Effect of Stepped Exposure on Quantitative In Vitro Marginal Microleakage

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ABSTRACT

Purpose: The aim of this in vitro study was to evaluate the effect of a soft-start curing mode on microleakage.

Materials and Methods: Standardized Class V cavities were prepared within all the margins in the buccal enamel or dentin surface of sound, freshly extracted inferior bovine incisors. Forty preparations were filled with a restorative system (Single Bond and Filtek Z250, 3M ESPE, St. Paul, MN, USA). Ten restorations of each group were made on both types of substrates and polymerized with a conventional curing technique (600 mW/cm^2/40 s) or with a soft-start technique (150 mW/cm^2/10 s + 600 mW/cm^2/30 s). All specimens were thermocycled 3,000 times and then immersed in methylene blue 2% for 12 hours. The specimen microleakage was quantitatively determined in a spectrophotometer.

Results: The soft-start technique resulted in statistically significant less microleakage for each substrate ($p < .05$). The conventional groups exhibited 6.1 (dentin) to 15.4% (enamel) more leakage compared with the soft-start groups. When compared with the enamel margins, the dentin margins demonstrated greater microleakage: from 15.5% greater with the conventional light-curing mode to 25.6% greater with the soft-start light-curing mode.

Conclusions: The polymerization technique using a very low initial intensity (150 mW/cm^2/10 s) decreased the microleakage of composite resin restorations.

CLINICAL SIGNIFICANCE

A soft-start light-curing approach to resin composite polymerization resulted in less microleakage at enamel and dentin margins in Class V cavities compared with resin composite restorations polymerized using a conventional light-curing approach.

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Since their introduction, esthetic resin-based restorative materials have been improved and widely used in modern dentistry. However, the most critical properties related to resin composites have not been satisfactory. One, in particular, is the shrinkage that occurs during polymerization when monomer

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molecules are converted into a polymer network.[1,2] This conversion produces contraction stress in a confined structure such as a tooth cavity.[2] This stress adversely affects the maintenance of the bonded interface between composite resins and dental hard tissues.[2] This can potentially cause debonding and lead to clinical failure of the restorations.[3] If the internal stress generated in the restricted environment of a tooth cavity exceeds the bond strength at the interface, the marginal seal can be interrupted.[4] Gap formation allows the possible entry of oral fluids and bacteria through marginal leakage. It is not easy to detect leakage around the cavity clinically immediately after placement. However, microleakage may be associated with postoperative sensitivity and may eventually produce discoloration of the margins and/or recurrent caries; consequently, it may reduce the life of a restoration.[5,6]

High-intensity lights for light-cured resin composites need to have superior mechanical and physical properties.[7] Unfortunately, maximization of physical and mechanical properties also results in increased polymerization shrinkage, which leads to increased marginal gap formation.[8] Recently, light-curing modes that alter initial intensity have been introduced with the aim of reducing or eliminating marginal gap formation.

It would seem that the controlled polymerization of composite resin restorations using prepolymerization at a low light intensity followed by a final cure at a high light intensity may result in improved marginal integrity without losing the desired material properties.[9–11] However, working with a qualitative analysis of marginal microleakage, Friedl and colleagues showed that soft-start polymerization does not provide better marginal adaptation.[1] In addition, no study has looked specifically at the differential marginal leakage of enamel and dentin when the soft-start curing mode is used.

This study aimed to test the influence of the soft-start curing mode by evaluating the quantitative microleakage pattern in dentin and in enamel margins using a resin composite placed in three-dimensional cavities with a high C-factor. The null hypotheses tested were (1) that the soft-start curing technique would not reduce marginal leakage compared with the conventional curing technique and (2) that with the soft-start curing technique, the microleakage would not differ between restoration margins completely placed in enamel compared with that in restorations margins completely placed in dentin.

