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Effects of Filling Techniques on the Regional Bond Strength to Lateral Walls in Class I Cavities

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Clinical Relevance

Using either total-etch or self-etch adhesives, the incremental technique is the optimal method to insert resin-based composites in large Class I cavities.

SUMMARY

Objectives: Using the push-out technique, this study compared the influence of different composite insertion techniques in Class I cavities on the regional shear bond strength to lateral walls.

Materials and Method: Standardized Class I cavities were prepared on the occlusal surface of 60 freshly extracted third molars, which were randomly assigned to one of five groups (n=10). The cavities were bonded with the self-etch adhesive AdheSE and restored with Tetric Ceram resin composite by one of five techniques: G1, incremental technique (four oblique layers); G2, flowable composite as liner and bulk technique; G3, bulk technique and G4, light cone technique. The total-etch adhesive (Single Bond) and incremental technique were used as the control procedure. Each specimen was sectioned perpendicular to the long axis of the tooth in 1 mm-thick dentin slices. A push-out test was performed to measure regional bond strengths and identify the type of failure. Two additional teeth per group were prepared for the morphological interface study using scanning electron microscopy.

Results: Differences between the groups were tested by one-way ANOVA and Scheffé post hoc test (F=29.635, *p*<0.001). The highest shear bond strength values were obtained with the incremental technique, regardless of the adhesive used. Significant differences in bond strength to superficial and deep dentin were only found when a total-etch adhesive was used (Single Bond).

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Conclusions: Use of the incremental technique with total-etch or self-etch adhesives is the most effective method of inserting resin-based composites in large Class I cavities.

INTRODUCTION

Light-cured resin composites are widely used in clinical practice, but the stress produced during resin polymerization may compromise the marginal seal of the restoration. Cavity geometry can have a negative influence on bond strength[1] and produce cavity wall gap formation.[2] When the resin shrinks during curing, the opposing walls of the cavity are pulled together, producing stress.[3] Most resin-dentin bond testing is performed on flat tooth surfaces, and bond strengths obtained under these conditions are significantly higher than in filled cavities.[4-7]

It is well documented that a high configuration factor (c-factor: ratio of bonded to non-bonded resin surfaces) is a risk factor for bonding, because polymerization stresses may be increased.[4] Several studies indicated that the incremental technique could improve bond strength in Class I and Class II cavities.[4-9] The C-factor of the cavity is reduced by this approach, thereby minimizing the harmful effects of stress on the adhesive interface.[3] Nikolaenko and others[4] reported that bond strength increased with the application of more layers.

The adequate selection of materials and control of polymerization contraction stress are key factors for a successful composite restoration. A hybrid composite has shown greater stress than a microhybrid composite.[10] Because of their low stiffness, flowable composites might reduce curing stress, acting as an elastic buffer at the resin-dentin interface.[11]

Few studies have evaluated the influence of high C-factors on regional bond strength to lateral walls in Class I cavities using two-step self-etching primer adhesive systems. Most studies of C-factor influence only investigated bond strength to the cavity floor.[6,8,12]

The null hypothesis of the current study was that, when using a self-etching adhesive, the various obturation techniques employed to decrease stress generated in Class I cavities do not influence the bond strength to superficial or deep dentin of lateral walls. The objectives of this study were to investigate, using the push-out technique, the influence of different Class I cavity composite insertion techniques on the regional (superficial/deep dentin) shear bond strength to lateral walls.

METHODS AND MATERIALS

Sixty caries-free human third molars with no previous restorations were used. These molars were cleaned and stored for up to three months in distilled water with thymol crystals at 4°C. The crown portion of each tooth was sectioned perpendicular to the long axis of the tooth 1 mm below the cementum-enamel junction using a Horico H350220 diamond blade (Horico GmbH, Berlin, Germany) under copious water cooling. Samples were connected to a simulated pulpal pressure system by a previously described method,[13] maintaining the tooth under pressure and humidity conditions throughout the preparation.

