Association of photoactivation methods and low modulus liners on marginal adaptation of composite restorations

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The aim of this study was to evaluate the effect of photoactivation methods, resin liners, and the association of these techniques on the marginal adaptation of composite restorations. One-hundred-and-twenty bovine incisors were selected. A circular cavity was prepared in a flat dentin area on the buccal surface and the Scotchbond Multi Purpose system was applied. These teeth were assigned to four groups in accordance with lining technique: control (one adhesive layer), three adhesive layers individually photoactivated, Filtek Flow, and Protect Liner F. Each group was subdivided depending on the photoactivation method: continuous light, soft-start, or intermittent light. All cavities were restored with Filtek Z250 and then polished. Caries detector was applied on each specimen for 5 s in order to verify marginal adaptation through dye-staining of the gaps formed on the outer margins. Images of the stained gaps were observed under the stereomicroscope, and transferred to a computer measurement program in order to determine gap length. Data were submitted to ANOVA and Tukey's test ($P < 0.05$). Significant differences among the lining techniques were only observed using the photoactivation method with continuous light. In this case, the lining technique with Filtek Flow significantly increased marginal adaptation of the composite to the outer dentin margins compared with the results of the control group. The other lining techniques showed intermediate values and no statistical difference from the other groups. For the photoactivation methods, intermittent light showed the best marginal quality of all the methods. This was statistically significant only for the control lining technique. □ *Composites; dental restorations; light-curing; stepped polymerization*

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Light-cured resin composites are commonly used in daily clinical practice to restore anterior and posterior teeth because of their esthetic advantages, improved bonding to tooth structure, and enhanced mechanical properties. However, polymerization shrinkage is still a major problem in light-curing restorations (1–4). In vitro measurements of polymerization shrinkage of resin composites range from 1.9% to 6% (5).

The insertion of these contracting resin composites into bonded cavity preparations leads to competition between polymerization shrinkage forces and the bonding strength to tooth structure (6). In light-cured composites in particular, the fast conversion induces a fast increase in composite stiffness, causing high shrinkage stresses at the interface (7). Such stress can disrupt the bond between the composite and the cavity walls or may even cause cohesive failure of the restorative material or the surrounding tooth tissue (6, 7). This is the main cause of marginal failure and subsequent microleakage in the resin composite restorations (8).

Considering the difficulty ensuring a perfect marginal seal of composite restorations, especially on dentin margins (9), the use of compensatory mechanisms has been proposed as a means of minimizing the stress generated by polymerization shrinkage and consequent potential to reduce the formation of marginal gaps (10–14).

The slow-curing method is one technique by which to relieve the shrinkage stress, because it permits slow development of the composite stiffness, allowing better flow (4, 15). Controlled polymerization with modulated light intensities can result in a high degree of conversion and decreased polymerization shrinkage stresses (1, 11, 16). Because of this, the soft-start technique and intermittent light have been proposed (1, 11, 16–19).

Previous studies (1, 16, 20) have shown that the marginal adaptation of resin composites can be improved by light-curing with low intensity light. However, high intensity is necessary to achieve deep and complete polymerization of the material (21). Resin composites cured with the soft-start technique revealed substantially lower viscosity and allowed better material flow during the earlier stages of curing while keeping the total curing time reasonably short. This could lead to better marginal adaptation (13, 22, 23). Bond strength can also be improved by soft-start polymerization (11). Soft-start leads to equal shrinkage, surface hardness, and residual mono-

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mer concentration so long as the total irradiation dose is adequate (4, 11, 23, 24).

The intermittent light photoactivation method, introduced by Obici et al. (19), consists of photoactivation of the composite in cycles of light-on and light-off periods. It has been demonstrated that intermittent light can effectively reduce polymerization shrinkage (19).

Another approach by which to reduce shrinkage stress is use of a low-stiffness intermediate layer. This acts as a stress-absorbing layer due to its lower elastic modulus, which allows its deflection between the rigid traditional composites and the dentin substrate, thus improving marginal seal and increasing the long-term durability of the dentin bond (10, 14, 25).

