Effect of Resin Liners and Photoactivation Methods on the Shrinkage Stress of a Resin Composite

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ABSTRACT

Purpose: This study was undertaken to evaluate the effect of three different photoactivation methods on the polymerization shrinkage stress of a resin composite using different resin liners.

Materials and Methods: Three photoactivation methods using a quartz-tungsten-halogen light were evaluated: continuous light, soft start, and intermittent light. Three lining groups were tested: one or three coats of adhesive, and flowable composite. The stress was measured using a universal testing machine. After the stress measurement, Knoop hardness numbers (KHNs) were evaluated to verify indirectly the degree of conversion of the composite using the three photoactivation methods. The data were submitted to analysis of variance and Tukey's test ($p < .05$).

Results: Intermittent light was always associated with statistically lower stress values when compared with continuous light. Statistical differences were not observed when continuous light and soft start were compared. The use of a flowable composite liner significantly reduced the stress generation when compared with the use of one adhesive coat. The three adhesive coats groups showed intermediate stress values. The hardness test showed no statistical difference between that achieved with continuous light and soft start. These two methods showed statistically higher KHNs when compared with results with intermittent light.

CLINICAL SIGNIFICANCE

Photoactivation using intermittent light may lead to a significant reduction in shrinkage stress levels. This effect could be attributed to a significant reduction of the polymerization rate and/or a decrease in the degree of conversion. The use of a flowable composite liner reduced the stress levels when compared with levels when one coat of adhesive was used. This is possibly related to the higher thickness of the flowable composite layer.

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Polymerization shrinkage and consequent stress generation are among the main disadvantages of using resin composites.[1,2] The intensity of the developed stress is associated with three main factors: the geometry of the cavity—the C-factor; the characteristics of the material; and the restorative technique used.[3]

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Concerning the restorative technique, different photoactivation methods and low elastic modulus materials have been investigated for their influence on stress generation and distribution.[4–7]

Traditionally, quartz-tungsten-halogen (QTH) lights have been used in a continuous output mode while emitting a fairly high-power density.[8,9] However, radiation from this type source can also be applied in different manners. The soft-start method employs an initial low irradiance followed by a high one equivalent in value to that of the continuous phase.[9] Some researchers have shown that this method leads to better marginal integrity of composite restorations.[4,5] Intermittent light exposure alternates periods of light on and off. The light-off periods could reduce the polymerization speed, which can be responsible for slow stress generation, decreasing the marginal gap formation.[10,11]

Besides the photoactivation method, the use of low elastic modulus resin liners between the restorative composite and the dental structure has been proposed.[11–13] This technique may represent an effective procedure to reduce stress and to improve marginal adaptation. This intermediate layer may act as an elastic zone, capable of absorbing part of the stress generated by the composite's polymerization shrinkage.[6]

The preservation of the tooth-composite bond is a crucial factor to the longevity of the restoration. Bond preservation is related to the ability to release stress from composite shrinkage by means of a modification in the polymerization kinetic, by the restorative technique employed, or both. Therefore, the objective of this study was to test the hypothesis that the use of resin liners and modulated photoactivation methods promotes a significant reduction in the stress generated by the composite shrinkage.

MATERIALS AND METHODS

Our experiment used cylindric, metallic devices ("b" in Figure 1). In one of the extremities, a screw formation attached the device to a universal testing machine (model 4411, Instron, Canton, MA, USA) in the upper area ("a" in Figure 1), connected to the load cell. On the other end, the cylindric, metallic device had a flat circular area where the resin liners were applied. Before each test the flat area was submitted to polishing with aluminum oxide sandpapers with a granulation of 600, and pressure-blowing with aluminum oxide particles (50 µm). The polishing and pressure-blowing procedures were accomplished in all the devices used. Three groups were tested:

- Group 1: one coat of adhesive (Scotchbond Multipurpose, 3M ESPE, St. Paul, MN, USA), with mean thickness of 0.15 mm
- Group 2: three coats of adhesive, individually photoactivated, with a mean thickness of 0.4 mm
- Group 3: one coat of adhesive and lining with a flowable composite (Protect Liner F. Kuraray Co., Osaka, Japan), with mean thickness of 0.7 mm

The photoactivation of the adhesive layer and of the flowable composite was accomplished previous to the testing, for 10 seconds for each adhesive layer and 20 seconds for the flowable composite liner. The light-