All molars were flattened on their occlusal surface with an Exakt Apparatebau D-2000 polisher (Nederstedt, Germany) and wet-ground with #500 SiC paper to create an occlusal plane perpendicular to the axial axis, ensuring their vertical stability. All specimens were placed inside 5-cm high cylindrical molds with an internal diameter of 2 cm. The occlusal surface was adhered to the bottom of the mold with a drop of cyanoacrylate (Araldite, Everberg, Belgium) to prevent tooth movement during pouring of the self-curing resin (Ortocryl EQ, Dentaurum, Germany). Once the resin hardened, in order to simulate intrapulpal hydraulic pressure, the specimens were removed from the molds and connected by flexible tubing to a pressure column containing distilled water.

A device was designed for the preparation of perpendicular and centered occlusal cavities. It consisted of a drilling column with free movement on the vertical axis, with a device to fix the handpiece and a perpendicular base to hold and move the specimen. To ensure that the occlusal cavities were centered, a perfectly fitting cap was made for the inclusion mold using a 2.3-mm diameter central hole for passage of the drill body, which was attached to a handpiece. A Cerana diamond cone-shaped bur (4.6 mm high, 4.8 mm upper diameter and 3.4 mm lower diameter) was used (Nordiska Dental, Ängelholm, Sweden). The specimen was inserted into the bottom part of the mold with the occlusal surface opposite the drill, and the mold was fixed to the base of the drilling tower (Figure 1). Two equidistant holes were made in the molds for air/water spray applications and for low-speed refrigerated cutting. After the cavities (height, 4.5 mm; occlusal diameter, 5.0 mm; floor diameter, 3.6 mm) were cut, they were studied under a stereomicroscope to ensure the absence of pulpal exposure in the cavity walls and floor.

Cavity Restoration

Teeth with prepared cavities were randomly assigned to one of five groups (n=10) for restoration by one of five filling techniques (Figure 2). In Group 1, the cavities were filled with four oblique incremental layers, placing a vestibular/pulpal increment followed by a lingual/vestibular increment and repeating the same increments to finish the obturation. In Group 2, the flowable composite Tetric Flow (Ivoclar-Vivadent, Schaan, Liechtenstein) was applied with a fine brush

Figure 1: *Device for preparation under simulated pulp pressure of well-centered, occlusal cavities that are perpendicular to the cavity floor.*

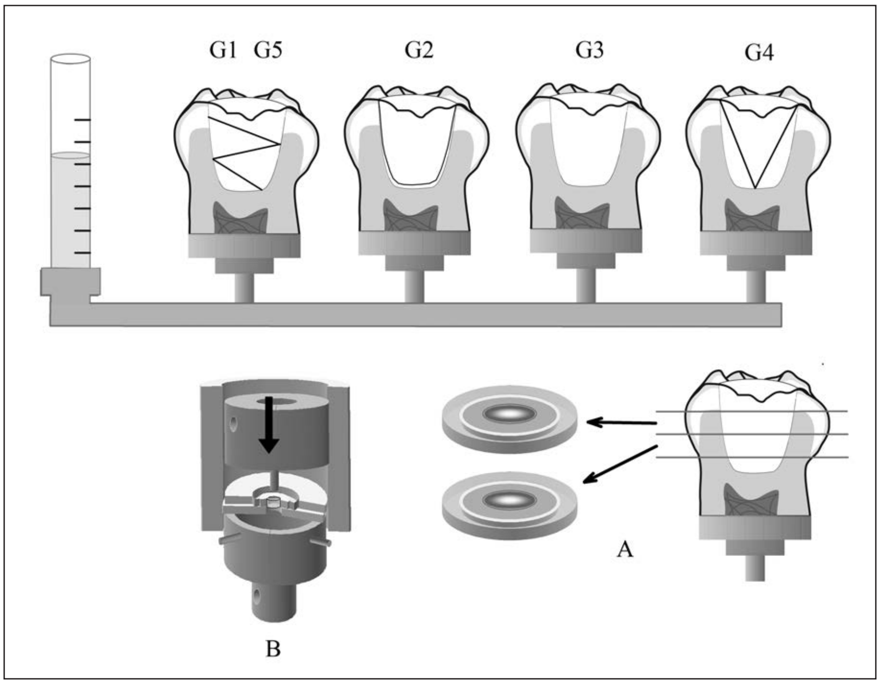

Figure 2: *Procedures. G1: Self-etch adhesive (AdheSE)/incremental technique (four oblique incremental layers); G2: Self-etch adhesive (AdheSE)/flowable composite as liner/bulk technique; G3: Self-etch adhesive (AdheSE)/bulk technique. G4: Self-etch adhesive (AdheSE)/light cone technique; G5: total-etch adhesive (Single Bond)/incremental technique (four oblique incremental layers). A: Occlusal slice, corresponding to occlusal enamel, was cut and discarded and 1-mm slices of superficial and deep dentin were marked. B: Push-out device with slice mounted.*

