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Effect of the Curing Method and Composite Volume on Marginal and Internal Adaptation of Composite Restoratives

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Clinical Relevance

Modulated curing methods were shown to be effective to reduce gap formation in composite restoratives.

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SUMMARY

The aim of the present study was to evaluate the influence of curing methods and composite volumes on the marginal and internal adaptation of composite restoratives. Two cavities with different volumes (Lower volume: 12.6 mm^3; Higher volume: 24.5 mm^3) were prepared on the buccal surface of 60 bovine teeth and restored using Filtek Z250 in bulk filling. For each cavity, specimens were randomly assigned into three groups according to the curing method (n=10): 1) continuous light (CL: 27 seconds at 600 mW/cm^2); 2) soft-start (SS: 10 seconds at 150 mW/cm^2+24 seconds at 600 mW/cm^2); and 3) pulse delay (PD: five seconds at 150 mW/cm^2+three minutes with no light+25 seconds at 600 mW/cm^2). The radiant exposure for all groups was 16 J/cm^2. Marginal adaptation was measured with the dye staining gap procedure, using Caries Detector. Outer margins were stained for five seconds and the gap

percentage was determined using digital images on a computer measurement program (Image Tool). Then, specimens were sectioned in slices and stained for five seconds, and the internal gaps were measured using the same method. Data were submitted to two-way analysis of variance and Tukey test ($p<0.05$). Composite volume had a significant influence on superficial and internal gap formation, depending on the curing method. For CL groups, restorations with higher volume showed higher marginal gap incidence than did the lower volume restorations. Additionally, the effect of the curing method depended on the volume. Regarding marginal adaptation, SS resulted in a significant reduction of gap formation, when compared to CL, for higher volume restorations. For lower volume restorations, there was no difference among the curing methods. For internal adaptation, the modulated curing methods SS and PD promoted a significant reduction of gap formation, when compared to CL, only for the lower volume restoration. Therefore, in similar conditions of the cavity configuration, the higher the volume of composite, the greater the gap formation. In addition, modulated curing methods (SS and PD) can improve the interfacial quality of composite restorations through the reduction of internal gaps in lower volume composite restoratives.

INTRODUCTION

Resin composites have been widely used in direct esthetic restorative procedures. However, polymerization shrinkage still harms the interfacial quality, creating adaptation problems.[1] When this shrinkage takes place under confinement, as a result of bonding to cavity walls, stresses on the bond interface will develop,[2] potentially leading to gap formation, marginal pigmentation, and secondary caries. The presence of gaps on the tooth/resin interface is considered the first sign of restoration failure.[3]

Although the polymerization shrinkage is the cause of adaptation problems of composite restorations, it is an inherent characteristic of the composite and directly related to the degree of conversion. Therefore, the actual factor to be managed is the shrinkage stress generated by the polymerization shrinkage.

Composite formulation and volume, curing protocols, and restorative procedures (as insertion techniques) are determinant factors with regard to shrinkage stress magnitude.[4] Even after light exposure, the polymerization reaction continues from five minutes to 24 hours, increasing the degree of conversion and the volumetric shrinkage and also leading to a significant increase of stress at the tooth/composite interface.[5,6]

The cavity configuration (C-factor) was considered the main determinant of shrinkage stress in composite restoratives.[7] However, Braga and others[8] showed that the volume of composite is also strongly related to shrinkage stress and microleakage of restorations. The higher the composite volume, the greater the amount of monomer to convert and the higher the stress generated on the bonded interface.[8] Moreover, previous studies[9,10] concluded that, for similar volumes, bulk or incremental filling have similar results on marginal adaptation.

Shrinkage stress is also regulated by the curing protocol. Low light intensity or modulated curing methods reduce the polymerization rate of composites, consequently reducing the stress rate generated[11,12] and improving the marginal adaptation of composite restoratives.[13] In this sense, modulated curing methods such as soft-start (SS) and pulse delay (PD) have been proposed.[7,14-16]

Yoshikawa and others[17] reported that the SS curing method promotes better marginal sealing of cavo-surface margins of composite restoratives. In addition, this curing method can provide similar properties, such as hardness and residual monomer concentration, when compared to the conventional continuous curing method.[18]

The PD curing method is a variation of the SS protocol. In this method, a lag period ranging from 10 seconds to five minutes is utilized between low and high light exposure scenarios.[19,20] Previous studies[19,21] have associated this method with reduced gap formation through the reduction on shrinkage stress. Cunha and others[11] showed that the PD method provided the greatest reduction in the stress rate of dental composites, with no significant reduction in the degree of conversion.

