Low shrinkage composite resins: influence on sealing ability in unfavorable C-factor cavities

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Abstract: The present investigation observed the sealing ability of low shrinkage composite resins in large and deep cavities, placed and photocured in one increment. Large, deep cavities (5.0 mm diameter and 2.5 mm deep) surrounded by enamel were prepared in bovine teeth, which were then divided into five groups. Groups 1, 2, 3 and 4: acid conditioning + Adper Single Bond (3M/ESPE, St Paul, MN, USA) and restoration with Aelite LS Posterior (BISCO Inc. Schaumburg, IL, USA) (G1); Filtek Z-350 (3M/ESPE,St Paul, MN, USA) (G2); Filtek Z-350 Flow (3M/ESPE, St Paul, MN, USA) (G3); Premisa (KERR Corporation, Orange, CA, USA) (G4). Group 5: Silorane Adhesive system (3M/ESPE, St Paul, MN, USA) + restoration with Filtek Low Shrinkage Posterior P90 (3M/ESPE, St Paul, MN, USA). After polymerization, the teeth were immersed in 0.5% basic fuchsine solution and immediately washed. Using the Imagetool Software, the extent of dye along the margins was calculated as a percentage of total perimeter. The restorations were then transversally sectioned and the depth of dye penetration was calculated in mm, using the same software. Kruskal-Wallis analysis for all groups showed no statistical differences for extent ($p = 0.54$) or depth ($p = 0.8364$) of dye penetration. According to this methodology, the so-called low shrinkage composite resins had the same sealing ability compared to regular and flowable nanocomposite materials.

Descriptors: Adhesives; Composite Resins; Dental Marginal Adaptation.

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Introduction

Composite resin/adhesive systems have become the first choice for direct restoration. However, in spite of the many advantages, polymerization shrinkage and its associated stress continues to be a concern.[1] As a result of shrinkage stresses, some events such as cusps deflection; debonding or enamel cracks, which may affect marginal sealing; and postoperative sensitivity,[2,3,4,5,6] are prone to occur. Among the reasons for restoration replacement are marginal staining and marginal fracture,[7] which could be related to the tensions present during polymerization.

Different adhesive formulations have been proposed recently, to prolong the clinical lifetime of composite restorations. The main focus is to reduce the clinical steps, to avoid mistakes, and improve the bonding stability.[8,9] This strategy is of great importance; however, adhesive ability alone is not enough to achieve immediate and durable marginal sealing.[10]

The restorative material is another part of the whole process, which has significant influence on marginal sealing. The so-called Low Shrinkage Composite (LSC) resins are undoubtedly an interesting alternative to prevent marginal sealing breakdown.[10]

Recently, a Silorane composite resin (3M/ESPE, St. Paul, MN, USA) that uses a dedicated two-step, self-etching adhesive system claims shrinkage near 1%, by volume (Filtek Silorane - Technical Profile - 3M/ESPE), lower than the 2% to 5% exhibited by some Bis-GMA composites.[11] In addition to the materials (adhesives and composites), there are other factors, such as cavity configuration,[12,13] composite application[6,13] and finishing techniques,[14] that may influence the marginal adaptation of resin restorations.

In 2007, a study[15] used a simple method to determine marginal adaptation of indirect restorations: a drop of a dye was poured onto the restoration surfaces, and the dye penetration in the margins of each restoration was calculated as a percentage of the cavity perimeter. Using a similar methodology, the proposal of this *in vitro* study is to assess the sealing ability, for depth and extent, of different types of composite resins, some of them advertising low shrinkage values, in large and unfavorable C-factor cavities restored in one increment. The purpose is to observe, mainly, the influence of the restorative materials on marginal behavior. Therefore, the hypothesis to be tested is that the LSC (Aelite/BISCO, Premisa/Kerr, P-90/3M-ESPE) produce less marginal breakdown after polymerization, when placed in large and unfavorable C-factor cavities using bulk filling technique, as compared to conventional (Z-350/3M-ESPE) and Low Viscosity (Z-350 Flow/3M-ESPE) nanocomposite resins associated with conventional two-step etch-and-rinse adhesives.

Materials and Methods

One hundred extracted bovine incisors presenting flat and regular buccal surfaces were selected, thoroughly cleaned and stored in distilled water. Standardized cavities with margins totally located in enamel (5 mm diameter and 2.5 mm deep) were cut with a # 4054 wheel shaped diamond bur (KG Sorensen - São Paulo, SP, Brazil), attached to a high-speed hand piece. The cavities were finished with the same burs, but in low speed. The dimensions of the cavities were constantly checked with a digital caliper (Starret - Las Vegas, NV, USA). Following these procedures, the teeth were randomly divided into five groups of twenty specimens each.

