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# Influence of C-factor and Light-curing Mode on Gap Formation in Resin Composite Restorations

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### Clinical Relevance

Gap formation in resin composite restorations may have influence on some parameters, such as C-factor and light-curing mode.

## SUMMARY

**To investigate the influence of the C-factor (Cf) and light-curing mode (LCM) on gap formation in resin composite (RC) restorations. Cylindrical Class I cavities with a 5.0 mm diameter and three different depths (1.0, 2.0 and 3.0 mm) were prepared in the occlusal surfaces of 60 human molars and restored with P60 (P) and Supreme (Su). *RCs* were light-cured in accordance with two modes: Standard (S)—850mW/cm²/20 seconds and Ramp (R)–100 up to 1000mW/cm²/10 seconds +1000mW/cm²/10 seconds. After storage in distilled water, the restorations were cut into three slices and the gap widths were analyzed in a 3D-scanning system. The data were analyzed by ANOVA and Student-Newman-Keul's test (α=0.05). ANOVA detected significant influence for the *RC*, *Cf* and *LCM* independent factors and for the double interactions *RC* vs *Cf* and *LCM* vs *Cf*. Smaller gap formation was found for cavities restored with *Su*. *R* was responsible for the smaller gap formation. The highest gap formation was found for cavities with *Cf*=3.4, followed by *Cf*=2.6 and 1.8 without statistical differences between them. These findings suggest that *Cf* played an essential role in gap formation. *R LCM* may allow *RC* relaxation during polymerization reaction. Finally, nanocomposites (*Su*) may lead**

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DOI: 10.2341/08-035-L

**to less gap formation at the resin-dentin interface.**

## INTRODUCTION

The optical characteristics and mechanical properties of light-curing resin composites are responsible for their safe use in both anterior and posterior restorations. Nevertheless, one of the problems that could interfere with their clinical performance is the shrinkage stress generated during their polymerization reaction.[1]

Rupture of the double carbon bonding of methacrylate monomers present in polymeric matrixes results in a reduction of 0.3 to 0.4 nm of the space maintained between polymer ranges by Van der Waals attraction forces and establishes 0.15 nm-long covalent bondings.[2] As a result, the material undergoes a decrease in volume, which can be interpreted as densification.[3] The polymerization shrinkage generated could lead to gap development, fluid penetration and bacterial presence at the tooth/composite interface and to post-operative sensitivity.[4-5] Variables, such as resin monomer, type and concentration of filler particles and photo initiators, influence this phenomenon.[6] One of the most promising contributions to the restorative material field currently is the use of nanotechnology in new resin composite formulations. Obtaining materials with a greater amount of charge decreases polymerization shrinkage.[7]

Clinically, light-curing mode and energy density provided by the light source can influence polymerization shrinkage stress developed by the material.[8] Activation with a high intensity light creates a rapid light-curing process, leading to higher shrinkage stress in the composite.[9] On the other hand, although activation with lower light intensity may reduce leakage development at the tooth-restorative material interface,[10] it could affect the degree of conversion and mechanical properties of composites.[11] Several recent studies have shown that the use of techniques in which the composite is first submitted to low light irradiance, followed by an increase in light intensity, are able to promote decreased shrinkage stress without interfering with the degree of conversion and mechanical properties of the material.[12-13]

The cavity shape is considered to be of great importance in conserving the composite-dentin bond.[1] Feilzer and others established the configuration factor concept (C-factor=bonded to unbonded surfaces), and it was demonstrated that, in most of the clinically relevant cavity configurations, the stress relieving flow is not sufficient to preserve adhesion to dentin by dentin-bonding agents.[14]

Considering the importance of the multifactorial aspect of the polymerization shrinkage phenomenon, the current study investigated influence of the C-factor and light-curing mode on restoration interface sealing using light-curing resin composites.