The main purpose of the low-stiffness intermediate layer is to absorb part of the stress generated by the composite shrinkage. For this purpose, thicker adhesive layers of unfilled adhesives (26), filled adhesives (27), and flowable composites (14) have been proposed. Using a 3D finite element analysis, Ausiello et al. (28) demonstrated that the thicker the adhesive layer, the higher the elastic releasing effect, which permits a more uniform stress distribution. Kemp Scholte & Davidson (14) showed that thicker adhesive layers are related to lower interfacial stresses and better preserved marginal adaptation.

Flowable composites such as liners have been proposed by several authors (14, 25, 28–31) as improving the marginal adaptation of composite restorations. Because flowable composites have higher concentrations of monomer system than traditional composites, their elastic modulus is lower, and consequently their tenacity values are better than those of conventional materials (32). In addition, Yazici et al. (33) have shown that the combination of flowable resin composite and hybrid composite yields the most effective reduction of microleakage.

Thus, based on the literature regarding the adhesive restorative technique with resin composites and their restrictions, this study was intended to evaluate the influence of resin liners and alternative photoactivation techniques on the marginal adaptation to dentin of resin composite restorations, and to verify whether the association of these techniques can effectively improve the marginal adaptation of resin composite restorations.

Materials and methods

Table 1 gives the manufacturers, the batch numbers, and the composition of the materials.

Specimen preparation

One-hundred-and-twenty bovine incisors were selected, cleaned, and stored in a 0.5% Chloramine T solution under refrigeration (4°C) for no more than a week. The roots were sectioned off 1 mm under the cement enamel junction using a double-face diamond saw (K. G. Sorensen Indústria e Comércio Ltda, São Paulo, SP, Brazil). The buccal surface of the teeth was then ground on a water-cooled mechanical polisher (Minimet 1000, Buehler Co., Chicago, Ill., USA) using 80-, 180-, 320-, and 600-grid silicon carbide (SiC) abrasive paper (Carbimet Disc Set, Buehler Co., Chicago, Ill., USA) in order to expose a flat dentin area of at least 6 mm in diameter. The teeth were observed in a stereomicroscope (Zeiss, Manaus, AM, Brazil) at × 25 magnification to verify whether the enamel had been completely removed.

Cavities (4 mm diameter × 1.5 mm deep) prepared on the central area of the flattened dentin surfaces were made using a round diamond tip no. 3053 (K. G. Sorensen Indústria e Comércio Ltda, São Paulo, SP, Brazil) mounted in a high-speed hand-piece (Kavo, Joinville, SC, Brazil) under constant cooling with air and water. Tips were replaced after every 10 preparations.

Internal walls of cavities were at a 90° angle to the surface plan (entirely located in dentin) and round internal angles accompanying the drawing of the diamond tip used. The C factor of the cavity was 2.5. The specimen was discarded if any pulp exposure was noted at the axial wall during preparation of the cavities.

Restorative procedure

The teeth were randomly assigned into four groups of 30 teeth each, according to the lining technique, as follows.

Control 1L: The Scotchbond Multi Purpose adhesive system (SBMP) was applied in accordance with the manufacturer's instructions: 35% phosphoric acid gel was

Table 1. Characteristics and main components of the materials used

Materials	Manufacturer and batch no.	Components
Scotchbond Multi Purpose	3M Dental Products St. Paul, Minn., 55144, USA Batch: 7543	Etchant: 35% Phosphoric acid; Primer: Aqueous solution of HEMA and polyalkenoic acid copolymer; Adhesive: Bis-GMA; HEMA; photoinitiator
Filtek Z250 (A3)	3M Dental Products St. Paul, Minn., 55144, USA Batch:1370A3	Bis-GMA; Bis-EMA; UDMA; Inorganic filler—Zirconia/silica (60% volume); photoinitiator
Filtek Flow (A3)	3 M Dental Products St. Paul, Minn., 55144, USA Batch: 1BA	Bis-GMA; Bis-EMA; UDMA; Inorganic filler—Zirconia/silica (47% volume); photoinitiator
Protect Liner F	Kuraray Co. Ltd Japan Batch: 0042AY	Bis-GMA; TEGDMA; UDMA; fluoride-methyl-methacrylate; silanized colloidal silica (42% by weight); prepolymerized organic filler; photoinitiator

