Marginal adaptation and microtensile bond strength of composite indirect restorations bonded to dentin treated with adhesive and low-viscosity composite

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ABSTRACT

Objectives. This study evaluated the marginal adaptation of composite indirect restorations bonded with dual curing resin cement after different strategies to seal dentin. Different bonding techniques associated or not with a low-viscosity composite resin (LVCR) were utilized. In addition, the bond strength between composite resin and pre-sealed dentin was evaluated in the buccal and pulpal walls of class I cavities, prepared for indirect restorations.

Methods. Thirty-three freshly extracted human molars were used for this study, divided into three groups (n=11) representing different techniques to seal dentin—(Group 1) Conventional technique: the adhesive system was applied and polymerized just before the cementation of the indirect restoration; (Group 2) Dual bonding technique: a first layer of the adhesive system was applied and polymerized just after preparation, and a second layer just before the final cementation; (Group 3) Resin coating technique: a LVCR was applied and polymerized after the first layer of the adhesive system, and before the impression. A further application of the adhesive system was performed before the placement of the restoration. The restorations were polished and a solution of acid red propylene–glycol was dropped on each specimen’s occlusal surface for 10 s. The dye penetrations were captured under stereoscopic lens and the images were transferred to a computer with a measurement program, in order to determine the extension of the dye penetration. The microtensile bond strength test (μTBS) was applied on pulpal (P) and buccal (B) walls of the restorations for Groups 1–3. The subgroups for μTBS were: Group 1P (n=13); Group 1B (n=7); Group 2P (n=6); Group 2B (n=14); Group 3P (n=14); Group 3B (n=15). All specimens were sectioned to obtain an area of 0.8 mm². The specimens were mounted on a microtensile device and fractured using a universal testing machine at a cross-head speed of 1 mm/min. Failure modes were analyzed by SEM. One-way ANOVA and multiple-comparison Tukey’s test were used for statistical analysis of the marginal adaptation scores and μTBS test. Non-parametrical Kruskal–Wallis test was used for failure mode analysis.

Results. Group 3 showed a significantly higher mean value of marginal dye penetration (45.59) when compared to Groups 1 (8.44) and 2 (18.92). For pulpal walls, Group 1P showed significantly higher mean μTBS (25.93 ± 2.27) when compared to Groups 2P (14.71 ± 1.78) and 3P (16.07 ± 2.81). There was no statistical difference between Groups 2P and 3P for buccal walls.

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1. Introduction

The modern concepts of direct or indirect restorative dentistry have tried to acquire in esthetic restorative materials, techniques to recover biomechanically teeth that have lost part of their structure due to caries or trauma. Composite resin has been the material of choice for this function, based on the similarity of its elastic modulus with the dental structures, and due to its high potential to bond to enamel and dentin [1].

These characteristics of composite resin, when associated with adhesive systems, have created technical alternatives that have increased the utilization of esthetic restorations. The improvements in inorganic filler (amount, type and average size), and the molecular weight of monomers that compose the organic phase, have made modern composite resins easier to manipulate and apply. However, these materials still present problems related to marginal integrity and leakage, mostly due to their inherent polymerization shrinkage [2–5].

Generally, composite resins are applied by the direct technique, in placement of restorations in anterior and posterior teeth. In the polymerization process, the chemical reaction that occurs in the organic phase of the composite produces the conversion of monomers into polymers, resulting in a molecular forthcoming with the consequent shrinkage [1]. The extent of this shrinkage influences the tension state generated at the interface composite/dental structure and, commonly, compromises the bond integrity at this region. In addition, the polymerization shrinkage of composites is also influenced by the geometric form of the cavity. When the ratio between the bounded to unbounded surfaces is higher than two, the stress generated by the composite shrinkage may exceed the bond strength to the cavity walls and produce marginal gaps [6]. When these problems are added to an incorrect placement technique and finishing mistakes, marginal leakage, inadequate anatomic form and proximal contacts occur clinically, which lead to a consequent reduction in the longevity of the restoration [7,8].