## METHODS AND MATERIALS

Two commercially available resin composites, chosen in accordance with their different types of filler particles, were tested: a mini-filled hybrid resin composite (P60 [P]) and a nanofilled resin composite (Supreme [Su]). Both materials have the same polymeric matrix. Their compositions are described in Table 1.

All the specimens in the current study were light-cured with a quartz-tungsten-halogen unit (Optilux 501, Kerr, Danbury, CT, USA). Two light-curing modes (LCM) were used: Standard (S)–850mW/cm$^2$ for 20 seconds (17J/cm$^2$) and Ramp (R)–100 up to 1000mW/cm$^2$ for 10 seconds + 1000mW/cm$^2$ for 10 seconds (≅17J/cm$^2$). The energy density (ED) was calculated by using a radiometer (Demetron Inc, Danbury, CT, USA). For the *R* mode, *ED* was obtained by the sum of mean irradiance over the first 10 seconds multiplied by 10 seconds with 10J/cm$^2$, corresponding to the *ED* in the last 10 seconds of light exposure.

### Selection and Preparation of Teeth/Restorative Procedure

The gap analysis steps are illustrated in Figure 1. Sixty human molars free of structural defects (0.5% chloramine solution/15 days) were used in the current study. All occlusal surfaces were wet ground in a polishing machine with 150 and 600-grit SiC papers until flat dentin surfaces were obtained. The roots were embedded in polyester resin inside PVC cylinders (0.5 inch in diameter) with the flat dentin surfaces parallel to the cylinder borders. The cylinders were fixed in a

Table 1: *Composition of Materials Used in Restorative Procedures*

| Material | Manufacturer/ Batch # | Composition |
|---|---|---|
| Single Bond2 | 3M ESPE (n 7650, St Paul, MN, USA) | BIS-GMA, HEMA, Dimethacrylates, Ethanol, Water, Photoinitiator, Methacrylate functional copolymer of polyacrylic, Polyitaconic acid, Polyalkenoic acid, 10% by weight of 5 nm-diameter spherical silica particles |
| Filtek P60 (P) | 3M ESPE (n 8490, St Paul, MN, USA) | *Filler*: 61 vol% silica/zirconia filler with mean particle size of 0.6 µm<br>*Polymeric matrix*: Bis-GMA, Bis-EMA, UDMA TEGDMA |
| Filtek Supreme (Su) | 3M ESPE (n 4318, St Paul, MN, USA) | *Filler*: 59.5 vol% combination of aggregated zirconia/silica cluster filler with primary particles size of 5-20 nm, and non-agglomerated 20 nm silica filler<br>*Polymeric matrix*: Bis-GMA, Bis-EMA, UDMA TEGDMA |

*Bis-GMA: bisphenol A di (glycidyl methacrylate); Bis-EMA: bisphenol A polyethylene glycol diether dimethacrylate; UDMA: urethane dimethacrylate; TEGDMA: triethylene glycol dimethacrylate*

