of 2-mm thick specimens.

The distance between the composite and light guide significantly influenced the degree of conversion only at the irradiated surface ($p<0.05$). When the composite was photoactivated at 7 mm, the irradiance decreased 40% on average (Table 2), causing the conversion to decrease, as previously demonstrated.[27-28] The decrease in irradiance at 3 mm (around 15%) was not enough to produce deleterious effects on the conversion. Regarding the photoactivation protocols, no statistical difference was observed in conversion, which is probably due to the fact that the radiant exposure employed in all methods was similar, within the same distance from the light guide. In fact, it has been reported that, at the range of irradiance tested in the current study, the conversion is determined by the radiant exposure.[29] Other authors have demonstrated that the reciprocity between irradiance and exposure (in seconds) does not always hold true.[30] In their study, it was demonstrated that irradiances higher than 1000 mW/cm², combined with exposure times shorter than five seconds, resulted in composites with degree of conversion and mechanical properties inferior to those obtained at 600mW/cm² x 40 seconds.[30] In the current study, intermediate irradiances were used to assure even polymerization, which appears to have been the case, since the conversion did not change regardless of the protocol used.

At the bottom of the specimen, the light attenuation observed with the 7 mm distance did not influence the degree of conversion, unlike what was observed at the irradiated surface (Table 3). Although a *t*-test applied within the same group to the top and bottom results was not able to find statistical differences between them, a trend towards lower conversion was observed at the bottom. It can be hypothesized that light scattering through the composite and the shift in the material's refractive index during polymerization[31] leveled off the irradiance at the bottom.

The microleakage test revealed a trend for reduced dye penetration at the groups irradiated at 7 mm when compared to groups irradiated at 0 mm, regardless of the photoactivation protocol (Figure 1). At the irradiated surface, this can be explained by the reduced degree of conversion observed for the 7 mm groups (in the pooled average). Indeed, the correlation plot drawn with these two parameters showed a positive linear relationship ($r^2=0.598$). A lower degree of conversion is expected to be accompanied by reduced volumetric shrinkage,[32] which, in turn, has been related to reduced polymerization stress.[33] Since a positive relationship has already been established between microleakage and stress,[23] it is possible that the reduced conversion led to reduced microleakage. However, another hypothesis may help to explain the reduced microleakage with the 7 mm groups. The reduction in irradiance achieved at this level might have caused the reaction rate to be slower, providing extended opportunity for chain rearrangement by flow, which relaxed some of the stress developed within the bonded interface.[34] Indeed, the use of higher initial irradiances has been related to greater polymerization stress.[35-36] If the irradiance is higher, a greater number of polymerization growth centers is activated at the same time, leading the reaction to auto-acceleration at an earlier time during conversion.[37] The viscosity then increases earlier as well, which, in turn, reduces the possibility for chain rearrangement by flow, as previously mentioned.[34]

Regarding the different photoactivation protocols, except for the 3 mm groups, the microleakage was reduced with the soft-start methods in comparison to the higher irradiance (600 mW/cm²) continuous protocol. It is likely that, at 3 mm, the 15% reduction on the irradiance values was not enough to produce differences in microleakage as previously discussed for the degree of conversion results. However, comparing the results obtained with 0 or 7 mm, the reduction in irradiance from 200 mW/cm^2 to 130 mW/cm^2 (35%) on the first step of the soft-start method reduced the microleakage. Indeed, Lim and others[12] suggested that irradiances no higher than 150mW/cm^2 should be used in pulse-delay methods. They found reductions of 26.5%, 15% and 0%, respectively, on polymerization stress with the use of 60, 100 and 150 mW/cm^2 irradiances, followed by a second pulse of 330 mW/cm^2 applied for 60 seconds, which led to a radiant exposure similar to the control group (±0.5 J/cm^2). This could also explain why, at 0 mm, the irradiation at 400mW/cm^2 produced the same microleakage values compared to the soft-start technique. It is likely that the initial irradiance of 200 mW/cm^2 was already too high to allow for a prolonged viscous state in which chain rearrangement by flow would still be possible. Therefore, the light attenuation caused by a photoactivation protocol may be insufficient to promote better marginal adaptation, making necessary its association with light-tip distancing to reduce even more photon flux and the resulting polymerization stress. In a recent clinical trial, authors who also used 200mW/cm^2 as the initial irradiance for the soft-start technique did not observe a significant reduction in post-operative sensitivity or visible signs of marginal stress.[38]

The positive correlation between the degree of conversion and microleakage found for the irradiated surface (Figure 2) implies that the better performance on the microleakage test provided by the soft-start methods was due to a lower conversion. However, the reduction in conversion, despite being statistically significant, was only 4%. This may not be enough to jeopardize the mechanical properties of a composite restoration, as previously reported[39] and still led to a reduction of 57.5% in microleakage.