on the cavity floor and walls. After light curing, the cavity was filled with a single increment of Tetric Ceram resin composite (Ivoclar-Vivadent). In Group 3, Tetric Ceram resin composite (Ivoclar-Vivadent) was compacted until the cavity was filled with a single increment that was then light-cured. In Group 4, Tetric Ceram resin composite (Ivoclar-Vivadent) was applied and compacted against the cavity floor and lateral walls, and a transparent plastic Focu-Tip (Hager Werken, Germany) cone was then inserted into the end of the cavity, pushing the restoring material against all cavity walls. The cone was removed after polymerization, and the remainder of the cavity was filled with a second increment that was then polymerized. Group 5 was considered as the control group, applying Single Bond adhesive (3M/ ESPE Dental Products, St Paul, MN, USA) after acid etching the cavity with 37% phosphoric acid gel for 15 seconds following the manufacturer's instructions. The incremental technique described for Group I was used for the obturation. All materials and components used in this study are described in Table 1.

In Groups 1, 2, 3 and 4, self-etching adhesive AdheSE (Ivoclar-Vivadent) was used and applied according to the manufacturer's instructions. The same composite was used as the filling in all teeth (Tetric Ceram, Ivoclar-Vivadent; color A3, batch #G11169). The same photoactivation protocol was followed in all experiments, using an Astralis 10 (Ivoclar-Vivadent) halogen lamp at 700 mW/cm^2 for 20 seconds for AdheSE and Single Bond dentin adhesive polymerization and for 40 seconds for each composite increment and flowable composite. The bulk group (Group 3) received an additional 40 seconds of polymerization on the vestibular and 40 seconds on the lingual walls, in addition to the 40-second curing on the occlusal surface.

Table 1: *Adhesive Systems, Components and Manufacturer*

Adhesives	Components	Manufacturer
AdheSE Primer	Phosphonic acid acrylate, bis–acrylamide, water, initiators and stabilizers	Ivoclar-Vivadent Schaan, Liechtenstein
AdheSE Bond	Dimethacrylate, hydroxyethyl methacrylate, silicone dioxide, initiators y stabilizers	Ivoclar-Vivadent Schaan, Liechtenstein
Single Bond	Bisphenol-A glycidyl methacrylate, 2-hydroxyethyl methacrylate, dimethacrylates, polyalkenoic copolymer, ethanol, water	3M/ESPE, St Paul, MN, USA

All the specimens were prepared at room temperature (21°C) and a relative humidity of 50-60%; they were then stored for 24 hours in distilled water at 37°C in an oven, maintaining an intra-pulpal pressure of 15 mm/Hg.

Specimen Preparation

Each specimen was sectioned perpendicular to the long axis using an Accutom 50 cutting machine (Struers A/S, Ballerup, Denmark) with a water-cooled diamond blade. The occlusal slice, corresponding to occlusal enamel, was cut and discarded, and 1-mm slices of superficial and deep dentin were marked and kept humid until their assessment with the push-out test. Each slice was measured using a Sylvae Ultra-Call II digital caliper (Mitutoyo, Japan) with 0.01-mm sensitivity. The apical and coronal diameter of each slice was also measured to estimate the adhesive surface.

Push-Out Technique

To assess the bond strength of restorations to the lateral walls of the occlusive cavity, the specimens were placed within a centralizing ring to ensure a centered application of the load, resting on another ring, with a central hole slightly larger than the restoration diameter. The load was applied on the apical surface of each slice in an apical-coronal direction using a 3-mm diameter punch tip, which passed through a guide cylinder to ensure a centered load application. The test was performed with an ELECTROTEST 500 machine (SAE-Ibertest, Madrid, Spain) at a crossbeam speed of 1 mm/minute until bond failure occurred. In the push-out technique, shear bond strength (MPa) was computed from the maximum load $F_{Push\text{-}Out}$ (dN) recorded by the machine and the area (mm^2) of bond interface (transversal surface of the cylinder):

$$\sigma_B \equiv \frac{F_{Push\text{-}Out}}{2\,\pi r h}$$

where σ_B is shear bond strength, h is disc thickness (mm) and r is restoration radius (mm).