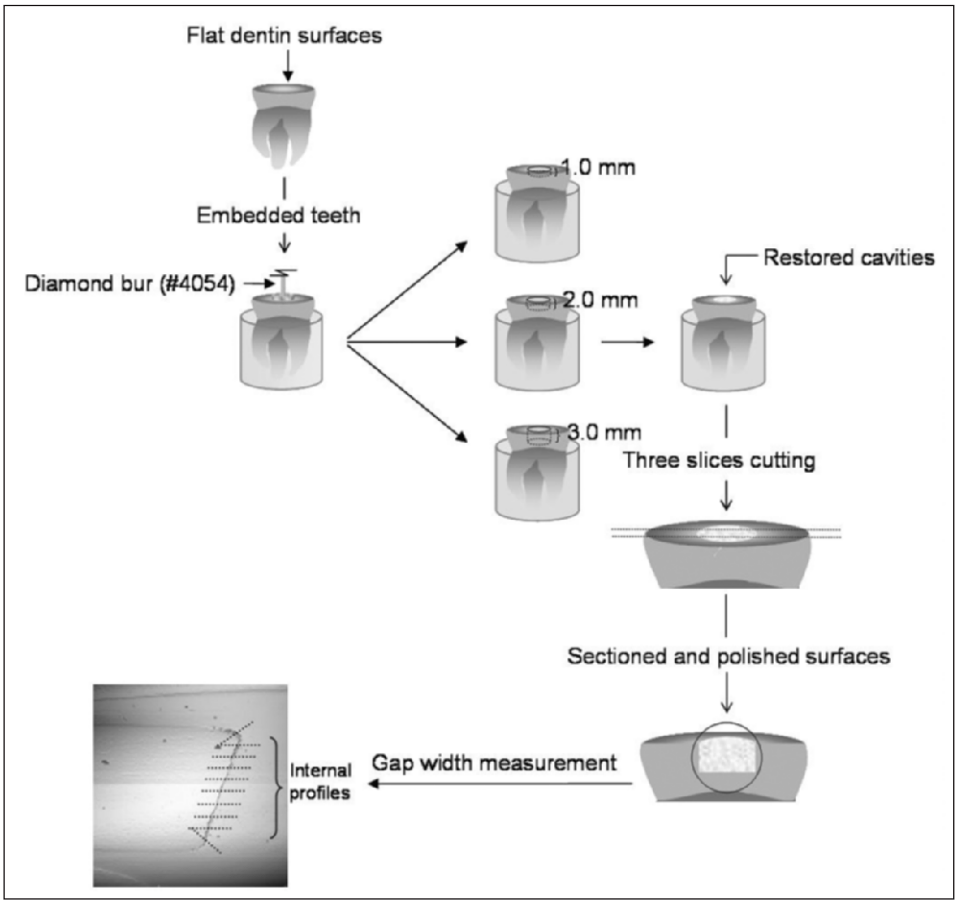


Figure 1. *Schematic illustration of the gap analysis.*

special sample aligning device, and cylindrical Class I cavities 5.0 mm in diameter having three different depths (1.0, 2.0 and 3.0 mm) were prepared in all flat dentin surfaces with a diamond bur (#4054, KG Sorensen, SP, Brazil) in a high-speed handpiece. The cavity depths were controlled by using a digital caliper (MPI/E-101, Mitutoyo, Tokyo, Japan). The C-factor (Cf) was obtained using the following formula:

$$C - factor = \frac{(2\pi rh) + \pi r^2}{\pi r^2}$$

where $r$ is the cavity radius and $h$ is the cavity depth. Therefore, *Cf* for the three cavities was: A=1.8; B=2.6 and C=3.4.

The cavities were bonded with the Single Bond2 adhesive system (3M ESPE, St Paul, MN, USA) in accordance with the manufacturer's instructions and restored in bulk with *P* or *Su*. The resin composites were covered with a polyester strip and light-cured. Twelve experimental groups, in accordance with resin composite *LCM* and *Cf,* were produced (n=5). After storage in distilled water (37°C/seven days), finishing and polishing procedures were performed with sequential Sof-Lex discs (3M ESPE). The restorations were cut into three slices in a buccolingual direction and spaced around 1.0 mm using a diamond disk (KG Sorensen, São Paulo, SP, Brazil). The sectioned surfaces were embedded in polyester resin, polished with 600/1200-grit SiC abrasive paper and sonicated in distilled water for five minutes.

### Gap Measurement/Statistical Analysis

The sectioned surfaces were analyzed in a 3D-scanning system (Talyscan 150, Taylor Hobson, Leicester, England). The GAP width was analyzed in 10 different positions for each slice. The statistical analyses were done with Statgraphics 5.1 (Manugistics, Rockville, MD, USA). The data were analyzed by Multifactor ANOVA and one-way ANOVA with Student-Newman-Keuls' test for multiple comparisons ($\alpha$=0.05).