MATERIALS AND METHODS

Tooth Preparation

Twenty fresh bovine incisors stored in 2% buffered formalin were used. All teeth were cleaned with a water slurry of pumice flour in a rubber prophylaxis cup at low speed and examined for the presence of craze lines, cracks, and surface defects that could influence dye penetration. After cleaning, the selected teeth were stored in distilled water at room temperature to prevent dehydration. Dental cubic blocks, with approximate dimensions of 5 × 5 × 5 mm obtained from the buccal surfaces of root dentin and crown enamel, were included in epoxy resin to facilitate handling.[12]

Standardized cylindrical cavities of 1.85 ± 0.05 mm diameter by 1.5 mm depth were prepared in the central part of the block (enamel or dentin) with a special diamond bur (Figure 1) (KG Sorensen Ind. Com. Ltda, Barueri, São Paulo, Brazil) that was made for this study.[12] The cavities were prepared with the purpose of having a high C-factor (C-factor is the ratio between bonded and unbonded areas[2]). All the cavities were prepared with a water-cooled high-speed turbine.

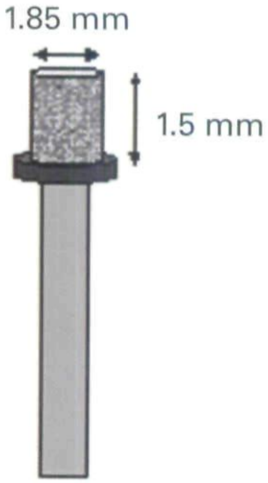

Figure 1. Special diamond bur used for making the cylindrical cavities.

A new bur was used for every lot of five specimens prepared. Cavity preparations were rinsed for 10 seconds with air and water spray and air dried for 10 seconds. The same investigator did all the restorations.

Power Density

The pilot study showed that by changing the distance between the light source (KM 200R, DMC Equipment's Ltd., São Carlos, São Paulo, Brazil) and the specimens, the intensity of the light at the surface of a specimen could be reduced. Light irradiation was done at a distance of 3 to 15 mm, until a smaller intensity than 100 mW/cm^2 was obtained, measured by the digital radiometer of the same light-curing unit. Thus, a linear regression graph of distance × power density was established (Figure 2). The linear regression equation ($y = ax \pm b$) was expressed as follows:

$$y = -0.0299x + 17.616$$

where y is the tip to specimen distance and x is the power density. With the regression equation, the specific distance of 13.13 mm for 25% intensity (150 mW/cm^2) was determined.

Tooth Restoration

Prior to restoration, cavity preparations were rinsed for 10 seconds with an air/water spray and air dried for 10 seconds. The same operator performed all cavity restorations. Each tooth was acid-etched with 35% phosphoric acid (Scotchbond, 3M ESPE, St. Paul, MN, USA) for 15 seconds. The cavities were rinsed for 15 seconds and gently air dried for 10 seconds. Two layers of adhesive system (Single Bond, 3M ESPE) were applied, and the second layer was light cured for 20 seconds, following the manufacturer's instructions. Teeth were then restored with Filtek Z250 composite resin (3M ESPE), filled in one (bulk) increment and light cured according to two polymerization methods: conventional irradiation (full intensity of 600 mW/cm^2 for 40 s) or soft-start irradiation (two-step mode with 10 s at low intensity of 150 mW/cm^2 plus 30 s at full intensity of 600 mW/cm^2). The low intensity used in the soft-start irradiation groups was obtained by positioning the light source at 13.13 mm (controlled by an electronic digital caliper, positioned in a specific device) from the specimen surfaces. Specimens were stored in distilled water at 37°C ± 1°C for 24 hours, and restorations were wet polished with a graded series of aluminum oxide disks (Sof-Lex Pop-on, 3M ESPE). Then, the specimens were stored in distilled water at 37°C ± 1°C for 24 hours.