Fractured slices were carefully removed and observed under an Olympus stereoscopic microscope (Olympus Optical España, Barcelona, Spain) at 20x to categorize the type of failure as follows:

Type 1: Adhesive failure between resin composite and dentin.

Type 2: Cohesive resin fracture.

Type 3: Mixed fracture: presence of fragments of dental tissue or resin composite adhered to the interface.

Type 4: Cohesive dentin fracture.

Scanning Electron Microscopy

Two additional teeth were prepared per group, maintaining simulated pulpal pressure for observation under a scanning electron microscope (SEM) (Figure 3). The additional teeth were cut longitudinally along the center of the cavity using an Acutton 50 cutting machine (Struers A/S, Ballerup, Denmark) to obtain two contralateral halves. One half was used for the interface morphological study and the other for tag density assessment. The surfaces were polished for the morphological study at 500, 1200 and 4000 grit (Exakt, Apparatebau D-2000, Norderstedt, Germany) and were etched with 37% phosphoric acid for 15 seconds. They were then washed and rinsed; next, the surfaces were deproteinized with 2% sodium hypochlorite for 120 seconds, carefully washed and dehydrated in ascending grades of ethanol.[14] They were then sputter-coated with gold/palladium for four minutes at 10 mA in a Polaron E-5000 unit (Polaron Equipment, Watford, UK). For assessment of tag density and presence, the other halves of the specimens were immersed in 30% HCl for 24 hours to completely dissolve the tooth, then immersed in 2% sodium hypochlorite for 10 minutes. The specimens were observed under a Zeiss DSM 950 (Carl Zeiss, Jena, Germany) field emission scanning electron microscope.

Statistical Analysis

One-way ANOVA was performed, followed by the post-hoc Scheffe test, in order to establish the relationship between shear bond strength (MPa) and cavity restoration technique, globally and at a superficial and deep level of the cavity wall. Differences among the groups were considered significant at $p<0.05$. The SPSS SN 9008108 statistical package (ISCS-SUL–Lisbon) was used for the data analysis.

Table 2

Groups	Adhesives	Sup Dentin (X ± DS) Mpa	Deep Dentin (X ± DS) Mpa	Total (X ± DS) Mpa
I. Incremental technique	AdheSE	16.3 (2.9) (a,c) (1)	15.9 (2.2) (a) (1)	16.1 (2.5) (a,c)
II. Flowable composite	AdheSE	13.4 (3.4) (a,b) (1)	15.2 (2.1) (a) (1)	14.4 (2.9) (a)
III. Bulk technique	AdheSE	9.6 (3.2) (b) (1)	10.1 (3.2) (b) (1)	9.9 (3.1) (b)
IV. Light cone technique	AdheSE	9.2 (2.3) (b) (1)	10.7 (3.1) (b) (1)	10.0 (2.7) (b)
V. Incremental technique	Single Bond	18.5 (2.2) (c) (1)	16.3 (2.0) (a) (2)	17.4 (2.3) (c)

ANOVA: same letters vertically indicate no statistically significant difference (p>0.05; Scheffe); same numbers horizontally indicate no statistically significant difference (p>0.05; Scheffe)

RESULTS

Table 2 shows the mean adhesive resistance values for each experimental group (overall and in superficial and deep dentin) and the results of the comparison among the groups and cavity levels (superficial/deep) by means of one-way ANOVA and *post-hoc* comparisons. The highest bond strength to the lateral cavity walls was obtained using the incremental technique, regardless of the adhesive employed (Group 1 and 5), although absolute values were higher when total-etch adhesive was used (Single Bond). When a flowable composite was placed as the liner, the results did not significantly differ from those obtained with the incremental self-adhesive technique (Group 1) (p=0.534), although they were inferior to those obtained with the total-etch adhesive (p=0.038). The worst outcomes were obtained when using the bulk (Group 3) or light cone (Group 4) techniques.