applied to dentin for 15 s and rinsed for 10 s. Water excess was removed using an air syringe, leaving the surface slightly moist. SBMP primer solution was applied to the tooth substrate and gently dried for 5 s in order to render a shiny surface. SBMP adhesive was then applied and light-cured for 10 s using the light-curing unit XL 3000 (3M/ESPE, St. Paul, Minn., USA).

Control 3L: SBMP was applied in accordance with the manufacturer's instructions, but in 3 layers light-activated individually for 10 s.

Control PL: SBMP was applied in accordance with the manufacturer's instructions followed by application of the flowable composite Protect Liner F as a liner.

Control FF: SBMP was applied in accordance with the manufacturer's instructions followed by application of the flowable composite Filtek Flow as a liner.

Application of the flowable composite as a resin liner (groups PL and FF) was standardized in volume: 1 cm of the material was dispensed on a glass slab, then applied in a spiral movement starting from the bottom and working towards the top of the cavity with a microbrush. This procedure allowed formation of a 0.2 mm thickness of liner at the cavity floor, on average. At the lateral wall, the thickness of liner was less (0.05 mm, on average). Liner photoactivation procedures were carried out following the restorative composite photoactivation technique.

Filtek Z250 resin composite was inserted in a single increment and light-cured in accordance with one of the three photoactivation techniques:

A. *Conventional continuous light:* The flowable composite and the restorative composite were photoactivated for 20 s with an intensity of 800 mW/cm^2, using the light-curing unit XL 3000 (3M/ESPE, St. Paul, Minn., USA).
B. *Soft start:* The curing unit was the same as used for the A groups. The flowable composite and the restorative composite were subjected to an initial 10 s exposure to the activating light of 150 mW/cm^2, a distance of 1.5 cm being maintained from the curing tip (using a spacer). The curing tip was then positioned close to the restoration, resulting in an increased light intensity of 800 mW/cm^2, which was maintained for 15 s.
C. *Intermittent light:* The curing unit used for photoactivation of the restorative composite was an experimental unit developed in the Dental Materials Department of the Piracicaba Dental School, UNICAMP. It was assembled from a commercial curing unit (Optilux 150—Demetron) in which halogen light is used. This unit was adapted to an electric circuit that allows cyclic irradiation (2 s light on and 2 s light off) with a power density of 600 mW/cm^2 for 40 s.

After the light-curing procedures, the specimens were stored in distilled water at 37°C for 24 h and then finished and polished under running water using 600- and 1200-grid SiC sandpaper.

Evaluation of marginal adaptation

In order to determine the degree of surface marginal adaptation, a dye staining test was carried out to detect the gap formed. A 1.0% acid red propylene glycol solution (Caries Detector, Kuraray Co., Osaka, Japan) was applied on the restoration margins for 5 s (34). The specimen was then rinsed in tap water and gently blown dry. Using this technique, gaps become highly stained and are thus easy to quantify. The dye-staining gaps on the surface margins were observed using a stereomicroscope LEICA MZ6 (Leica Microsystems Ltd., Heerbrugg, Switzerland) at 16× magnification. A digital image of each specimen was obtained at this stage (Fig. 1). The length of dye staining along the cavity margins was measured from the images using Leica Win Software (Leica Microsystems Ltd., Heerbrugg, Switzerland). The degree of marginal gap was determined as the ratio of the margin stained with the dye divided by the total length of the cavity margin and then converted to percentage. This was referred to as the marginal gap formation.