## RESULTS

The results are shown in Figures 2, 3, 4 and 5. Multifactor ANOVA detected a significant influence for the resin composite *LCM* and *Cf* independent factors ($p$<0.0001) and for the double interactions resin composite vs *Cf* and LCM vs *Cf* ($p$<0.0001). Conversely, no significant differences were found for double interaction resin composite vs *LCM* ($p$=0.2122) and for the triple interaction among the three factors studied ($p$=0.6731). Smaller gap formation was found for the cavities restored with *Su*. Regarding *LCM*, *R* was responsible for the smaller gap formation. The Student-Newman-Keuls' test showed that the highest gap formation was found in cavities with *Cf*=3.4, followed by *Cf*=2.6 and 1.8 without statistical difference between them (Figure 6).

## DISCUSSION

Shrinkage stress generated during resin composite polymerization can be responsible for maintaining the interface tooth-restorative material and for the consequential failure of the restoration.[1] Light-curing initiates the conversion of monomer molecules to a polymer network, a process that leads to resin composite shrinkage because of closer packing of the molecules and transformation of the resin composite from a viscous-plastic state to a rigid-plastic state.[15] Initially, shrinkage stresses in a cavity are compensated by vis-

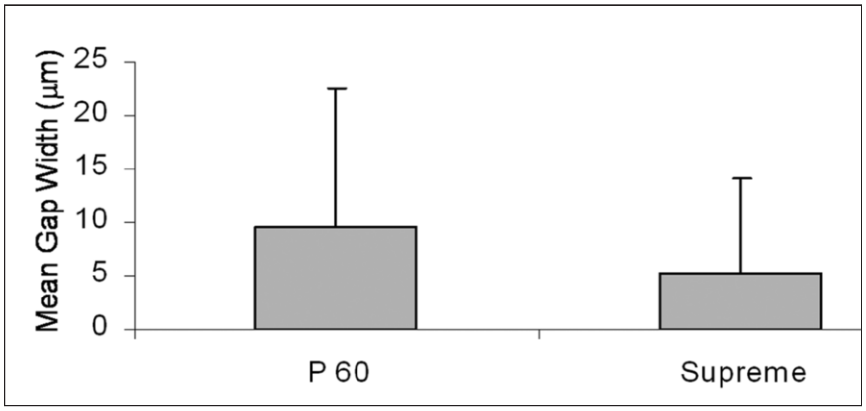


Figure 2. *Mean gap width for independent factor resin composites (vertical bar represents the standard deviation).*

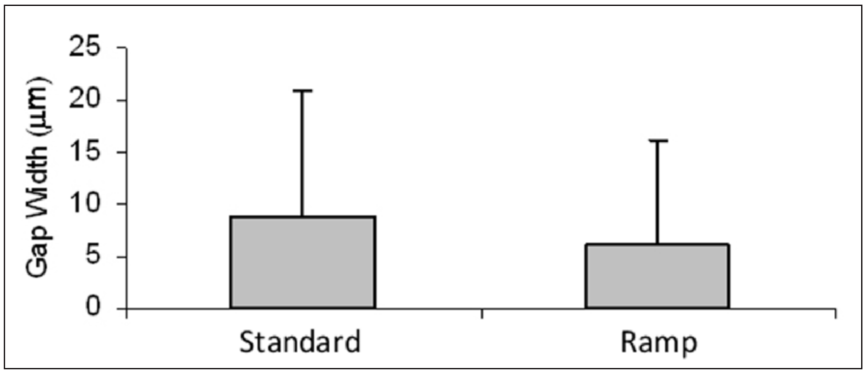


Figure 3. *Mean gap width for independent factor* LCM *(vertical bar represents the standard deviation).*