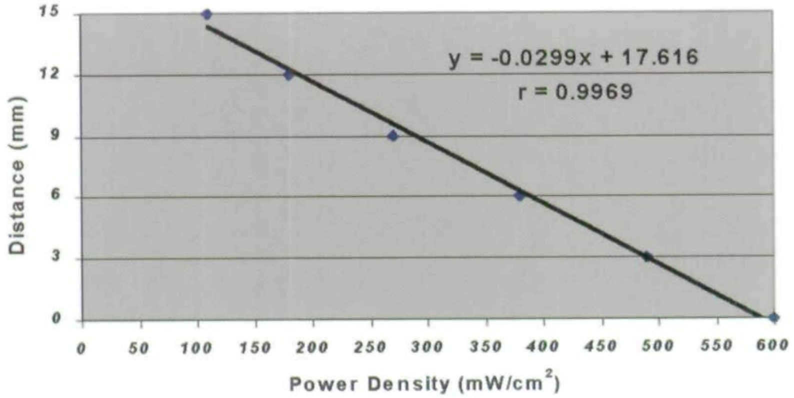

Figure 2. Linear regression of distance from tip of light-curing unit to specimen by power density of the light.

All restorations were thermocycled for 3,000 cycles between 5°C ± 2°C and 55°C ± 2°C with a dwell time of 60 seconds and transfer time of 6 seconds. Prior to immersion in the dye solution, the interfaces between the dental cubes and polystyrene resin were sealed with a coat of a cyanoacrylate adhesive (SuperBonder, Loctite do Brasil Ltda., Iatapevi, SP, Brazil) that was extended up to 1 mm of the tooth-restoration interface.

Specimens were immersed in a 2% methylene blue buffered solution (Vip Fórmulas Ltda, Piracicaba, São Paulo, Brazil) at room temperature for 12 hours and then rinsed carefully for 2 minutes under running water. The restorations were wet polished with 1,200-grit silicon carbide (SiC) sandpaper to eliminate the surface layer of material and substrate that was stained. The average thickness removed was 0.04 to 0.05 mm as measured with a digital caliper (Mitutoyo Co., Tokyo, Japan).

Microleakage Quantification

Two surfaces of the epoxy resin cylinder were wet abraded with SiC paper no. 100 and no. 300 grit so that the cubic dental blocks could be removed. Microleakage was determined quantitatively by a dye-recovery method adapted from Douglas and Zakariasen,[13] which was well described recently by Aguiar and colleagues.[12] Each block was weighed before and after being ground into powder in a hard tissue mill (Marconi Equip. Ltda, Piracicaba, SP, Brazil). If the difference between the initial and final weight had been greater than 10%, the specimen would have been discarded. In this study, no specimens were discarded. The powder of each block was individually immersed in a glass tube containing 4 mL of absolute alcohol pro analysis for 24 hours to dilute the methylene blue. After this procedure, the solutions were centrifuged (Tomy–IC 15AN, Tomy Ind., Tokyo, Japan) at 3,000 rpm for 3 minutes. The supernatant (floating solution) was analyzed through a spectrophotometer (Beckman DU-65, Beckman Instruments, Inc., Fullerton, CA, USA) adjusted to a wavelength of 668 nm.

To determine the absorbance, the spectrophotometer was adjusted to an appropriate wavelength for the methylene blue, corresponding to the maximum absorbency for the dye. To calibrate the spectrophotometer, the absorbance of each standard solution (0.1, 0.2, 0.3, 0.5, 1, 2, 4, and 6 µg/mL) was determined at wavelengths ranging from 400 to 700 nm, and the maximum value was obtained at 668 nm. With these values, a coefficient of linear correlation ($r = .9998$) and a straight-line equation ($y = a + bx$) were determined. The following relationship was obtained:

$$\text{Absorbance} = 0.2716 \times \text{Dye concentration} - 0.0075$$

To quantify the dye concentration (in micrograms per milliliter) infiltrated between the tooth and the restoration, the y value was changed for the absorbance of each sample.

Statistical Analysis

Results were statistically analyzed at a .05 level of significance by a two-way categorical analysis of variance (ANOVA), involving two main factors (dental margins and curing mode). In addition, the interaction among factors was tested. These analyses were conducted with an SAS personal computer (SAS Institute, Cary, NC, USA). Response variable was microleakage expressed in dye concentration values. The Tukey multiple comparisons test was applied to determine differences among means at a preset α of .05.

RESULTS

The results revealed a significant main effect of both types of substrate and curing modes ($p < .05$). No statistical significance was detected for the interaction between the curing mode and substrate ($p = .6354$). Dye concentration results are presented in Table 1.