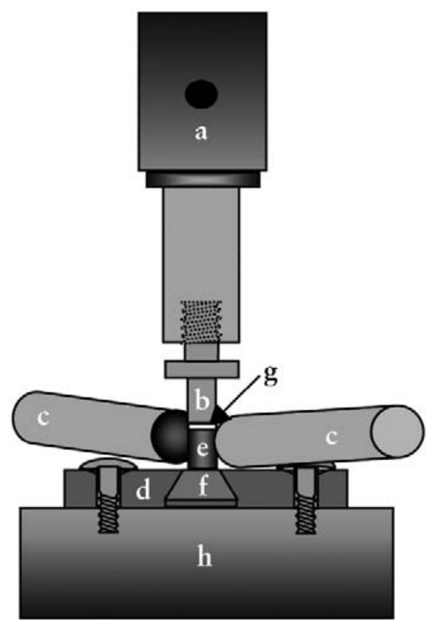

Figure 1. Polymerization stress testing configuration: upper part of the testing device connected to the load cell (a); cylindric, metallic device used for attaching the composite sample (b); light rods from light curing units (c); lower metallic mold with central hole (d); composite sample (e); precured composite sample (f); liner (g); and lower part of the testing device (h).

curing unit used was the XL 2500 (3M ESPE), with an irradiance of 800 mW/cm^2 as measured with a radiometer (Model 100, Demetron Research Corp., CT, USA).

The composite specimens were prepared in transparent plastic conduits 5 mm in diameter and approximately 5 mm high for groups 1 and 2, and approximately 4.3 mm high for group 3. Filtek Z250 composite (3M ESPE) was inserted in the conduit until it was completely filled. The standardization of the composite volume used in the different samples was performed in the universal testing machine before the photoactivation, controlling the height of the composite part of the specimen at 4.85 mm for group 1, 4.6 mm for group 2, and 4.3 mm for the group 3. The height of the specimens was 5 mm for all groups. A liner thickness of 0.7 mm in the flowable composite group was selected to reproduce in this experiment the clinical use of the flowable composite as a liner.

In the lower area of the universal testing machine was a metallic mold with a central hole of 8 mm in diameter and a cone format ("d" in Figure 1). This region was filled completely with the same composite, and a load of 9.81 N was applied for surface standardization and composite excess removal. This region was photoactivated before the adaptation of the plastic conduits filled with the resin composite Filtek Z250, using continuous light for 20 seconds. This was the bond region for the specimen to the lower area of the universal testing machine.

After the assembly of the system in the upper area with the adaptation of the metallic device with the liner material, and in the lower area with the fixation of the metallic mold filled with the previously polymerized composite, the conduit filled with the unpolymerized composite was placed between the two extremities of the machine, respecting the distance of 4.85 mm for group 1, 4.6 mm for group 2, and 4.3 mm for the group 3 ("e" in Figure 1).

Two curing units were used simultaneously for photoactivation of the composite on opposite sides of the specimen ("c" in Figure 1). The evaluated photoactivation methods based on QTH light were as follows:

- Continuous light: 800 mW/cm^2 for 40 seconds using the XL 2500
- Soft start: 150 mW/cm^2 for 10 seconds followed by 800 mW/cm^2 for 30 seconds using the XL 2500
- Intermittent light: cycles of 4 seconds—2 seconds light on and 2 seconds light off—for 80 seconds at 600 mW/cm^2 using an adapted Optilux 150 (Demetron Research Corp.)

The curing units used for the photoactivation of the composite in the intermittent light group were experimental curing units developed in Dental Materials Area, Piracicaba Dental School, UNICAMP. These experimental curing units were assembled from two commercial QTH curing units (Optilux 150) adapted to an electric circuit that allows a cyclic irradiation.

The irradiance of each unit was measured with a radiometer (Model 100). The reduction of the irradiance in the soft-start method was obtained using standard separators, which reduced the irradiance from 800 to 150 mW/cm^2 in the first 10 seconds.

After the photoactivation the maximum stress value generated during the following 5 minutes was recorded. If an abrupt fall of the stress value occurred during this period, it was considered a partial fracture of the specimen. This was related to local adhesive or cohesive rupture, which caused stress release and a fall in these values. In such a case, the stress value recorded was the one verified before the occurrence of the partial fracture. The number of specimens fractured was registered for each group.

For each specimen a new cylindric, metallic device was used in the upper area and a new composite layer was prepared in the lower area. Ten specimens were prepared for each group.