Analysis of regional bond strengths showed that all techniques obtained similar results in superficial dentin compared to those obtained overall. The highest bond strength was obtained with the incremental technique, regardless of the adhesive used, although the values obtained with the self-etching adhesive were slightly lower. In deep dentin, the highest bond strength was again obtained with the incremental technique, regardless of the adhesive used (Group 1 and 5). The lowest bond strengths to both superficial and deep dentin were obtained with the bulk and light cone techniques.

A comparison of bond strength values between superficial and deep dentin only showed a significant difference when total-etch adhesive was used (p=0.031), and no significant regional differences were observed among the remainder of the groups in which a self-etching adhesive was used. Although lower absolute bond strength values were recorded in deep versus superficial dentin in Group 1 and in superficial versus deep dentin in Groups 2, 3 and 4, these differences did not reach statistical difference.

Failure Type

Table 3 shows the % of failure type in each experimental group. No cohesive dentin fractures were observed in any group. In Group 1, interface adhesive fracture predominated (75%). In Groups 3, 4 and 5 (Control), around 50% were adhesive and 50% were cohesive resin fractures. In Group 2, 47% were adhesive failures, 30% cohesive resin fractures and 23% mixed fractures. Globally, the most frequent failure type was adhesive fracture in both superficial and deep dentin. Group 3, alone, showed a predominance of cohesive resin composite fracture in deep dentin. In Groups 4 and 5, around 50% of adhesive and cohesive resin composite fractures were in both superficial and deep dentin.

Scanning Electron Microscopy

Interface morphology showed differences in relation to adhesive type (self- or total-etch) but not in relation to the composite insertion technique applied (Figure 3). In

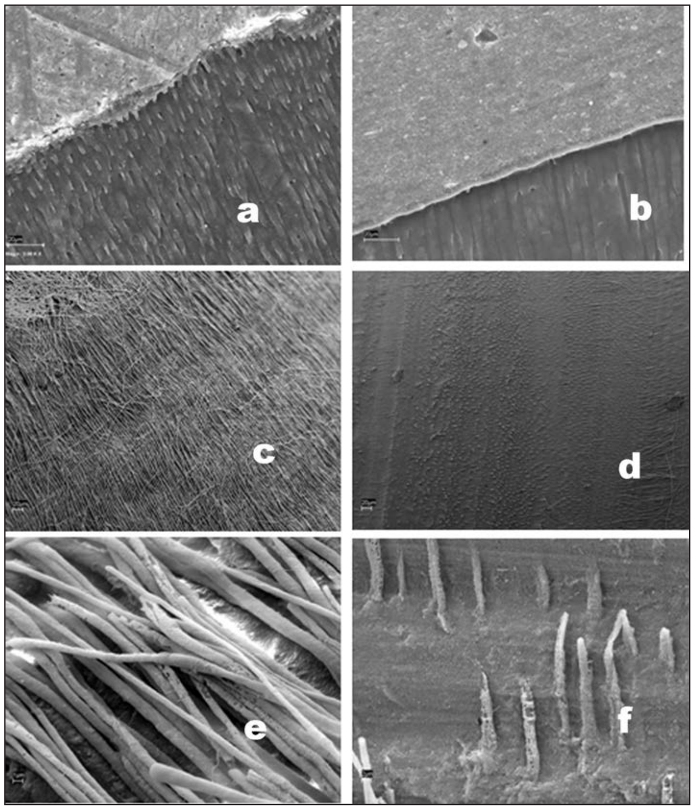

Figure 3: *Total-etch (Single Bond) obtained a uniform hybrid layer with numerous long tags and conical swelling (a). Self-etch adhesive obtained a thin hybrid layer with scarce tags (b). Total-etch adhesive obtained numerous parallel long tags in all areas (c). In the AdheSE group, most areas show no tags, and there are areas with scarce and short tags (d). High-magnification SEM images show that all tags were porous and hollow with both total-etch (d) and self-etching (f) adhesives. Photographs a, b, c and d: bar = 20 μm; photograph e: bar = 1 μm; photograph f: bar = 2 μm.*