At the beginning of the 1990s, indirect composite restorations were shown to present improved clinical conditions with respect to proximal contact, occlusal anatomy and marginal adaptation [9,10]. In these cases, all technical procedures of manufacturing and polymerizing of the restorations were performed externally and just a thin layer of a high flow composite resin (so-called resin cement) was used to lute the restorations [11]. It is important to highlight, however, that during the polymerization of the resin cements, tensions could arise, causing a disruption between the restoration and the cavity walls, leading to marginal leakage, mainly if the margins are located in dentin [12–17]. Thus, marginal integrity is directly related to the bond strength between the dentin surface and the adhesive system/resin cement indicated for luting indirect restorations [18,19].

Tooth preparation for indirect restorations can induce significant dentin exposures and, consequently, sensitivity. The conventional technique for indirect restorations consists in molding the cavity immediately after preparation and protecting temporarily the teeth for the patient’s functional and esthetic needs. Then, after the fabrication of the indirect restoration, the provisional cement is removed and the adhesive/luting procedures are performed. It is important to emphasize that freshly cut dentin has been demonstrated to be the ideal substrate for bonding, therefore, dentin contamination due to provisional cements could reduce the potential for dentin bonding, leading to lower bond strength, failure in the hybridization process and post-operative sensitivity [20–22]. Alternative techniques have been suggested to overcome these problems; it has been reported that it is possible to considerably augment bond strength values when the dentin surface is sealed with an adhesive system, prior to molding procedures and after the application of temporary materials, and when a new layer of adhesive is applied at the moment of the final luting of the restoration, the so-called “dual bonding” or “immediate dentin sealing” technique [20,21,23]. The reasons supporting this technique are the increase in bond strength over time, since dentin bond can develop without stress, resulting in improved adaptation [24,25], and the protection of dentin against bacterial leakage and sensitivity during provisionalization and after final luting [26].

The application of a LVCR on the adhesive layer has also been suggested immediately after cavity preparation [27]. This technical procedure seems to reduce gap formation at the interface dentin/resin cement [28,29], and improve bond strength. Moreover, it could serve as a resilient layer between the restorative composite resin and dentin, absorbing the tensions generated by the polymerization shrinkage of the resin cement and mastication efforts [5,25,30].

Thus, the aim of the present investigation was to evaluate the marginal adaptation of indirect composite resin restorations luted with resin cement, after sealing dentin with an adhesive system associated, or not, with LVCR. Additionally, the study aimed to evaluate the bond strength between composite resin and pre-sealed dentin, in buccal and pulpal walls of Class I cavities, configured for indirect restorations.
2. Materials and methods

The materials, manufacturers, compositions and batch numbers for this study are listed in Table 1.

2.1. Marginal adaptation test

Thirty-three freshly extracted caries-free human molars, stored in distilled water at 4°C, were used for the marginal adaptation test. The teeth roots were embedded in plastic cylinders with acrylic resin, leaving the crown totally exposed and projected beyond the cylinder’s edge. The teeth were ground on their occlusal surfaces with a water-irrigated grinding wheel using 320-grit silicone carbide (SiC) paper to obtain flat dentin surfaces and then finished with 600-grit SiC. Standardized cavities with margins totally located in dentin (4 ± 1 mm diameter and 2.5 ± 0.5 mm deep) lightly expulsive to occlusal were made using diamond burs, nos. 30006–31-131 025 and 843KB 31 055, and finished with steel multi-laminated burs, H339-014 (Brasseler, Savannah, GA, USA). The teeth were then ultrasonically cleaned for 10 min.

The teeth were randomly divided into three groups of eleven specimens each. For Group 1, the cavities were immediately molded with a polyvinyl siloxane material (Express—3M/ESPE, Dental Products Division, St. Paul, MN, USA), using a twin-mix technique. The molds were poured with a type IV dental stone (Vel-Mix—Kerr Co., Orange, CA, USA). After mold-setting, the cavity walls sealed, the molding/pouring processes were immediately commenced with oil-free compressed air from a syringe for 5 s, keeping the tip 2 cm from the surface and light cured for 10 s. With the tip 2 cm from the surface and light cured for 10 s. With the cavity walls sealed, the molding/pouring processes were the same as for Group 1. The teeth were stored in distilled water at 4°C. All light-curing procedures used a 3M XL 3000 curing unit (3M Dental Products Division, St. Paul, MN, USA) curing unit Targis Power Curing Unit (Ivoclar/Vivadent, Schaan, Liechtenstein) for 10 s each layer. All the restorations were then submitted to the Targis Power Curing Unit (Ivoclar/Vivadent, Schaan, Liechtenstein), which combines a light and heat polymerization for 20 min, according to the manufacturer’s instructions. The restorations were luted in the respective cavities using resin cement Rely X ARC (RX) associated to SB. For Group 1, SB was then applied on cavity surface, as previously described for Group 2, just before the luting of the restoration. Then, equal portions of RX were mixed during 20 s and applied in internal cavity walls and the restoration was positioned and adapted to the cavity, kept under a pressure of 500 g for 10 min. Additionally, the cavity margins were light-cured for 40 s from three directions. No excess of RX was removed during this step.