Although several studies[1,11,13,17,19,22-24] have pointed out the benefits of the modulated photoactivation, this issue has not yet been completely established as successful. One of the reasons is because composites behave differently when subjected to modulated photoactivation.[25] In this sense, some studies showed no positive effect of modulated photoactivation on shrinkage stress[26] or gap formation.[27-29] In addition, Stansbury and others[30] stated that modified photo-curing protocols, including stepped or pulsed irradiation programs, appear to have limited potential to reduce the overall stress developed if comparable levels of conversion are achieved compared to a standard protocol. Also, Fróes-Salgado and others[31] have suggested that modulated curing methods may also reduce the overall degree of conversion, not just the rate, and this may contribute to the reduced stress. Conversely, several studies[5,11,14,24] showed that modulated curing methods cause no reduction in the degree of conversion or in mechanical properties if the energy dose is not reduced. Thus, a definitive answer about the effect of modulated curing protocols has not been determined; therefore, further evaluation of this issue is necessary.

The aim of the present study was to evaluate the influence of modulated curing methods and composite volume on superficial and internal adaptation of composite restoratives. The first hypothesis tested was that the higher the volume of composite, the higher the gap formation due to shrinkage stress. The second tested hypothesis was that modulated curing methods can improve the marginal and interfacial quality of composite restorations. In addition, aiming to compare the studied factors, the third hypothesis was that situations related to higher shrinkage stress, such as cavities with higher volumes, would experience higher benefits of using modulated curing methods.

MATERIALS AND METHODS

Specimen Preparation

Sixty bovine incisors were selected, cleaned, and stored in a 0.5% chloramine T solution at 4°C for no more than a week. Roots were sectioned off 1 mm under the cement enamel junction using a double-face diamond saw (K. G. Sorensen, São Paulo, SP, Brazil). The buccal surface was ground on a water-cooled mechanical polisher (Metaserv 2000, Buehler, UK Ltd, Lake Bluff, IL, USA) using 80-, 180-, 320-, and 600-grit silicon carbide (SiC) abrasive paper (Carbimet Disc Set, #305178180, Buehler, UK Ltd) in order to expose a flat dentin area of at least 8 mm. These teeth were observed on a stereomicroscope (Zeiss, Manaus, AM, Brazil), at 25× magnification, to observe whether the enamel had been completely removed.

Two kinds of cylindrical cavities with different volumes and the same C-factor (2.0) were prepared on the flattened surface using cylindrical diamond tips (#3053 and #4054; K. G. Sorensen, São Paulo, SP, Brazil) mounted in a high-speed hand piece (Kavo, Joinville, SC, Brazil) under constant air-water cooling, as follows:

- Lower volume cavity—4 mm diameter×1 mm deep, volume of 12.6 mm^3, prepared using tip #3053.
- Higher volume cavity—5 mm diameter×1.25 mm deep, volume of 24.5 mm^3, prepared using tip #4054.

Diamonds tips were replaced after every fifth preparation. At the superficial margin, the cavity walls formed a 90° angle with the dentin surface plane, while the internal cavity angles were rounded based on the design of the diamond tip used. If any sign of pulp exposure was noticed during cavity preparation, the specimen was discarded.

Restorative Procedure

Each specimen was restored using an etch-and-rinse adhesive system (Adper Single bond 2, batch #3HR, 3M/ESPE, St Paul, MN, USA), applied in accordance with the manufacturer's instructions: the cavity was etched with 35% phosphoric acid gel (Scotchbond Etchant, 3M/ESPE) for 15 seconds, rinsed for 10 seconds, and blot-dried. The adhesive system was applied twice with a five-second interval in between, dried carefully with air for 15 seconds in order to remove residual solvent (observing a glossy surface), and light cured for 20 seconds using a LED curing unit (Ultrablue IS, DMC, São Paulo, SP, Brazil) with a power density of 600 mW/cm^2. Both cavities were bulk filled with a hybrid composite (Filtek Z250, shade A3, batch #3AM, 3M/ESPE) and teeth were randomly assigned into six groups (n=10), according to the curing method and composite volume. Curing methods are described in Table 1, and for this step the same LED curing unit previously described was used, with a radiant exposure of around 16 J/cm^2, for all curing methods. The power density was frequent-