Marginal gap values were analyzed using ANOVA (two-way analysis) and compared using the Tukey test at 5% significance.

Results

According to the data, the ANOVA test detected a statistically significant interaction between the use of a resin liner and the photoactivation methods ($P < 0.05$).

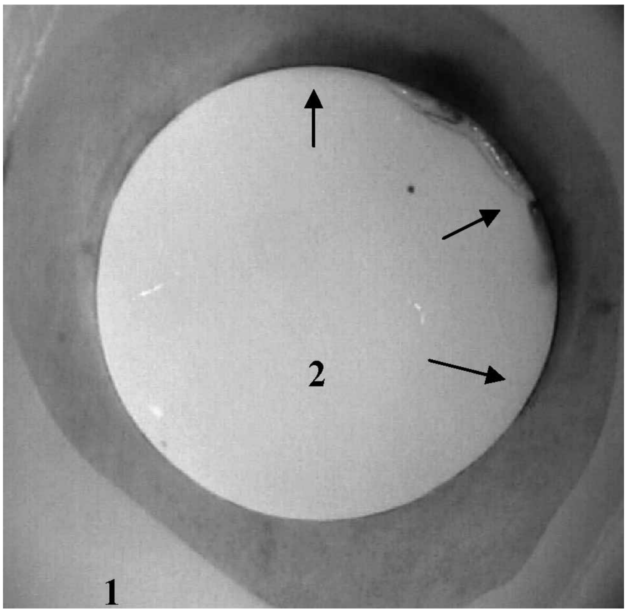

Fig. 1. Digital image of a dyed specimen: (1) dentin; (2) composite restoration. The arrows indicate marginal gaps stained by the caries detector.

Table 2. Percentage of gaps in marginal adaptation test

	Photoactivation method		
Resin liner	Continuous light	Soft-start	Intermittent light
One adhesive layer	56 (5.8) A a	58 (7.6) A a	26 (5.4) A b
Three adhesive layers	36 (4.1) AB a	48 (6.0) A a	33 (5.5) A a
Protect Liner F	36 (3.5) AB a	44 (4.0) A a	30 (8,4) A a
Filtek Flow	29 (7.4) B a	47 (4.3) A a	37 (4.2) A a

Statistical differences are expressed by different capital letters in columns, and by different lower-case letters in rows ($P < 0.05$).

The statistically significant differences, according to the Tukey test, are expressed in Table 2.

As far as factor photoactivation is concerned, a significant difference was observed only when the conventional lining technique (one adhesive layer) was employed. The lowest value of gap formation was found for intermittent light; this differs statistically from those of the continuous-light and soft-start methods. Regarding the other lining techniques (three adhesive layers, Filtek Flow, and Protect Liner F), there was no statistical difference among the photoactivation methods.

For the factor restorative technique, significant differences could be observed only with continuous light. The lower value of gap formation was found for the Filtek Flow group differing from the conventional technique, while the three adhesive layers and the Protect Liner F groups showed intermediate values. To the other photoactivation methods, the restorative technique with resin liners had no effect on marginal adaptation, considering that there was no significant difference among the groups for soft-start method and intermittent-light method.

Discussion

Successful restoration with resin composites depends on a combination of complete polymerization, adequate mechanical properties, good bond strength, and optimal marginal adaptation.

The early marginal adaptation does not necessarily correspond to microleakage. However, it is accepted that the detectable marginal gap would lead to interfacial microleakage (35). In vitro microleakage measurements have not been accepted as predictive of restoration failure. The presence of gaps is considered to be more reliable once this is considered as the first sign of restoration failure. It can be clinically evidenced by marginal staining. The identification of early marginal changes could therefore facilitate the prognosis of longevity/stability of the composite restorations.