The first hypothesis was confirmed, since the degree of conversion achieved by all methods was similar, provided that the radiant exposure was kept constant. The second hypothesis was partially accepted, as the reduction in microleakage achieved with the soft-start method was only observed for the 7-mm distance. The third hypothesis was also partially accepted, because the reduction in both the degree of conversion and microleakage depended on the irradiation method tested.

CONCLUSIONS

Within the limitations of the current study, it can be concluded that soft-start methods were able to reduce microleakage when the initial irradiance was low due to the 7-mm distance from the light source. This was accompanied by only a slightly lower conversion.

(Received 5 August 2008)

References

1. Feilzer AJ, de Gee AJ & Davidson CL (1987) Setting stress in composite resin in relation to configuration of the restoration *Journal of Dental Research* **66(11)** 1636-1639.

2. Lee SY & Park SH (2006) Correlation between the amount of linear polymerization shrinkage and cuspal deflection *Operative Dentistry* **31(3)** 364-370.

3. Tantbirojn D, Versluis A, Pintado MR, DeLong R & Douglas WH (2004) Tooth deformation patterns in molars after composite restoration *Dental Materials* **20(6)** 535-542.

4. Peutzfeldt A & Asmussen E (2004) Determinants of *in vitro* gap formation of resin composites *Journal of Dentistry* **32(2)** 109-115.

5. Dauvillier BS, Feilzer AJ, de Gee AJ & Davidson CL (2000) Visco-elastic parameters of dental restorative materials during setting *Journal of Dental Research* **79(3)** 818-823.

6. Goncalves F, Pfeifer CS, Ferracane JL & Braga RR (2008) Contraction stress determinants in dimethacrylate composites *Journal of Dental Research* **87(4)** 367-371.

7. Odian G (1991) *Principles of Polymerization* 3rd ed John Wiley & Sons New York.

8. Lim BS, Ferracane JL, Sakaguchi RL & Condon JR (2002) Reduction of polymerization contraction stress for dental composites by two-step light-activation *Dental Materials* **18(6)** 436-444.

9. Ernst CP, Brand N, Frommator U, Rippin G & Willershausen B (2003) Reduction of polymerization shrinkage stress and marginal microleakage using soft-start polymerization *Journal of Esthetic and Restorative Dentistry* **15(2)** 93-103 discussion 104.

10. Kanca J 3rd & Suh BI (1999) Pulse activation: Reducing resin-based composite contraction stresses at the enamel cavosurface margins *American Journal of Dentistry* **12(3)** 107-112.

11. Brandt WC, de Moraes RR, Correr-Sobrinho L, Sinhoreti MA & Consani S (2008) Effect of different photo-activation methods on push out force, hardness and cross-link density of resin composite restorations *Dental Materials* **24(6)** 846-850.

12. Asmussen E & Peutzfeldt A (2001) Influence of pulse-delay curing on softening of polymer structures *Journal of Dental Research* **80(6)** 1570-1573.

13. Asmussen E & Peutzfeldt A (1998) Influence of UEDMA BisGMA and TEGDMA on selected mechanical properties of experimental resin composites *Dental Materials* **14(1)** 51-56.

14. Lu H, Stansbury JW & Bowman CN (2004) Towards the elucidation of shrinkage stress development and relaxation in dental composites *Dental Materials* **20(10)** 979-986.

15. Lu H, Stansbury JW & Bowman CN (2005) Impact of curing protocol on conversion and shrinkage stress *Journal of Dental Research* **84(9)** 822-826.

16. Pfeifer CS, Braga RR & Ferracane JL (2006) Pulse-delay curing: Influence of initial irradiance and delay time on shrinkage stress and microhardness of restorative composites *Operative Dentistry* **31(5)** 610-615.