Table 1: *Curing Methods Used in the Present Study*

Curing Method	Power Density and Time Exposure
Continuous Light	600 mW/cm^2 during 27 s
Soft-Start[a]	150 mW/cm^2 during 10 s+600 mW/cm^2 during 24 s
Pulse Delay[a]	150 mW/cm^2 during 5 s+3 min light off+600 mW/cm^2 during 25 s

[a] *The reduction of power density was obtained using neutral density filters.*

ly checked by a radiometer (Demetron Research Corp, Danbury, CT, USA).

After the light curing procedures, specimens were stored in distilled water at 37°C for 24 hours and were then finished under water using 600- and 1200-grit SiC sandpaper and polished with 1- and 0.5-μm diamond pastes using a polish cloth under water. Specimens were ultrasonically cleaned for five minutes between finishing and polishing steps.

Evaluation of Marginal and Internal Adaptation

Marginal adaptation was measured using a staining technique. A 1.0% acid red propylene glycol solution (Caries Detector, Kuraray Co., Osaka, Japan) was applied at the restoration margins for five seconds.[14,18,32] Specimens were then rinsed in tap water and gently blow-dried. Digital images of the dyed restorations with 2400-megapixel resolution were obtained using a scanner (HP ScanJet G4050, Hewlett-Packard Company, Palo Alto, CA, USA). The length of the dye-stained gaps along the cavity margins was measured (mm) from the images using the UTHSCSA Image tool software, version 2.0 (alpha 2_ September 1997), developed by the Department of Dental Science at The University of Texas Health Science Center (San Antonio, TX, USA). The length of the gap formed was calculated as a percentage of the entire margin length.

After the evaluation of gap formation at superficial margins, the restorations were cut in the buccal-lingual direction in slices (1 mm thick) using a cutting machine (ISOMET 1000, Buehler, UK LTD, Lake Bluff, IL, USA) in order to obtain two slices of each restoration. On each slice, Caries Detector was applied to stain the internal gaps, and the same procedures described previously were accomplished for the evaluation of the internal adaptation of the composite restorations. The obtained data (marginal and internal adaptation) were transformed (arcsine root x/100) in order to obtain normal distribution and were submitted to two-way analysis of variance and Tukey tests at 5% significance.

RESULTS

None of the curing methods was capable of ensuring a perfect marginal seal of restorations. Table 2 shows that marginal gap formation in restorations cured using SS and PD was significantly reduced, when compared to restorations cured using continuous light (CL), in the higher volume cavity group. For CL, the higher volume cavity group presented gap formation that was statistically greater compared to the cavity with lower volume. No difference was observed when SS and PD were compared in the different volumes. Additionally, no difference among curing methods was observed for the lower volume restorations. Concerning internal adaptation (Table 3), the modulated curing methods SS and PD showed a reduction on gap formation, when compared to CL, in lower volume cavities. However, in higher volume cavities, no significant difference among curing methods was observed. In addition, from the results of internal adaptation, it was possible to observe that the higher volume cavity group presented gap formation that was statistically greater compared to the cavity with lower volume for the SS and PD curing methods. For CL, no difference between higher and lower restoration volume was detected.

Table 2: *Means in % of Marginal Gap Length (Standard Deviation) on Superficial Margins of Cavities with Different Volumes and Curing Methods*

	Continuous Light	Pulse Delay	Soft-Start
Low Volume	8.62 (1.42) Ab	8.13 (2.43) Aa	7.44 (1.88) Aa
High Volume	17.76 (2.64) Aa	9.10 (2.42) Ba	4.70 (0.69) Ca

Mean values followed by different small letters in the column and capital letters in the row differ statistically among themselves for the Tukey test at the level of 5%. Values in parentheses represent standard deviations.