The stress data, obtained for each liner material in relation to the different photoactivation methods, were submitted to two-way analysis of variance (ANOVA), and the means were compared using Tukey's test ($p = .05$) to verify differences among the photoactivation methods and lining techniques.

After the stress test, five cylinders of each photoactivation method were randomly selected for measurement of Knoop hardness numbers (KHNs) to determine, indirectly, the degree of conversion of the composite submitted to the different photoactivation methods. The representative specimens of each group were placed vertically, and polystyrene resin (Resapol T208, São Paulo, Brazil) was poured around them to keep them fixed. The specimens of each group were flattened with carbide sandpaper of decreasing grit (320, 400, 600, and 1,200) on an automated polisher APL-4 (Arotec Ind. Com., São Paulo, Brazil) to obtain flat surfaces, followed by polishing with a diamond paste containing particles of 1 and 0.25 µm.

KHN measurements were taken with an indenter (HMV-2000, Shimadzu, Tokyo, Japan), under a mass of 50 g for 15 seconds. The measurement of the indentation was performed immediately after the period of 15 seconds. Twenty-one indentations per specimen were carried out (105 indentations/group) for each photoactivation method. Figure 2 shows a schematic illustration of the Knoop hardness test.

The hardness data were submitted to one-way ANOVA, and the means were compared using Tukey's test ($p = .05$).

RESULTS

The mean values of stress in the different groups are shown in Table 1. When comparing the results among the appraised photoactivation methods for the different resin liners, it was observed that when one coat of adhesive was applied on the metallic device surface, the intermittent light method produced the lowest stress value, which was statistically different from the others. With the application of three adhesive coats, the continuous light method showed the highest mean stress value, statistically different from results with the intermittent light method. The soft-start method presented intermediate results and was not statistically different from the other appraised methods. In the groups in which a liner was prepared with flowable composite, soft-start and continuous light methods presented the highest mean stress values, and these differed statistically from the mean value with the intermittent light method.

When comparing the results for the application of resin liners in associ-

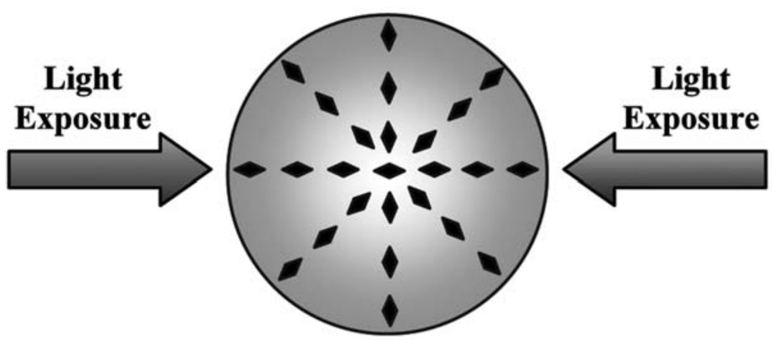

Figure 2. Schematic illustration of the Knoop hardness evaluation in a specimen of the shrinkage stress test. Twenty-one indentations per specimen were carried out.

TABLE 1. MEAN STRESS GENERATED BY PHOTOACTIVATION METHODS THROUGH THE APPLICATION OF DIFFERENT RESIN LINERS.

Photoactivation Method	Mean Stress in MPa (SD)*		
	1 Adhesive Coat	3 Adhesive Coats	Flowable Composite
Continuous light	4.5^{Aa} (0.5)	4.4^{ABa} (0.4)	3.7^{Ba} (0.2)
Soft start	4.4^{Aa} (0.2)	4.1^{ABab} (0.3)	3.7^{Ba} (0.4)
Intermittent light	4.0^{Ab} (0.2)	3.3^{Bb} (0.3)	2.4^{Cb} (0.3)

*Different lowercase letters in the column and different uppercase letters in the row indicate statistically significant differences among values for Tukey's test at the level of 5%.

ation with the photoactivation method, it was noted that the three adhesive coats showed intermediate stress values and did not present statistically significant differences from the results with one adhesive coat or with the flowable composite lining for the continuous light and soft-start methods. For the intermittent light method, the application of three adhesive coats was responsible for statistically lower values when compared with values with the one adhesive coat.

The flowable composite lining significantly reduced the stress generated in all photoactivation methods tested when compared with the one adhesive coat. In addition, the flowable composite lining, when combined with the intermittent light method, showed a significant reduction compared with results of one adhesive coat and three adhesive coats.