For groups 1, 2, 3 and 4, the cavity walls were etched with 37% phosphoric acid (Scotchbond Etchant - 3M ESPE, St. Paul, MN, USA) for 30 seconds, rinsed for another 30 seconds, and the excess water was blot dried. Adper Single Bond (3M/ESPE, St. Paul, MN, USA) was applied, gently air dried for 5 seconds, then light activated using a curing unit Flashlight (Discus Dental, Culver City, CA, USA) for 10 seconds. When an entire shiny surface was not achieved, the application was repeated.

Group 5 used a specific self-etch adhesive system (Silorane, 3M/ESPE, St Paul, MN, USA), comprising a self-etch primer and a light-cured bonding agent that were applied independently and polymerized according to the manufacturer's directions.

The materials used in this study, their composition and the different groups are depicted in Table 1.

The cavities were bulk filled as close as possible to the margins, then light-cured for 40 s. Next, the restorations were lightly ground, wet, using 320 and 600-grit Si-C paper to remove composite overhangs.

Extent of Dye Penetration: Each specimen was immersed in a 0.5% solution of basic fuchsine for one second, removed immediately, and rinsed with running water. The excess dye on the surface of the composite and the enamel was removed using a cotton pallet and alcohol.

All restorations were positioned perpendicularly in a stereomicroscope (Opton - TA0123 - Germany), magnification X7, and the images were captured (Figure 1A-D) and transferred to a computer equipped with the Imagetool software (UTHSCSA - University of Texas Health Science Center - San Antonio, TX, USA). The total perimeter of each restoration and the extent of dye penetration along the margin were measured in millimeters (Figure 2).

Table 1 - Overview of the different materials used in the five experimental groups.

Restorative Material / Group	Composition	Manufacturer / Lot
AELITE Low Shrinkage Posterior - Group 1	Ethoxylated bis-GMA, glass filler, amorphous silica	Bisco Inc., Schaumburg, IL, USA 60193 (lot 0700006567 2010-05)
Filtek Z350 - Group 2	Bis-GMA, UDMA, bis-EMA, TEG-DMA, silica-zircon nanoparticles and nanoagglomerated	3M ESPE, Dental Products, St. Paul, MN, USA 55144-1000 (lot 7HR 2009-10)
Filtek Flowable Z350 - Group 3	Bis-GMA, UDMA, bis-EMA, TEG-DMA, silica-zircon nanoparticles and nanoagglomerated, silica nanofiller, zircon nanofiller	3M ESPE, Dental Products, St. Paul, MN, USA 55144-1000 (lot 8BH 2010-02)
Premisa Low Shrinkage Composite - Group 4	**Trimodal filler system:** prepolymerized filler (PPF), 30 to 50 μm; barium glass, 0.4 μm; silica filler, 0.02 μm **Resin:** ethoxylated bis-phenol-A-dimethacrylate, triethylene glycol dimethacrylate (TEGDMA), light-cure initiators and stabilizers	Kerr Corporation, Orange, CA, USA (lot 2702189 item 32797 – 2009-11)
Filtek Low Shrinkage Posterior P90 (Silorane) - Group 5	Silorane, quartz filler, radiopaque fluoride itreo	3M ESPE, Dental Products, St. Paul, MN, USA (lot BU 2009-11)
Adper Single Bond 2 - Groups 1, 2, 3 and 4	**Adhesive:** bis-GMA, HEMA, dimethacrylate, photo-initiators, polyacrylate acid functional polymer methacrylate, nanofillers (5 nm)	3M ESPE, Dental Products, St. Paul, MN, USA (lot HE2010-05)
P90 System Adhesive - Group 5	**Self etch primer:** methacrylate phosphated, bis-GMA, HEMA, ethanol, water, camphorquinone **Adhesive:** bifunctional monomer hydrophobic, bis-GMA, silica filler. pH 2.7	3M ESPE, Dental Products, St. Paul, MN, USA Lot 8BU 2009/11