In this study, none of the techniques was capable of ensuring a perfect marginal seal of restorations with margins completely located in dentin. The evaluation of cavities with dentin margins is important in restorative dentistry because root decay has become more prevalent, especially in the elderly population (36). According to the root anatomy of most teeth, dentin thickness is lower at the root than at the crown; 1.5 mm depth can be considered adequate (37) for root cavities. A flawless bond to dentin has proved to be a great challenge for clinicians and researchers (9, 38). The bonding process is difficult because dentin is a vital, hydrated composite material with structural components and properties that vary with location (37). Bovine dentin is an adequate substitute for human teeth in adhesion tests (39), although it is more difficult to ensure good marginal quality in bovine dentin, and is possibly responsible for high marginal gap values.

The design of this study aimed to evaluate dental cavities with margins entirely located in dentin in order to produce homogeneous stress at all walls during polymerization shrinkage. Cavities with margins partially located in enamel and dentin tend to produce asymmetric stress, harming the bonding to dentin. Several authors have also observed perfect marginal sealing using the adhesive bonding systems in cavities where the entire margins were located in enamel (40–42).

Besides locating the margins in dentin, the high percentage of marginal gaps on most of the restorations is also explained by the high C factor (2.5) of the cavity in this study, causing high stress levels (43) and failure of the bonding between dentin and composite (6, 44–46).

However, during the early stage of setting, the resin network is still weak and therefore the elastic limit is low. Plastic yielding to the stress at this stage of setting can be achieved without damage to the internal structure of the resin composite and the adhesive bond, since the molecules can still split into new positions and directions. This kind of deformation can be characterized by flow and, at this stage, no stress acts at the dentin/composite interface. This is defined as the pre-gel stage. When curing proceeds, shrinkage and flow decrease gradually, while stiffness increases. As a result, the stress will still grow with time and may mean serious problems with maintenance of the adhesive bond or even cohesive failure of the restorative material or the surrounding tooth tissue. It characterizes the post-gel stage (6, 44–46).

Modulation of the light intensity could enable resin flow, thus prorogating the pre-gel stage (13). In this case, post-gel shrinkage can be reduced, and shrinkage stress, which actually acts at the interface, is partially released (12). This may lead to maintenance of the bond between the tooth and resin composite, allowing better marginal quality (10).

In this study, intermittent light was effective in reducing marginal gap formation, probably because of the increased ability of the composite to flow when it is polymerized at a reduced rate (47). This phenomenon is caused by the slower formation of the polymer network and cross-links which provide favorable conditions for the adaptation of molecules within the polymeric chain that has developed (18).

Additionally, the conversion degree should be considered. As in this group the total energy dose was lower (9.9 J/cm^2) than in that of the other groups (continuous light—16 J/cm^2 and soft start—13.5 J/cm^2), the conversion degree could be lower (16, 19, 24), thus leading to lower shrinkage levels and consequently reduced shrinkage stress. The reduced energy obtained by the intermittent method occurs because, during each cycle, when the light turns on it takes 0.7 s to reach 600 mW/cm^2; consequently, during this period the energy is reduced. In fact, the full power density (600 mW/cm^2) is applied to the composite only for 1.3 s in each light cycle. So, during the first 0.7 s of each cycle there is a loss of energy that must be considered. To calculate the energy dose in the intermittent light method, the following formula was used:

$$\underbrace{(600\,\mathrm{mW/cm^2} \times 0.7\mathrm{s}\ /\ 2)}_{\text{Period 1}} \quad + \quad \underbrace{(600\,\mathrm{mW/cm^2} \times 1.3\mathrm{s})}_{\text{Period 2}} \quad \times \quad \underbrace{10}_{\text{No. of cycles}} \quad = \quad \underbrace{9.9\,\mathrm{J/cm^2}}_{\text{Energy dose}}$$