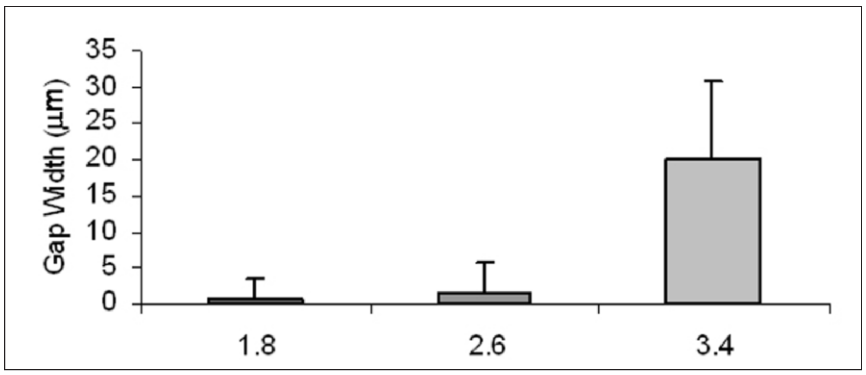


Figure 4. *Mean gap width for independent factor* Cf *(vertical bar represents the standard deviation).*

cous flow of the resin composite, but within a very short time after light-curing begins, viscous flow is reduced and the resin composite starts to transfer stresses to the cavity walls.[14-15]

Filler content, type of organic matrix and flexural modulus have a direct influence on shrinkage stresses and marginal adaptation in cavities restored with light-curing resin composites.[16] Due to the composition of the materials used in this experiment, a difference in gap width among composite factor groups was expected. In spite of their similar organic matrix composition, there are differences in filler content and flexural modulus (e) of *P* and *Su* ($e_p$=11700 MPa and $e_{Su}$=10500 MPa).[17] This may justify the different behavior with regard to shrinkage stress and gap formation values that were observed (Figure 2). *Su* is a resin composite with nanometric filler that involves the lower *e* of the material and would possibly allow for greater reduction in shrinkage stresses during light-curing and a smaller gap formation. On the other hand, a resin composite with a higher *e*, such as P, would cause higher, and therefore more extensive stress formation. This assumption was confirmed in an *in vitro* study of the marginal integrity of Class V restorations.[18] From another viewpoint, it is also possible that nanometric fillers promote a light scattering effect (similar to minifilled particles) that would not permit light energy to activate the deepest resin composite layers.[19] A recent study of the polymerization depth of dental composites observed lower microhardness values at a polymerization depth of more than three millimeters.[20] This was explained by the light scattering effect that decreases the degree of conversion of the material. Further investigations are necessary to support this hypothesis.

The polymerization reaction comprises three phases: pre-gel, gel and post-gel. In the pre-gel phase, a viscous behavior is presented by the composite, and shrinkage stresses generated during the polymerization reaction can be released by the material flow.[1,21-23] Polymer chains are distributed in a linear mode and have mobility that permits tensions induced by polymerization shrinkage to be dissipated by flowing.[24] As the reaction progresses, the post-gel phase starts the first crosslinks between chains, making flow difficult and simultaneously promoting the increase of mechanical properties and *e* that involve inducing tensions in the restoration.[24] But light-curing the material in accordance with protocols that use lower irradiance at the beginning can extend the pre-gel phase, allowing polymerization shrinkage stress relief.[10,25] Retarding the resin composite from reaching its gel point could explain the smaller gap formation when *R* polymeriza-

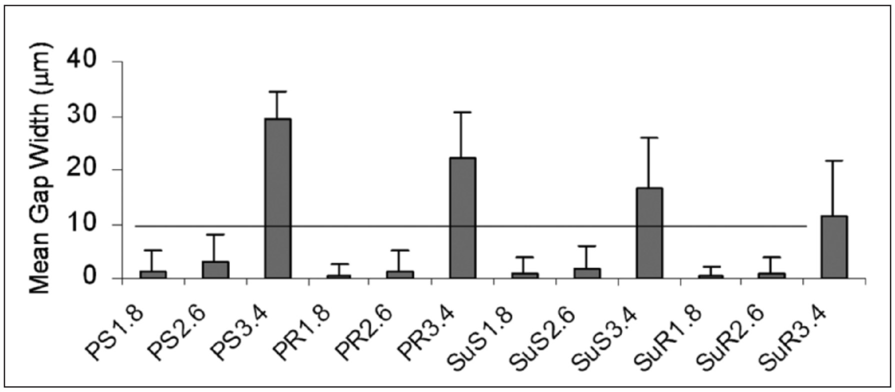


Figure 5. *Mean gap width for all experimental groups (vertical bar represents the standard deviation). Columns under the horizontal line are not statistically different (*p*>0.05).*