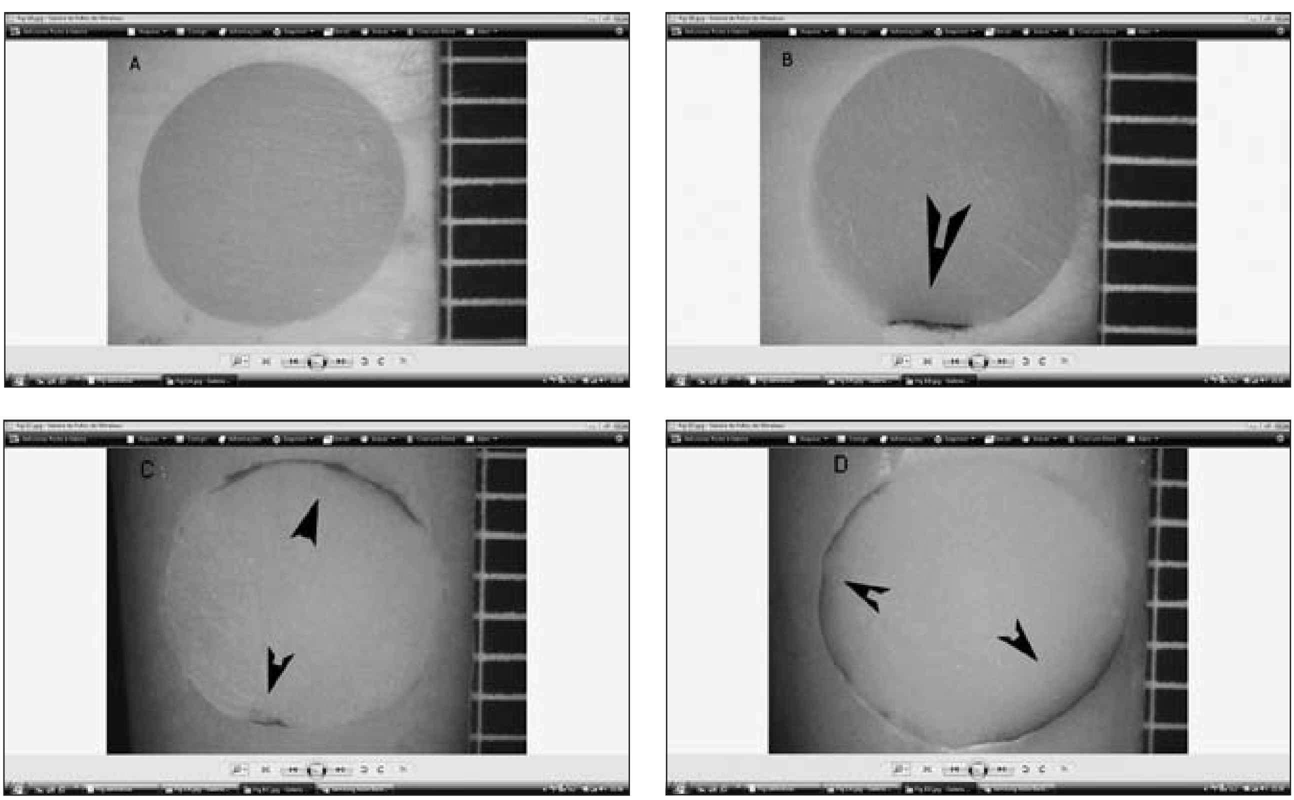

Figure 1 - A: Sample depicting no gap formation. The contraction forces were not enough to disrupt the marginal seal. **B, C and D:** View of the whole perimeter of the restorations. Note that some areas are stained (violet) and indicate different gap formations due to polymerization shrinkage.