DISCUSSION

An important factor to consider in promoting the clinical success of resin composite restorations is a satisfactory marginal and internal adaptation. The presence of gaps is considered the first sign of restoration failure, clinically evidenced by marginal staining.[13] It has been accepted that a detectable marginal gap would lead to interfacial leakage.[3,13]

Table 3: *Means in % of Gap Length (Standard Deviation) on Internal Margins of Cavities with Different Volumes and Curing Methods*

	Continuous Light	Pulse Delay	Soft-Start
Low volume	13.53 (3.18) Aa	5.10 (2.26) Ba	3.96 (1.68) Ba
High volume	9.60 (1.52) Aa	9.92 (1.54) Ab	7.24 (1.82) Ab

Mean values followed by different small letters in the column and capital letters in the row differ statistically among themselves for the Tukey test at the level of 5%. Values in parentheses represent standard deviations.

Clinically, the bacterial leakage along the adhesive interface has been related to a severe pulpal response.

In addition to the importance of bacterial leakage, *in vitro* microleakage tests have not been accepted as predictive of restoration failure, because they can show overestimated results as a result of dentin permeability to low-molecular-weight colorants/dyes.[32] In this sense, evaluating the presence of gaps is considered to be more reliable because it should be considered as the first sign of restoration failure that can be clinically evidenced by marginal staining.[3] Thus, the identification of early marginal changes could facilitate the prognosis of the longevity/stability of a composite restoration, because it has been accepted that a detectable marginal gap will lead to interfacial leakage.[32-34]

Composite shrinkage stress can damage the interfacial quality of composite restorations, compromising the durability of the restorative treatment. In the present study, none of the curing techniques or employed material volumes was able to ensure a perfect sealing of the interfacial margin of composite restorations. Internal gap formation was particularly located at pulpal wall and axiopulpal angles, which are problematic areas for composite insertion.[32] At the pulpal floor, gap formation is related to difficulty with the adhesion due to an increase in tubular density and diameter and proportional reduction in intertubular dentin.[35] This condition allows the shrinkage stress to overcome the bond strength. Gap formation on the axio-pulpal angle could be attributed to the difficulty of accommodating composite in this region. Indeed, previous studies[1,36,37] related the axio-pulpal angle to an area of significant difficulty related to the insertion of composite, and this difficulty of composite accommodation could promote a gap between the composite and the bonding agent/cavity wall, increasing the probability of gap formation.

Additionally, gap formation at these sites is also related to shrinkage vectors, as observed by Chiang and others.[38] These authors explained that the composite shrinks with an upward movement, which is determined by two conditions: 1) debonding at the bottom of the cavity and 2) intact adhesion to the enamel margins. As soon as the debonding occurs, the intact adhesion will cause the upward movement. This can be explained by the fact that the bonding agent usually exhibits a higher bond strength to enamel than to dentin. Therefore, adhesion to the enamel remains intact while the bond to dentin is lost as a result of the contraction stress. In addition, gap formation at the pulpal wall and axiopulpal angles may promote fluid flow in the dentin tubules, resulting in postoperative sensitivity.[39]

The composite used in the present study, Filtek Z250, has high inorganic filler volume content (60%) and monomeric system based on components with a high molecular weight (BisGMA, BisEMA, UDMA), which leads to a low volumetric shrinkage (about 2.2%), according to manufacturer's information. However, Filtek Z250 presents a high concentration of photoinitiators in order to offer a satisfactory cure in 20 seconds of light exposure, leading to a fast photo-curing reaction and, consequently, fast development of shrinkage stress.[5]

In addition, the use of bovine teeth could be considered a limitation of this study. One may argue that using this substrate is not as accurate as using human teeth when different interactions between bonding systems and tooth substrate are compared. However, in the present study, the adhesive bonding system and substrate were standardized for all groups, thereby standardizing the interaction between them. The major aim of this study was to evaluate composite characteristics under confinement cured with different methods. Therefore, the observed differences were caused by the tested variables: volume of composite and curing method. In this sense, bovine teeth were selected because they are a suitable substrate for the type of test used, they are easier to obtain than human teeth, and their use does not result in ethical problems. According to Reeves and others,[40] bovine dentin is an adequate substitute for human teeth in adhesion tests. However, it has been observed that it is more difficult to ensure good marginal quality using bovine dentin, and this fact could explain the high marginal gap values. Considering that, a successful technique with bovine teeth tends to be even more successful than can be achieved using human teeth. In addition, the use of bovine incisors has been supported by several authors.[36,39,41]