A partial fracture of the sample was observed in nine samples in the continuous light method and in two samples in soft-start method. In the intermittent light method, none of the samples presented partial fracture.

Table 2 shows the mean values of Knoop hardness for the three photoactivation methods. The soft-start and continuous light photoactivation methods resulted in the highest Knoop hardness mean values, which are statistically superior to the value for the intermittent light method.

DISCUSSION

The results of this study supported the hypothesis that the stress generated by the shrinkage of the composite is related to the photoactivation method, the restorative technique, or both. For the continuous light method, the lining with flowable composite resulted in decreased stress generation when compared with values for the group with one adhesive coat. This could be explained by the behavior of the polymeric materials with lower elastic modulus, which exhibit a viscous flow when submitted to stress, showing plastic deformation (viscous flow) absorbing part of the stress.[14] In addition, the volume of restorative composite was reduced in group 3. This may be responsible for a decrease in the volumetric shrinkage of the composite. As the stress is a consequence of this shrinkage, it was also reduced.

It was also observed that partial fractures occurred in five samples in the group with one adhesive coat, as well as in four samples in the group with three adhesive coats. However, none of the 10 samples with the Protect Liner F liner showed partial fractures. This may confirm the efficiency of this technique in enhancing bond preservation. Montes and colleagues,[6] through a tensile bond strength test, also reported better results when lining with flowable composites.

Likewise, the application of three adhesive coats was responsible for the creation of a layer with a low elastic modulus, capable of absorbing partial stress. However, the lower thickness of this region

TABLE 2. MEAN KHN VALUES FOR THE PHOTOACTIVATION METHODS.

Method	Mean KHN (SD)*
Continuous light	97.6^{a} (3.6)
Soft start	99.0^{a} (4.7)
Intermittent light	81.6^{b} (3.7)

KHN = Knoop hardness number.
*Different letters indicate statistically significant differences among values for Tukey's test at the level of 5%.

(0.4 mm) compared with the thickness of the flowable composite layer (0.7 mm) added to the higher volume of restorative composite in group 2, resulting in higher stress generation. This could be responsible for the intermediate stress values.

The modulation of the photoactivation process has been related to fewer disruptions of the bond interface, reducing the damage to the physical and mechanical properties of the material.[1,15] The soft-start technique represents one of the most studied modulated methods.[4,5,16,17] Ernst and colleagues found that soft-start polymerization can significantly reduce polymerization stress.[18] However, in the current study, the final stress values reached with the soft-start method using all lining techniques were similar to those with the continuous light method. This may be related to the fast polymerization of the composite Z250 that decreases the ability to flow, even using modulated techniques. In addition, the composite cure may have become saturated beyond the 24 J/cm^2 radiant exposure. Thus, any further increase in light energy did not result in greater cure, greater hardness (and elastic modulus), or greater contraction stress. In spite of no statistical difference in stress values between the two appraised methods, differences were verified in the number of partially fractured specimens. This fact is possibly due to the initial photoactivation period of low irradiance with the soft-start method, which is associated with a reduction in the polymerization speed, modifying the formation and distribution of the stress generated, and has been verified by Hofmann and colleagues.[19] Such a situation could be related to a greater probability of bond preservation, as verified in this study.

Additionally, the soft-start and continuous light methods had similar degrees of conversion, as was indirectly confirmed by the Knoop hardness test. Silikas and colleagues and Vandewalle and colleagues found a high correlation ($r^2 > .99$) between the degree of conversion and stress generation.[9,20] The results of the present study are in agreement with those found by Cunha and colleagues and Price and colleagues that stated that the soft-start method, when compared with the continuous light method, does not reduce the degree of conversion and the mechanical properties of the composite.[1,17] Following the same pattern of degree of conversion, the results found for each lining technique were similar for the soft-start and continuous light methods.