The dye concentration values varied from 0.0313 µg/mL (soft-start irradiation in enamel group) to 0.0755 µg/mL (conventional irradiation in dentin group). With both curing modes, the restorations with dentin margins showed significantly more microleakage ($p < .05$). There were significant differences between the curing modes ($p < .05$). The soft-start technique resulted in statistically significantly less microleakage for each substrate ($p < .05$). Results from the restorations polymerized with the conventional curing technique showed 6.1 (dentin margins) to 15.4% (enamel margins) more leakage when compared with the results obtained with soft-start curing technique.

DISCUSSION

Curing lights with very high intensity are necessary for a complete polymerization and optimal mechanical properties.[14] The minimum degree of conversion (DC) of com-

TABLE 1. MEAN VALUES OF INFILTRATED DYE CONCENTRATION.

	Infiltrated Dye Concentration (μg/mL ± SD)	
Curing Mode	**Enamel Margins**	**Dentin Margins**
Conventional	0.045 ± 0.005	0.052 ± 0.011
Soft start	0.039 ± 0.004	0.049 ± 0.005

All group comparisons were statistically significantly different ($p < .05$).

posites for a clinically satisfactory restoration has not yet been precisely established. However, an increase in DC is generally associated with a corresponding increase in shrinkage strain.[15] Thus, the possible negative influence of high-intensity lights on stress development should be considered. Some polymerization techniques have been developed in an attempt to decrease the stress caused by polymerization shrinkage. In the literature, a method described for reducing the effect of polymerization shrinkage is to use a low-intensity dental curing light.[9]

In this study, the results showed that the soft-start irradiation, starting with lower light intensity, presented the lowest leakage means, statistically different from those with the conventional curing mode. The soft-start technique resulted in less microleakage for each substrate, with the conventional curing mode groups exhibiting 6.1 (dentin) to 15.4% (enamel) more leakage. This work supports results of others studies, in which the use of low-intensity initial curing was also described and associated with better marginal integrity and adaptation.[10,16,17] Hence, null hypothesis 1 was thus rejected.

The major aim of this technique is to minimize or control polymerization shrinkage. Polymerization shrinkage has three didactic phases: the pre-gel, gel point, and post-gel phase. But, the post-gel phase is the only one that is capable of disrupting the marginal seal between the composite restoration and dentin or enamel because, in the phase before the gel point, the monomers can still move or slip into new positions within the resin matrix without causing stress at the interface.[1,11] With the increase in the numbers of monomers converted into polymers, the flow gradually decreases, while the resin composite stiffness increases and the material becomes sufficiently strong to exert forces or stress in the bond system.[1,2] The theory is that a slower rate of conversion allows for a better flow of the material by extending the initial polymerization period, thus leading to reduced post-gel shrinkage.[8] A low-intensity light for the first 20 seconds extends the viscoelastic stage of setting, thereby moderating the development of curing stress.[18] Rueggeberg and colleagues showed that an appropriate cure of the composite cannot be obtained with an intensity lower than 233 mW/cm^2 in a 1 mm thick layer.[7] The intention of the initial irradiation is not to promote an appropriate cure of the composite, but to have a penetration capable of activating the initiators of deeper layers, leading to a slow but homogeneous cure.[19,20] According to Feilzer and colleagues,[17] the main effect of stress reduction in a restorative material occurs within the first 10 seconds of curing, when the light intensity is 250 mW/cm^2. In the present investigation, the initial intensity used was 150 mW/cm^2 for 10 seconds.[17] The polymerization stress reduction mechanism seems to be prolonging the gel point, which allows the resin-based composite to flow for a longer period of time. This effect seems to be less effective in resins containing a higher concentration of light-sensitive initiator or in resin composites with a higher elastic resin matrix.[21]