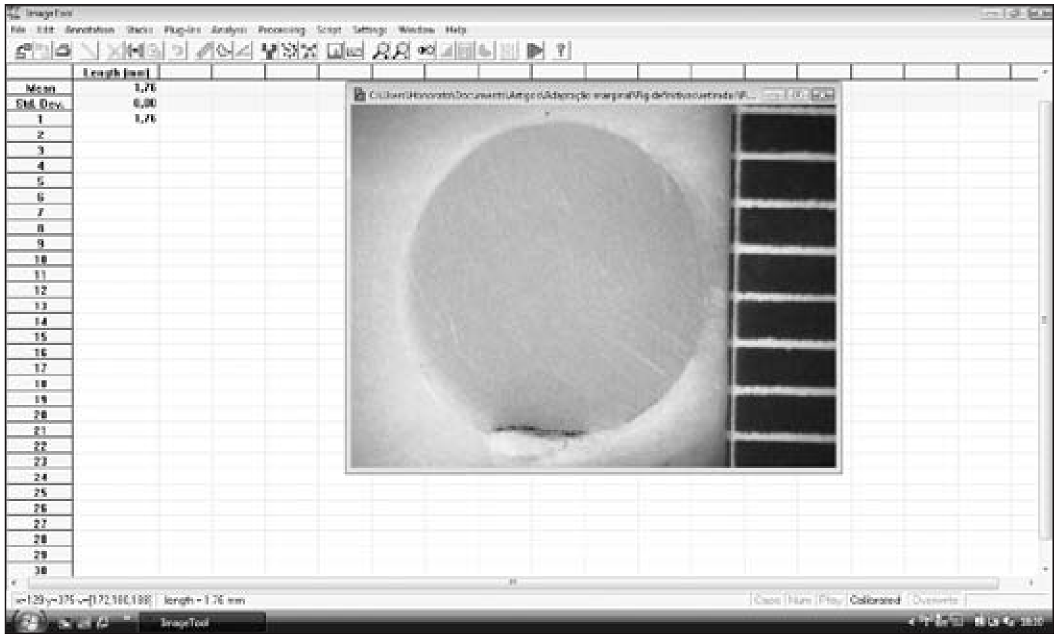

Figure 2 - This image shows the moment when the Imagetool software was being used to determine the extent of dye penetration.

Figure 3 - Image depicting the depth of dye penetration after the restoration was sectioned. The image was then transferred to a computer to calculate the depth of dye penetration using the same software (Imagetool).

Hence, it was possible to calculate the extent of dye penetration as a percentage of total perimeter.

Depth of Dye Penetration: The restorations were transversally sectioned using a # 7020 diamond disc (KG Sorensen - São Paulo, SP, Brazil) under constant water cooling. The direction of each sectioning was guided by the areas of more evident dye staining. The sectioned samples were positioned in the stereomicroscope to allow capture and transfer of the images to a computer (Figure 3). Depth of dye penetration was measured in millimeters, using the same software. Only the highest value of each sectioned specimen was considered for statistical analysis. The specimens which did not exhibit marginal staining were not sectioned, and the value

Table 2 - Mean values for dye penetration along the cavity margins in millimeters. Means with the same letter are not statistically different (p = 0.54).

Groups	Mean values	Standard deviation
1	2.18[a]	± 2.29
2	3.31[a]	± 4.50
3	3.9[a]	± 3.91
4	2.61[a]	± 3.61
5	1.96[a]	± 2.84

Table 3 - Mean values for depth of dye penetration in bovine incisors, in millimeters. Means with the same letter are not statistically different (p = 0.8364).

Groups	Mean values	Standard deviation
1	0.3145[b]	± 1.4548
2	0.2650[b]	± 1.4210
3	0.2265[b]	± 1.6570
4	0.3475[b]	± 1.7139
5	0.2050[b]	± 1.5134

0 (zero) was assigned. The Kruskal-Wallis analysis was applied to the results ($P > 0.05$).

Results

Marginal Adaptation - Extent of Dye Penetration: Table 2 summarizes the results according to the extent of dye penetration along the margins.

Marginal Adaptation - Depth of Dye Penetration: Table 3 depicts in millimeters the mean depth of dye penetration. All groups were statistically similar ($p = 0.8364$).

Discussion

Bovine teeth have been used due to ethical concerns related to the use of human teeth. The advantages of availability, similarity in age, low risk of infection to the researcher and ease of preparation are aspects that may be considered as well. The histological aspects of human and bovine permanent teeth seem to be similar and no differences in bond strength values have been found.[16]

The marginal sealing breakdown of adhesive restorations may possibly occur as a consequence of long-term thermal and mechanical stresses; or immediately, during the restorative procedure itself, due to polymerization shrinkage stress. Hence, the marginal gaps in a clinically placed composite restoration occupy between 14% and 54% of the total interface, depending on materials and techniques used.[17] Several clinical methods have been suggested to reduce polymerization stress, such as incremental layering technique,[13,18,19] modulated curing methods,[20,1] use of a flowable resin layer and filled adhesives.[13,21] Recently, some composite resin materials classified as low-shrinking composites have been commercialized; however, the material itself has not proved to be totally effective in preventing the harmful consequences of the shrinkage stresses generated at the dentin-composite interface.[13]

Polymerization stress is a concern due to its consequences, and cavity configuration has been strongly related to it. For instance, the study conducted by Loguercio *et al.*,[22] using linear polymerization shrinkage measurements inside the cavities, has shown that the higher the ratio of bonded to unbonded surfaces, the greater the shrinkage in the top-to-bottom direction. Thus, the restriction caused by bonding to the cavity walls would prevent the composite resin from reducing its length on the cavosurface margins during the polymerization process.