For Groups 2 and 3, 35% phosphoric acid and SB were also applied on the pre-sealed cavities, as previously described, before luting the restorations with RX as described for Group 1. The specimens were stored for 24 h in distilled water at 37°C, finished with 320, 400, 600 and 1000-grit SiC under water and ultrasonically cleaned for 10 min between the grits. The specimens were then thermocycled at 5–55°C for 1200 cycles, lasting 30 s at each temperature. On each restoration surface a solution of propylene-glycol and acid red 52 (Caries Detector, Kuraray Co., Tokyo, Japan), used for caries detection, was applied for 10 s, rinsed with running water and dried with tissue paper. Each restoration was positioned in a Leica MZ6 stereomicroscope (Switzerland) in which the image of the restoration was captured and transferred to a computer equipped with the image program Pro-Plus 4.1 (Media Cybernetic, Silver Springs, MD, USA) where the marginal adaptation of the restorations was evaluated [31].

Table 1 – Materials used in this study

<table>
<thead>
<tr>
<th>Materials used in this study</th>
<th>Composition</th>
<th>Batch</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targis Dentin-220</td>
<td>Bis-GMA, UDMA, Copolymer of Bis-GMA, Barium glass, colloidal silica</td>
<td>D90938</td>
<td>Ivoclar/Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>Rely X ARC</td>
<td>Paste A: Bis-GMA, TEGDMA, Zirconia/silica filler, photoinitiators, Amine, pigments; paste B: Bis-GMA, TEGDMA, barium peroxide, zirconia/silica filler</td>
<td>CACA</td>
<td>3M Dental Products Division, St. Paul, MN, USA</td>
</tr>
<tr>
<td>Single Bond</td>
<td>HEMA, Bis-GMA, dimethacrylates, Ethanol, water, polyalkenoic acid, copolymer, initiator</td>
<td>1FM</td>
<td>3M Dental Products Division, St. Paul, MN, USA</td>
</tr>
<tr>
<td>Protect Liner F</td>
<td>Bis-GMA, TEGDMA, fluoride-methyl methacrylate, camphorquinone, silanized colloidal silica, pre-polymerized organic filler</td>
<td>K100</td>
<td>Kuraray Co. Ltd., Osaka, Japan</td>
</tr>
</tbody>
</table>
The dye penetration in the margins of each restoration was calculated as a percentage of the cavity perimeter for each specimen (Fig. 1).

The results were subjected to one-way analysis of variance ANOVA ($p < 0.05$) and Tukey’s test ($\alpha = 0.05$).

### 2.2. Microtensile bond testing

The same specimens used in the marginal adaptation test were used for the $\mu$TBS test. The occlusal surface of each specimen was acid-etched, followed by application of SB and 4 mm layer of composite resin (Z100—3M/ESPE, Dental Products Division, St. Paul, MN, USA), in increments of 2 mm each. The specimens were then sectioned perpendicular to the pulpal wall with the Isomet low speed wheel saw under water, in order to obtain slabs of approximately 0.8 mm thick (Fig. 2).

To obtain slabs of buccal region, a 4 mm layer of composite resin Z100 was placed as previously described on the buccal enamel. The lingual half of the specimen was removed, and the internal exposed surface of the indirect restoration received a 4 mm layer of composite resin Z100 (Fig. 3).

Another 15 teeth were prepared, restored and submitted to the same experimental conditions, in order to obtain at least 10 sections to the microtensile bond test, specific for each group and region. Each slab was individually secured with sticky wax and further sectioned into an approximately 0.8 mm$^2$ slice in its narrowest part, located at the interface SB-dentin or SB/LVCR-dentin.

The slabs to be tested were fixed to a modified Bencor—Multi t-testing assembly using cyanoacrylate adhesive. The specimens were pulled to failure under tension using a universal testing machine (Model 4411, Instron Inc., Canton, MA, USA) at a crosshead speed of 1 mm/min.