The quantitative microleakage measurements were significantly higher at the dentin-restoration interface. The dentin margins demonstrated 15.5 (conventional exposure) to 25.6% greater (soft-start exposure) microleakage than did the enamel margins. Therefore, null hypothesis 2 was not confirmed. Uno and colleagues, in their study examining the effect of slow curing on cavity wall adaptation with five irradiation conditions, reported that the beneficial effect of slow curing is found at the line angle rather than on the cavity floor.[22] The contraction stress has been reported to be about 8 to 23 MPa, which are bond strength values that can be higher than many dentin bond strengths.[23,24] Kinomoto and Torjj showed that in a box-shaped cavity, the principal stress is developed around the internal line angle.[24] The explanation is that the flow of composite decreased with an increasing distance from the free surface, promoting an increase of wall-to-wall polymerization contraction gaps in the deeper parts of the fillings. With the lower stress developed near the cavosurface margin, the gap is probably formed at the interface between the pulp floor and resin composite in the tooth restoration.

When the composite resin is placed in contact with dentin and enamel at the same time, the above-mentioned situation would be even more accentuated owing to the adhesion to enamel being stronger than the adhesion to dentin.[25] So, during the stress generated by polymerization shrinkage, the gap would be formed in the weakest bond area between the resin bond and the wall cavity.[5] Under conditions of competition between enamel and dentin walls, the enamel margins would be better preserved and present lower microleakage than dentin margins. Using three-dimensional cavities with a high C-factor, Yoshikawa obtained better results with a soft-start light-curing approach in a bond strength test.[26] The beneficial effect of the soft-start light curing was found at the enamel and dentin margins. This was well demonstrated in the present study, carried out with standardized cylindrical preparations with the margin entirely in one substrate and a high C-factor. In this study, the C-factor value of each cavity was approximately 4.24. (This value was obtained by calculating the ratio between bonded [approximately 11.41] and unbonded areas [approximately 2.69].) The cavity geometry may determine the ability of restorative material to contract freely.

Analogous to Class I cavities, the configuration of Class V cavities may be less favorable since a high stress is expected to be generated by the polymerization shrinkage.[24,27,28] This study evaluated the leakage of the composite in dentin and enamel margins and suggests that the best way to decrease marginal leakage is by using a soft-start curing mode. Further research is required to confirm the potential of soft-start irradiation for other resin composite filling materials, as well as in association with various cavity designs.

CONCLUSIONS

Under the experimental conditions of this study, the following can be concluded:

1. No light-curing technique avoided leakage.
2. The soft-start curing mode (10 s at 150 mW/cm^2 plus 30 s at 600 mW/cm^2) was able to significantly reduce the marginal microleakage compared with the conventional light-curing mode.
3. The beneficial effect of the soft-start light curing is found at the enamel and dentin margins.
4. The quantitative microleakage measurements were significantly higher at the dentin-restoration interface.

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COMMENTARY

EFFECT OF STEPPED EXPOSURE ON QUANTITATIVE IN VITRO MARGINAL MICROLEAKAGE

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Over the years, many innovations in visible light curing of resin composites have been introduced to dentistry. Light-activation units range from conventional quartz-tungsten-halogen (QTH) models to plasma arc curing units to argon ion lasers to light-emitting diodes. Curing lights have been developed with varying outputs and curing cycles and have evolved along two divergent paths. One trend is to push output readings close to or over 1,000 mW/cm^2 using high-intensity lights, such as the higher-output QTH bulb, plasma arc lamp, and argon ion laser. The other philosophy is to use ramped or step lights, which are programmed to yield slower initial polymerization, also called "soft-start" polymerization.[1]

Soft-start polymerization is a concept that has appeared in the literature since the late 1990s. The idea behind the two-step approach is to allow viscoelastic flow of the dental composite during polymerization, with the goal of reducing the overall polymerization shrinkage at the margin of the final restoration.[2] The results of this study corroborate those of several similar studies,[1,3,4] which confirm that the use of soft-start polymerization can lead to a significant reduction in marginal microleakage compared with the use of conventional light curing. However, the current study also confirms that, to date, neither techniques nor materials have provided perfect adaptation of the restorative material around the entire periphery of the restoration. Despite significant improvements in dentin bonding systems and a reduction in dental composite shrinkage, no system is currently able to completely prevent the formation of contraction gaps, especially at the cementum/dentin-restoration junction.

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