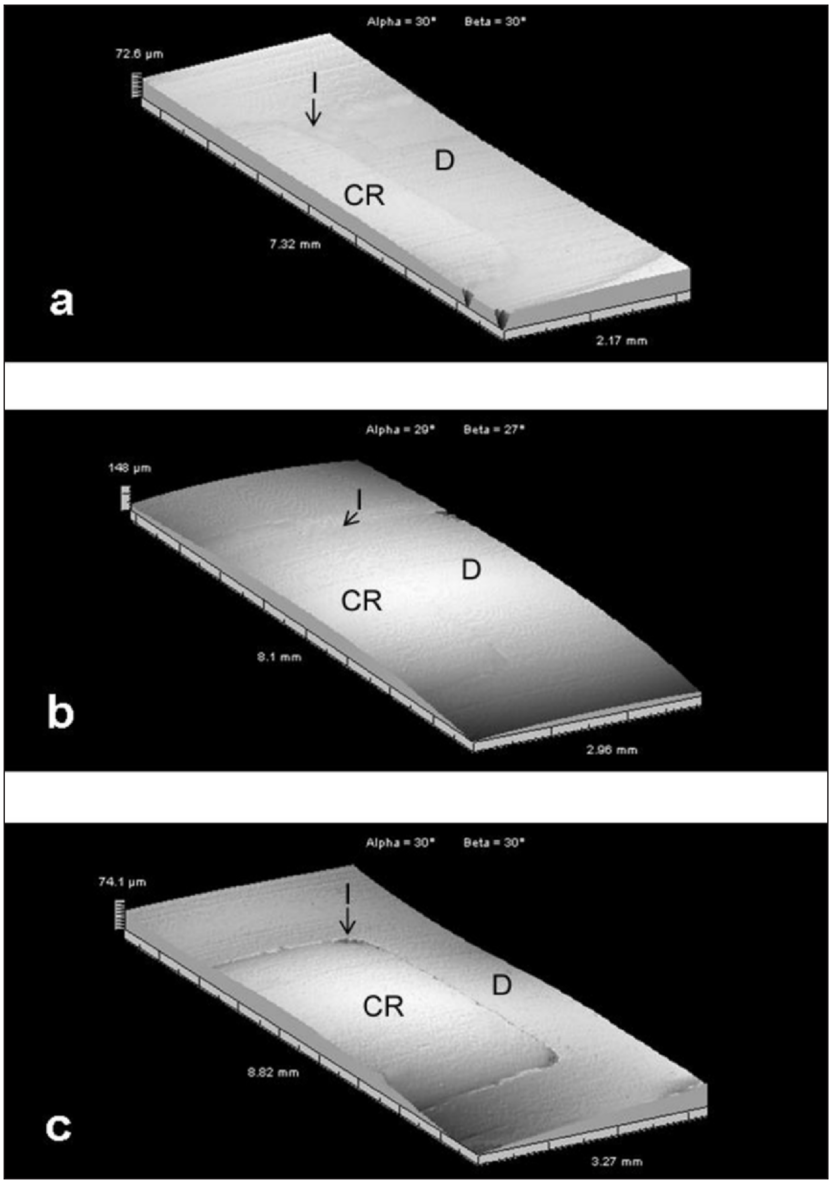


Figure 6. *Representative image of gap measurement (cavities with* Cf *=1.8, 2.6 and 3.4) (D=dentin; CR=composite resin; and I=interface).*

tion is used (Figure 3).[26] Previous studies have demonstrated that the highest stress development associated with polymerization shrinkage occurs during the first 30 to 40 seconds of light irradiation.[16,27] In agreement with these findings, Feilzer and others demonstrated that light-curing with low irradiance was related to better marginal sealing of cavities restored with light-curing resin composites.[10] On the other hand, light-curing with low irradiance may promote a decrease in the degree of conversion and negatively influence the mechanical properties of the material.[13,28]