In this study, we tested the hypothesis that the higher the volume of composite, the greater the gap formation, and this hypothesis was accepted. However, it should be noted that the reduced gap formation associated with lower volume cavities occurred differently depending on the curing method employed. For CL groups, marginal gap formation was greater for higher volume cavities. However, for SS and PD groups, a higher percentage of gap formation was observed in higher volume cavities, to internal margins. The reduction in gap formation associated with lower volume cavities can be explained based on the reduction in shrinkage stress in a lower volume of composite.[8]

The effect of modulated curing methods depends on the volume of the cavity. In higher volume cavities, modulated curing methods generated reduction of superficial gap formation, and in lower volume cavities, these methods generated reduction of internal gap formation. Therefore, the second tested hypothesis was accepted, because modulated curing methods reduced gap formation, but this reduction occurs in different modes, depending on the volume of the cavity. Considering that, the third hypothesis, related to a superior benefit of modulated curing methods in situations of higher shrinkage stress, cannot be accepted. The benefits of modulated methods occur differently in both cavities. In higher volume cavities, the benefits occur in the external margins (marginal gap formation is reduced by modulated curing methods). However, in lower volume cavities, the benefits occur in the internal margins (internal gap formation is reduced by modulated curing methods).

For CL, the fast polymerization process decreases the time allowed for viscous flow and leads to a rigid polymer matrix in a few seconds.[40] So, shrinkage stress starts almost immediately after polymerization, and a significant part of the shrinkage occurs after the polymer matrix has reached a significant level of rigidity, which causes higher shrinkage stress and may culminate in greater gap formation, as observed in the present study.

The benefits of modulated curing methods have been related to the increased ability of the composite to flow, delaying the pre-gel stage,[8] and to reduced stress rates associated with these methods.[7] Conversely to CL photoactivation, this scenario promotes a slower formation of the polymer network and cross-links, favoring better conditions, compared to molecular adaptation, within the polymeric chain that has been developed under the cavity confinement.[42] The low initial intensity employed for these curing methods could reduce the stress rate and consequently the stress magnitude of composite restoratives, causing less damage to the restoration margins and improving bond strength.[1,11,19,22,42] After this initial step, a complement of the polymerization using high intensity ensures satisfactory energy dose to guarantee adequate degree of conversion and mechanical properties.

Two modulated curing methods were tested in the present study: SS and PD techniques. According to Lim and others,[19] an initial irradiance of 150 mW/cm^2 is too high to significantly reduce the magnitude of shrinkage stress. However, in the present work, even when using an initial irradiance of 150 mW/cm^2, gap formation was significantly decreased when compared to use of the CL curing method. And this gap reduction is attributed to a reduction in shrinkage stress due to a slower curing rate.[5,11] The low modulus phase (pre-gel stage) is extended, allowing stress to be relieved by polymer flow and deformation.

Despite the advantageous effects of the modulated curing methods, some concerns have to be addressed. Studies have pointed out that the efficacy of these methods varies according to formulation, which limits the results of the present study to the specific material used.[19] Another potential problem is reduction of polymer cross-link density related to modulated curing methods,[14] which can render the polymer network more susceptible to degradation. However, it should be considered that the main cause of adhesive restoration failure is the debonding of the composite-tooth interface,[12] and it is directly related to gap formation. Thus, even if less cross-link density is formed,[14] a similar degree of conversion,[7] better bond strength values,[7,12] and improved marginal adaptation[1,13,43] are achieved, and these benefits can be considered superior to the afore-mentioned problems.

CONCLUSION

Based on the results, it can be concluded that the higher the volume of composite, the greater the gap formation. In a general way, exposing the composite to CL intensity (600 mW/cm^2) during the entire irradiation period can damage the bonding interface, thereby increasing marginal gap formation. However, none of the curing methods tested were able to ensure perfect sealing of margins, although modulated curing methods (SS and PD) could reduce gap formation, depending on the volume of the cavity.

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