Table 3: *Percentage Failure Type*

Groups	Adhesives	Adhesive	Cohesive Resin	Mixed	Cohesive Dentin
I. Incremental technique	AdheSE	75%	25%	-	-
II. Flowable composite	AdheSE	47%	30%	23%	-
III. Bulk technique	AdheSE	47%	53%	-	-
IV. Light cone technique	AdheSE	50%	50%	-	-
V. Incremental technique	Single Bond	45%	50%	5%	-

a bonding system with phosphoric acid pre-etch (total-etch), the interface showed a uniform hybrid layer, with numerous long tags and conical swelling at the base. In the self-etch adhesive groups, the hybrid layer was finer, with fewer and sometimes thinner tags and numerous empty tubules.

When self-etch (AdheSE) was used, an irregular distribution was observed in the tag assessment, which showed areas with scarce and short tags and areas with more numerous and long tags. The total-etch adhesive (control) group presented numerous long tags in parallel in all areas, with a frequent presence of anastomosis between tags. In all groups, arrangement of the tubules influenced the direction of the tags, which was perpendicular to the cavity floor and oblique to the obturation floor on the lateral walls. Both self-etching and total-etch adhesive tags appeared hollow and porous under high magnification.

DISCUSSION

The polymerization reaction of light cured resin composites leads to the development of higher stress when the resin composite is bonded to the cavity walls.[15] The magnitude of this phenomenon depends on the shape of the cavity.[15-16] A high C-factor produces greater contraction stress by limiting the flow capacity of the resin composite.[15-16] Bouillaguet and others[7] demonstrated 20% lower bond strength values in cavities with C-factor influence compared with the traditional flat-bonding surfaces that are usually evaluated with the microtensile bond test. Studies on flat dentin surfaces are removed from clinical reality, since they do not take into account the stress generated in 3-D cavities, which leads to an overestimation of outcomes.[15] The current study was carried out in Class I occlusal cavities with a C factor of 5-6, similar to those routinely observed in the clinical setting.

The microtensile bond test is the most widely used method to study the influence of C-factor on adhesion. A high incidence of premature debonding has been reported during specimen sectioning, preparation and beam manipulation.[17] Premature debonding before testing was reported to be more frequent in cavities with a higher C-factor.[4,9] In the case of a weak adhesive, it was suggested that beams that do not fail may not represent the true bond strength of these adhesives. Furthermore, it is common for the same specimen to show premature debonding and shear bond strength values as high as 50 MPa,[4] with large variations (high standard deviations) in these values.[7] These discrepancies are difficult to explain but do not occur with use of the push-out technique, which avoids premature failure.

Push-out test methodology involves extrusion of material from dentin, and it appears to be especially suitable for studying the adhesive interface. The main advantage of the push-out test is that uniform shear stress can be applied to the tooth-material interface without the presence of a tensile component.[18] The push-out test has been reported to be more efficient and dependable than both the trimming and non-trimming versions of the microtensile technique; it also provides a realistic measurement of low bond strength levels.[19] The current study used a micro push-out type test, in which the size of the specimens was reduced (1 mm) to obtain a more uniform stress distribution, reducing the friction component; moreover, superficial and deep dentin bonding sites can be differentiated in a single tooth.[19] With the shear bond technique, the stress is not uniformly distributed on the adhesive interface.[20]

A system of alignment, as used in the methodology of this study, is very important in push-out tests, to ensure that the sheer force is concentrated on the adhesive interface. If the force is not perfectly centered, there may be greater friction on the part of the dentin wall, modifying the result.

This test has been widely used for intracanal post adhesion but has only been applied by Wakefield and others[18] and Cheylan and others[21] in coronal dentin adhesion studies. Nevertheless, the approach of these authors did not fully correspond to clinical reality, since the cavities were made in dentin slices that had been previously cut. In contrast, the authors of the current study cut cavities into the crown using low speed diamond drills and obturated them before slices were obtained. Thus, influence of the C-factor was similar to that in the clinical setting. Tests performed under clinically relevant conditions may more reliably predict the behavior of restorations in the oral environment.[21]

As also reported by Wakefield and others,[18] bond strength to superficial dentin was significantly greater than to deep dentin when total-etch adhesive was applied. However, no significant differences in bond strength to superficial versus deep dentin were observed with the use of self-etching adhesives. Smear layer thickness is an important factor in the performance of self-etching primer adhesive systems, due to incorporation of the residual smear layer into the primer-adhesive complex and hybrid layer. In the current study, the smear layer was produced with diamond burs, which are routinely used in daily dental practice. Ogata and others[22] reported that dentin surfaces prepared with diamond burs were more acid-resistant than those prepared with Si_2O abrasive paper and that tubules remained occluded with grinding debris.