Conversely, the soft-start technique showed no improvement on marginal adaptation. At first, the results seemed to contradict the findings of Mehl et al. (22), who pointed out that soft-start polymerization improved the marginal adaptation of resin composite restorations in class V cavities. However, Mehl et al. (22) also showed that this positive effect was strongly dependent on the density of the initial and final curing power. Whereas starting power densities of 180 mW/cm^2 and 166 mW/cm^2 (for 20 s) and final power densities of 600 mW/cm^2 and 450 mW/cm^2 (for 40 s) caused even worse marginal adaptation compared with conventional curing of 600 and 450 mW/cm^2, initial curing at higher power densities (360 and 315 mW/cm^2) provided much better marginal adaptation. The results of the present study using a similarly low initial power density of 150 mW/cm^2 support the theory that this power density may not have activated a sufficient number of initiator molecules to start an adequate polymerization reaction. Therefore, the final cure of the unpolymerized material, at 800 mW/cm^2, may have corresponded to an immediate full-power density curing, similar to the control group (continuous light).

Other studies, too, have shown no improvement on marginal adaptation when soft-start polymerization was used (17, 48–50). According to Hasegawa et al. (48) and Sahafi et al. (49), soft-start photoactivation did not significantly influence the marginal integrity of resin composite restorations. These authors claimed that the optimum combination of dentin bonding and resin composite is more important than the irradiation method.

Ernst et al. (12) found that soft-start polymerization can significantly reduce polymerization stress. However, the effect of stress reduction in resin composites due to prolonged ability to flow seems to be less effective in composites containing a higher concentration of photoinitiators such as Z250.

Taking this into account, it is not certain whether the results obtained in this study are valid for other types of composites. The cure of composites is affected by several variables: the camphorquinone hit by light and converted to its excited state, and the excited camphorquinone molecule collides and reacts with the reducing agent to form free radicals. Furthermore, phenomena such as attenuation, scatter, and absorption of the light occur in the deeper parts.

Besides photoactivation methods, the contracting curing stress could also be regulated by ‘an elastic cavity wall’, first proposed by Kemp-Scholte & Davidson (10). Nowadays, it is proposed that flowable composites as liners reduce shrinkage stress, enhance bonding strength to dental substrate, and improve the marginal adaptation of composite restorations (29, 30, 51, 52).

The results of the present study showed an improvement on marginal adaptation using the flowable composite Filtek Flow as a liner, but only in the case of continuous light (gap fell from 56% in 1L to 29% in FF). This is because polymeric materials with a lower elastic modulus exhibit viscous flow when submitted to stress, showing plastic deformation (53). So, when this low modulus liner is applied on the cavity before insertion of the restorative composite, the stress occurring on the cavity walls will be lower once the liner suffers plastic deformation (viscous flow) absorbing part of the shrinkage stress (53). This can reduce the stress that is applied to the tooth structure, allowing reduction in gap formation and better adaptation to the cavity walls.

In addition, the volume of restorative composite is reduced and consequently the shrinkage rate at the cavities is reduced too. The flowable composite is located mainly at the internal angles of the cavity and at the pulp wall (high stress sites), which could contribute to reduced stress and gaps.

For the other restorative techniques with resin liner (three adhesive layers and Protect Liner F), no statistical difference from the control group was observed, although there was a tendency for improved marginal quality for these groups. Nevertheless, it should be noted that the application of thicker layers of adhesive has some drawbacks: a thick layer of unfilled adhesive at the margin of a restoration can lead to enhanced wear in this region, and this radiolucent layer may pose diagnostic problems at subsequent examination (26, 31).

Considering the other photoactivation methods, the restorative technique with resin liners showed no effect on marginal gap formation. This seems to be related to the camouflage effect of the intermittent light, which has already reduced the formed gaps. As far as groups 1L are concerned, a clear tendency for gap values to decrease for the intermittent light groups can be seen from Table 2.

Based on the results of this study, it can be concluded that regulated polymerization with intermittent light using the conventional lining technique is effective in reducing marginal gap formation. The flowable composite Filtek Flow as a liner was capable of improving marginal adaptation. However, the effect of the association of lining technique with low modulus materials and modulation of light could not be clearly observed.

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