17. Hansen EK & Asmussen E (1997) Visible-light curing units: Correlation between depth of cure and distance between exit window and resin surface *Acta Odontologica Scandinavica* **55(3)** 162-166.
18. Rueggeberg FA & Jordan DM (1993) Effect of light-tip distance on polymerization of resin composite *International Journal of Prosthodontics* **6(4)** 364-370.
19. Leloup G, Holvoet PE, Bebelman S & Devaux J (2002) Raman scattering determination of the depth of cure of light-activated composites: Influence of different clinically relevant parameters *Journal of Oral Rehabilitation* **29(6)** 510-515.
20. Rode KM, Kawano Y & Turbino ML (2007) Evaluation of curing light distance on resin composite microhardness and polymerization *Operative Dentistry* **32(6)** 571-578.
21. Abate PF, Zahra VN & Macchi RL (2001) Effect of photopolymerization variables on composite hardness *Journal of Prosthetic Dentistry* **86(6)** 632-635.
22. Calheiros FC, Sadek FT, Braga RR & Cardoso PE (2004) Polymerization contraction stress of low-shrinkage composites and its correlation with microleakage in Class V restorations *Journal of Dentistry* **32(5)** 407-412.
23. Ferracane JL & Mitchem JC (2003) Relationship between composite contraction stress and leakage in Class V cavities *American Journal of Dentistry* **16(4)** 239-243.
24. Corciolani G, Vichi A, Davidson CL & Ferrari M (2008) The influence of tip geometry and distance on light-curing efficacy *Operative Dentistry* **33(3)** 325-331.
25. Nalcaci A, Salbas M & Ulusoy N (2005) The effects of soft-start vs continuous-light polymerization on microleakage in Class II resin composite restorations *Journal of Adhesive Dentistry* **7(4)** 309-314.
26. Cavalcante LM, Peris AR, Amaral CM, Ambrosano GM & Pimenta LA (2003) Influence of polymerization technique on microleakage and microhardness of resin composite restorations *Operative Dentistry* **28(2)** 200-206.
27. Price RB, Derand T, Sedarous M, Andreou P & Loney RW (2000) Effect of distance on the power density from two light guides *Journal of Esthetic Dentistry* **12(6)** 320-327.
28. Vandewalle KS, Roberts HW, Andrus JL & Dunn WJ (2005) Effect of light dispersion of LED curing lights on resin composite polymerization *Journal of Esthetic and Restorative Dentistry* **17(4)** 244-254; discussion 254-245.
29. Bouschlicher MR, Rueggeberg FA & Boyer DB (2000) Effect of stepped light intensity on polymerization force and conversion in a photoactivated composite *Journal of Esthetic Dentistry* **12(1)** 23-32.
30. Musanje L & Darvell BW (2003) Polymerization of resin composite restorative materials: Exposure reciprocity *Dental Materials* **19(6)** 531-541.
31. Chen YC, Ferracane JL & Prahl SA (2005) A pilot study of a simple photon migration model for predicting depth of cure in dental composite *Dental Materials* **21(11)** 1075-1086.
32. Venhoven BA, de Gee AJ & Davidson CL (1996) Light initiation of dental resins: Dynamics of the polymerization *Biomaterials* **17(24)** 2313-2318.
33. Braga RR & Ferracane JL (2002) Contraction stress related to degree of conversion and reaction kinetics *Journal of Dental Research* **81(2)** 114-118.
34. Feilzer AJ & Dauvillier BS (2003) Effect of TEGDMA/BisGMA ratio on stress development and viscoelastic properties of experimental two-paste composites *Journal of Dental Research* **82(10)** 824-828.
35. Cunha LG, Alonso RC, Pfeifer CS, Correr-Sobrinho L, Ferracane JL & Sinhoreti MA (2007) Modulated photoactivation methods: Influence on contraction stress, degree of conversion and push-out bond strength of composite restoratives *Journal of Dentistry* **35(4)** 318-324.
36. Sakaguchi RL, Wiltbank BD & Murchison CF (2004) Contraction force rate of polymer composites is linearly correlated with irradiance *Dental Materials* **20(4)** 402-407.
37. Lovell LG, Newman SM & Bowman CN (1999) The effects of light intensity, temperature, and comonomer composition on the polymerization behavior of dimethacrylate dental resins *Journal of Dental Research* **78(8)** 1469-1476.
38. Chan DC, Browning WD, Frazier KB & Brackett MG (2008) Clinical evaluation of the soft-start (pulse-delay) polymerization technique in Class I and II composite restorations *Operative Dentistry* **33(3)** 265-271.
39. Calheiros FC, Kawano Y, Stansbury JW & Braga RR (2006) Influence of radiant exposure on contraction stress, degree of conversion and mechanical properties of resin composites *Dental Materials* **22(9)** 799-803.