SEM images showed that self-etching adhesives do not completely remove the smear layer or achieve direct exposure of the dentin, which may explain the non-influence of regional histological differences, as also found with total-etch adhesives. In agreement with the findings of Kenshima and others,[23] who observed incomplete resin monomer infiltration when applying AdheSE to a thick smear layer, only total-etch adhesives produced tags in high density and with uniform distribution, regardless of the smear layer thickness. AdheSE has a high pH of 1.7, but Grégoire and Millas[24] reported that the pH did not determine the action of the self-etching adhesives and that AdheSE produced thick, uniform, hybridized, complex and numerous thick tags. These observations differ from the results of the current study and may be explained by the fact that they obtained a fine smear layer with a rotating diamond-impregnated copper disk under water spray; whereas, the smear layer was obtained with a low-speed thick diamond drill in the current investigation. Selection of the proper bur type for cutting dentin is important for improving the bond strength of some self-etching adhesive systems.[25]

Several researchers have sought to develop techniques and materials that overcome the undesirable curing effects of composites.[8,17,26-27] Most authors have associated the obturation technique used with bond strength to the cavity floor.[8,17,27] It would be interesting to determine whether these results can be extrapolated to lateral walls, since an adequate bond is required at this interface to avoid deterioration from cyclic fatigue. Regardless of the adhesive type used (Single Bond versus AdheSE), the highest bond strength to lateral walls was achieved with the incremental technique, since an incremental filling ensures a uniform, maximum polymerization of the resin composite[28] and the total photocuring time is longer. This finding agrees with the conclusions of Nikolaenko and others,[4] that an appropriate layering technique is the most promising method to obtain a good bond to cavity walls. However, He and others[27] pointed out that the incremental technique is only superior in large cavities, since no significant difference was found between bulk and incremental filling techniques in small cavities.

Shear bond strength values were similar between Groups 2 (flowable composite) and 1 (incremental technique with self-etch adhesive) but lower than when total-etch adhesive was applied. The low stiffness of flowable composites might compensate for the polymerization contraction of restorative composites with a high modulus of elasticity. The liner may act as a buffer for the stress produced by contraction of the resin under polymerization, thereby reducing stress at the resin-dentin interface.[12] The use of flowable composites improved adhesion to deep dentin, possibly because its presence on the cavity floor reduced stress in deeper parts of the lateral walls, increasing bond strength in deep but not superficial dentin.

The bulk-filling and light cone techniques achieved significantly lower bond strength values compared with the other methods studied. The bulk technique causes major stress in Class I cavities when the resin composite is light cured,[12] and there is a low degree of conversion deep within the restoration. In a deep cavity, attenuation of light intensity by the composite prevents complete polymerization of the bottom surface.[4,8,27,29] It has been hypothesized that insertion of a light cone can displace the filling material towards the walls, increasing the free surface area of the composite. This would facilitate the release of contraction stress by deformation of this surface,[26] and resin composite cured by this method has shown significantly greater hardness.[30] In the current study, application of a transparent cone appeared to have no positive effect on adhesion to lateral walls, and the same bond strength values were observed as with the bulk technique.

The null hypothesis of this study must be rejected, since the different filling techniques used to decrease stress generated in Class I cavities obtained different bond strength values, although the technique used did not affect bond strength to superficial or deep dentin when self-etching adhesive was used.

CONCLUSIONS

Within the limitations of the study, the authors can conclude:

1. The highest bond strength to lateral cavity walls was obtained using the incremental technique, regardless of the adhesive employed (total-etch or self-etch).
2. When total-etch adhesive was applied, bond strength was significantly greater to superficial dentin than to deep dentin.

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