The other modulated method of the QTH light was the intermittent light. Theoretically, the advantage of this method is the reduction of the polymerization rate owing to the light-off periods. These periods could allow a slow formation of the polymeric chains and accommodation in the initial phase of polymerization, resulting in decreased stress generation and increased probability of bond preservation. This was confirmed by the results of the present study, in which the mean stress value was statistically lower than the ones for the other photoactivation methods. In addition, no partial fracture of the specimens occurred in the intermittent light groups. Alonso and colleagues showed a significant reduction in marginal gap formation using the intermittent light photoactivation.[11]

The slow stress generation could increase the probability of partial stress absorption, especially in the groups with low modulus liners (groups 2 and 3). Group 2 (three adhesive coats) showed statistically lower stress values than the group with one adhesive coat. Our results are in agreement with Choi and colleagues.[21] The use of three adhesive coats, even with a low thickness (0.4 mm), effectively reduced the stress generation owing to the slow polymerization rate using the intermittent light. Likewise, results for group 3 (Protect Liner F) statistically differed from those for groups 1 and 2 (one and three adhesive coats). In this study the association between slow polymerization and stress absorption by the resilient layer generated the lowest shrinkage stress.

Although the reduced stress values of the intermittent light technique are encouraging, when the Knoop hardness was measured, this photoactivation method presented a mean hardness value that was statistically inferior to the ones with soft-start and continuous light. The inferior results of the intermittent light method could be associated with the difference in the radiant exposure values among the three appraised methods. Radiant exposure is calculated as the product of the light irradiance and the time of light exposure. In this study these values were 35.4 J/cm^2 for intermittent light method and 64 and 51 J/cm^2 for the continuous light and soft-start methods, respectively (values corresponding to the sum of the energy emitted by the two units used simultaneously). In the beginning of each cycle of light exposure using the intermittent light method, a mean period of 0.7 seconds is necessary to reach the full irradiance (600 mW/cm^2). Consequently, during this period the energy is reduced, and this reduction must be considered. Therefore, the light exposure in full power density is only accomplished for a period of 1.3 seconds, as follows:

$$(600 \text{ mW/cm}^2 \times 0.7 \text{ s}/2) + (600 \text{ mW/cm}^2 \times 1.3 \text{ s}) \times 20 = 17.7 \text{ J/cm}^2 \text{ (per unit)}$$

where the first phrase indicates the initial period, the second the full intensity period, the third the number of cycles, and the final phrase the radiant exposure. The reduction of the energy density affected the mechanical properties of the composite, as verified. Thus, the lower shrinkage stress generated with this method may be associated with the lower degree of conversion of the composite.

CONCLUSIONS

In conclusion, the tested hypothesis regarding a significant reduction of the stress with the use of certain resin liners and modulated photoactivation methods was partially validated by the results. The restorative technique, using low elastic modulus resin liners as well as the photoactivation method, can influence the stress generation process of the composite. This situation should be promoted; however, the physical/mechanical properties of the restorative material must be preserved. In that sense, the soft-start photoactivation method showed a similar degree of cure when compared with the continuous light method, but the intermittent method did not. The use of low elastic modulus resin liners with the composite was shown to be a satisfactory technique for partial absorption of the stress generated by the polymerization shrinkage. Therefore, these results can serve as a pattern of what may occur clinically when using different photoactivation methods and resin liners, separately or not, contributing to the bond preservation in an adhesive restorative procedure.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are discussed in this article.

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COMMENTARY

EFFECT OF RESIN LINERS AND PHOTOACTIVATION METHODS ON THE SHRINKAGE STRESS OF A RESIN COMPOSITE

Jack L. Ferracane, PhD*

This study evaluated the effects of two clinically relevant methods for reducing the potentially deleterious contraction stresses generated in dental composite restorative materials during photopolymerization. The use of low elastic modulus liners and modifying the method of light application have previously been shown to be beneficial for reducing stresses. However, the results of previous and the current study point to the complex nature of this problem and the difficulty encountered when trying to make generalized statements about the potential benefits of these different methods. The reader should be made aware of the difficulty in assigning clinical relevance to the values of stress reported in these types of studies as the results are highly variable and largely dependent upon the testing setup.

In the current study, one brand of flowable liner (Protect Liner F) was shown to be more effective than a single layer of unfilled adhesive (Scotchbond Multipurpose) but equivalent to three coats of adhesive resin in terms of reducing the contraction stress of a dental composite (Filtek Z250). This result is consistent with previous work reported by Choi and colleagues, in which the contraction stress of a composite was shown to be reduced as the number of adhesive layers was increased.[1] This stress-relieving phenomenon has further been explored by Ausiello and colleagues using three-dimensional finite element analysis.[2] The numeric analysis showed that the use of several layers of higher elastic modulus material as a liner can have the same effect as a thinner layer of very low elastic modulus in terms of reducing

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