The shrinkage values presented by different types of composite resins are another point to be considered. When the extent of dye penetration along the margins was determined, the Kruskal-Wallis test showed no significant differences ($p = 0.54$) among the groups. The bulk filling technique used in this study may have generated stresses on the cavity walls above the adhesive strength during polymerization, regardless of the type of composite used, and thus led to gap formation for all groups. From the statistical viewpoint, it could be assumed that all composite resins used presented similar shrinkage, and/or the bonding ability of the adhesive systems used was not sufficient to prevent the breakdown of marginal sealing. However, another aspect that must be highlighted is that the difference in the stiffness of the uncured resin may impair the composite-dentin adaptation and, thus, the dimmer effect caused by the thickness and transparency of the composites used.[13] It is important to emphasize, though, that the Silorane (P-90) composite was used with a self-etching adhesive system and, for the other four groups, the adhesive used was the same, the etch-and-rinse Adper Single Bond. It is a common understanding that conventional etch-and-rinse adhesive systems produce higher bond strength on enamel than do self-etch ones.[8,9] The self-etch adhesive used in conjunction with the Silorane composite can be considered ultra-mild, pH 2.7;[13] and, the enamel acid-etching prior to the application of the self-etching adhesive, as recommended in some studies,[8,9] was not performed. Thus, even if the Silorane composite resin could reduce the shrinkage stress on cavity walls, the bond strength achieved by the self-etching system, especially on enamel margins, would impair the observation of the effect of a low shrinkage restorative material.

A recent investigation,[23] using micro-Raman spectroscopy and SEM, studied the hybrid layer formed by the Silorane adhesive. A hybrid layer, comparable in thickness to two other self-etch systems (G-Bond and Adhese One), was observed. To ensure adhesion to hydrated dentin, Silorane Primer contains hydrophilic monomers, whereas the Bond has hydrophobic bi-functional monomers to match the Silorane hydrophobic composite resin. Although the Bond is placed on the cured Silorane Primer surface prior to being cured itself, Raman spectra indicated an intervening zone of about 1 μm of mixed spectral intensities associated with both Silorane Primer and Bond. According to the authors, this may be due to the oxygen inhibition layer remaining on the cured Silorane Primer surface. They concluded, from this particular observation, that further investigation into the bond strength of the Silorane adhesive system is necessary to assess whether this intervening zone may act as a weak link in the bonding process.

One important feature was the large standard deviation in the analysis of the extent of dye penetration (Table 2). It is essential to remember that each group had 20 specimens, a sample that can be considered elevated. These large standard deviation values would be also responsible for the absence of significant differences. It is important to mention, however, that in addition to the interpretation of the data obtained from this applied methodology, the discussion of the related literature also shows that several factors are involved in gap formation, and that they are not clearly understood.[3,10,13,19,20] Therefore, establishing a precise methodology, both to individualize the mechanisms that are responsible for gap formation and to counteract them, is still a challenge.

When the dye penetration was analyzed in depth, no significant differences were found as well ($p = 0.8364$). Nevertheless, these results need to be discussed more profoundly. Although not statistically different, the mean (0.2265 mm) of the dye penetration for the low viscosity composite group (Filtek Flowable Z-350) was close to those observed for the other experimental groups, some of which employed low-shrinking composites. According to Hooke's law, stress is determined by the volumetric shrinkage and the E-modulus of the material. Although low-viscosity composites generally present higher shrinkage values than high-density composites, the low E-modulus (20-25% lower) may compete with the stress development that would help to maintain the marginal seal.[24,25]

The polymerization rate of composites, especially in deep areas, is of great importance. The depth of the cavities in this study was 2.5 mm, thus on the limit of light energy, necessary to achieve an adequate level of polymerization.

The incremental filling technique can be considered advantageous, since the C-factor of the individual layer drops and the amount of energy available at the interface increases.[26] The choice of a large and unfavorable C-factor cavity, as well as the bulk insertion technique, was made specifically to concentrate the task of sealing the cavities on the restorative system. Therefore, based on the results of this particular study, associated with the information available in the literature, the layering technique remains recommended even for the low-shrinking materials.

Conclusion

According to the methodology of this *in vitro* study, the results achieved and the statistical analysis performed, the tested hypothesis must be rejected since the LSC/adhesive restorations could not produce better marginal adaptation, either in extent or in depth, than the other restorative systems used in this investigation.

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