Despite the differences in *LCM*, the final *ED* used in the current study for both techniques was the same: 17J/cm$^2$.[12-13] According to Rueggeberg and others, this *ED* would be adequate to light-cure restorative resin composites.[11]

In particular, influence of the confinement conditions imposed on the resin composite (usually expressed as the bonded to unbonded ratio, known as *Cf*) plays an essential role in gap formation.[14] In the current study, cylindrical cavities with different *Cfs* were produced by varying the depth and keeping to the same diameter. The results obtained demonstrated that high *Cf* values (3.4) indicated high gap formation (Figures 4 and 6). This can be explained, because the stress relieving flow was not sufficient in this case to preserve adhesion to dentin by dentin-bonding agents. On the other hand, lower *Cf* values (1.8 and 1.6) permitted more resin composite relaxation.[22] High gap formation values were commonly observed at the internal angles in all groups tested, and this could be related to high shrinkage stress in these areas.[29] As shown in Figure 6, in the cavo-surface region, restoration sealing was improved by the proximity of free surfaces that allowed stress relief by resin composite flow.[22,29] This explains why gap measurement was analyzed only on the cavity floor. In microleakage studies, cavity depth was found to have a stronger influence than diameter.[29] In accordance with these findings, the current study always used the same diameter and different depths to create experimental groups with different *Cf* values.

In summary, based on the results obtained in this *in vitro* study, which simulated clinical restorative procedures in a tooth cavity, gap formation is a multifactor phenomenon that depends on several intrinsic factors[3,15] related to restorative materials and extrinsic factors, such as *Cf*[14-16] and *LCM*.[10,13] Furthermore, it is also important to study other factors, such as the incremental technique and use of liner materials in order to improve restoration sealing.

## CONCLUSIONS

Considering the limitations of this *in vitro* study, it was possible to conclude that:

1. High C-factor values produced the highest gap formation.
2. The ramp light-curing mode was efficient for reducing gap formation.
3. Nanofilled composite was more efficient for cavity sealing than mini-filled hybrid composites.

The results suggest that further investigations should be conducted in order to promote the better sealing of cavities restored with light-curing resin composites.

### Acknowledgements

This study was supported by Adhesion and Adherence Laboratory (LAA—Department of Mechanical Engineering) of State Rio de Janeiro University (Nova Friburgo—RJ, Brazil). The authors thank 3M ESPE and Kerr for supplying materials for this study.

*(Received 8 October 2008)*

### References

1. Davidson CL, de Gee AJ & Feilzer A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63(12)** 1396-1369.
2. Peutzfeldt A (1997) Resin composites in dentistry: Monomer systems *European Journal of Oral Sciences* **105(2)** 97-116.
3. Braga RR, Ballester RY & Ferracane JL (2005) Factors involved in the development of polymerization shrinkage stress in resin-composites: A systematic review *Dental Materials* **21(10)** 962-970.
4. Eick JD & Welch FH (1986) Polymerization shrinkage of posterior composite resins and its possible influence on postoperative sensitivity *Quintessence International* **17(2)** 103-111.
5. Krejci I & Lutz F (1991) Marginal adaptation of Class V restorations using different restorative techniques *Journal of Dentistry* **19(1)** 24-32.
6. Condon JR & Ferracane JL (1998) Reduction of composite contraction stress through non-bonded microfiller particles *Dental Materials* **14(4)** 256-260.
7. Bayne SC (2005) Dental biomaterials: Where are we and where are we going? *Journal of Dental Education* **69(5)** 571-585.
8. 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.
9. Jain P & Pershing A (2003) Depth of cure and microleakage with high-intensity and ramped resin-based composite curing lights *Journal of the American Dental Association* **134(9)** 1215-1223.
10. Feilzer AJ, Dooren LH, de Gee AJ & Davidson CL (1995) Influence of light intensity on polymerization shrinkage and integrity of restoration-cavity interface *European Journal of Oral Sciences* **103(5)** 322-326.
11. Rueggeberg FA, Caughman WF, Curtis JW Jr & Davis HC (1993) Factors affecting cure at depths within light-activated resin composites *American Journal of Dentistry* **6(2)** 91-95.
12. Muangmingsuk A, Senawongse P & Yudhasaraprasithi S (2003) Influence of different softstart polymerization techniques on marginal adaptation of Class V restorations *American Journal of Dentistry* **16(2)** 117-119.
13. Sakaguchi RL & Berge HX (1998) Reduced light energy density decreases post-gel contraction while maintaining degree of conversion in composites *Journal of Dentistry* **26(8)** 695-700.
14. 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.
15. Peutzfeldt A & Asmussen E (2004) Determinants of *in vitro* gap formation of resin composites *Journal of Dentistry* **32(2)** 109-115.
16. Silikas N, Eliades G & Watts DC (2000) Light intensity effects on resin-composite degree of conversion and shrinkage strain *Dental Materials* **16(4)** 292-296.
17. da Silva EM, dos Santos GO, Guimarães JGA, Barcellos AAL & Sampaio EM (2007) The influence of C-factor, flexural modulus and viscous flow on gap formation in resin composite restorations *Operative Dentistry* **32(4)** 356-362.
18. Kemp-Scholte CM & Davidson CL (1990) Marginal integrity related to bond strength and strain capacity of composite resin restorative system *Journal of Prosthetic Dentistry* **64(6)** 658-664.
19. Ruyter IE & Øysaed H (1987) Composites for use in posterior teeth: Composition and conversion *Journal of Biomedical Materials Research* **21(1)** 11-23.
20. Moore BK, Platt JA, Borges G, Chu TM & Katsilieri I (2008) Depth of cure of dental resin composites: ISO 4049 depth and microhardness of types of materials and shades *Operative Dentistry* **33(4)** 408-412.
21. Bausch JR, de Lange K, Davidson CL, Peters A & de Gee AJ (1982) Clinical significance of polymerization shrinkage of composite resins *Journal of Prosthetic Dentistry* **48(1)** 59-67.
22. Davidson CL & de Gee AJ (1984) Relaxation of polymerization contraction stresses by flow in dental composites *Journal of Dental Research* **63(2)** 146-148.
23. Emami N, Soderholm KJ & Berglund LA (2003) Effect of light power density variations on bulk curing properties of dental composites *Journal of Dentistry* **31(3)** 189-196.
24. Ferracane JL (2005) Developing a more complete understanding of stresses produced in dental composites during polymerization *Dental Materials* **21(1)** 36-42.
25. Feilzer AJ, de Gee AJ & Davidson CL (1993) Setting stresses in composites for two different curing modes *Dental Materials* **9(1)** 2-5.

26. Davidson CL & Feilzer AJ (1997) Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives *Journal of Dentistry* **25(6)** 435-440.

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

28. Rueggeberg FA, Caughman WF & Curtis JW Jr (1994) Effect of light intensity and exposure duration on cure of resin composite *Operative Dentistry* **19(1)** 26-32.

29. Braga RR, Boaro LC, Kuroe T, Azevedo CL & Singer JM (2006) Influence of cavity dimensions and their derivatives (volume and "C" factor) on shrinkage stress development and microleakage of composite restorations *Dental Materials* **22(9)** 818-823.