After testing, $\mu$TBS values were recorded, the halves of the fractured specimens were paired, positioned in aluminum stubs and gold-sputter coated with gold/palladium, and observed by SEM (JEOL, JSM-5600VP, scanning electron microscope, Japan) for evaluation of the fracture pattern.

During the removal from the testing machine, some specimens fractured in fragments, making analysis of these specimens impossible. Thus, the number of specimens analyzed for each group and region are described with the results in Table 4.

Fracture modes were classified into one of three types:

- **Type 1 (cohesive failure in hybrid layer).** When the fracture occurred within or at the base of the hybrid layer.
- **Type 2 (cohesive in composite resin).** When the fracture occurred within the composite resin, either for fixation or LVCR.
- **Type 3 (mixed).** When both types of fracture were present within the same specimen, in approximately 50% of the area.

The results of SEM-analysis were subjected to non-parametrical multiple comparison Kruskal-Wallis test ($p < 0.05$).

### 3. Results

#### 3.1. Marginal adaptation

Table 2 summarizes the results for marginal adaptation. Group 3 showed the highest average values (43.59%) for dye penetration at the cavity margins, which were statistically different ($p < 0.05$) from Groups 1 (8.44%) and 2 (18.92%). There was no significant difference between Groups 1 and 2.
Table 2 – Mean values (%) for dye penetrations at the cavity margins

<table>
<thead>
<tr>
<th>Group</th>
<th>Repetitions</th>
<th>Mean valuesa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: one layer adhesive</td>
<td>11</td>
<td>8.44 b</td>
</tr>
<tr>
<td>Group 2: two layers adhesive</td>
<td>11</td>
<td>18.92 b</td>
</tr>
<tr>
<td>Group 3: adhesive/LVCR/adhesive</td>
<td>11</td>
<td>43.59 a</td>
</tr>
</tbody>
</table>

* Same letters indicate no statistical difference \((p < 0.05)\).

3.2. Microtensile bond testing

Table 3 summarizes the \(\mu\)TBS values and standard deviations for all groups. The mean values ranged from 25.92 ± 2.27 MPa for Group 1P to 11.37 ± 1.14 MPa for Group 1B.

For pulpal wall, the values of \(\mu\)TBS were higher and statistically different for Group 1P (25.92 ± 2.27 MPa), where SB was applied just before the luting of the restoration, when compared to Groups 2P (14.71 ± 1.78 MPa) and 3P (16.07 ± 2.81 MPa), where dentin was pre-sealed, which were not significantly different to each other. For buccal wall, the highest values were presented by Group 2B (23.29 ± 1.42 MPa), which were statistically different to those of Groups 1B (11.37 ± 1.14 MPa) and 3B (17.54 ± 2.20 MPa). A statistical difference between Groups 1B and 3B was observed.

When pulpal and buccal walls were compared for \(\mu\)TBS values, a higher mean value for pulpal wall was observed in Group 1, which was statistically different to that of the buccal wall. The converse was observed for Group 2, where the mean value for the buccal wall was higher and statistically different to that of the pulpal wall. For Group 3 the mean values for the pulpal and buccal walls did not differ statistically.

Table 3 – Microtensile bond strength at buccal and pulpal walls (MPa)

<table>
<thead>
<tr>
<th>Group</th>
<th>Buccal</th>
<th>Pulpala</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: one layer adhesive</td>
<td>25.92 (2.27) bA</td>
<td>11.37 (1.14) cB</td>
</tr>
<tr>
<td>Group 2: two layers adhesive</td>
<td>14.71 (1.78) bB</td>
<td>23.29 (1.42) aA</td>
</tr>
<tr>
<td>Group 3: adhesive/LVCR/adhesive</td>
<td>16.07 (2.81) bA</td>
<td>17.54 (2.20) bA</td>
</tr>
</tbody>
</table>

* Mean values (SD). Same letters in uppercase indicate no statistical difference on columns, and in lowercase indicate no statistical difference on lines \((p < 0.05)\).

3.3. Fracture mode

Fracture pattern observations showed considerable variation among the groups. These results are summarized in Table 4.

The use of one SB layer in the pulpal wall, Group 1P, resulted in a prevalence of Type 1 failure \((n = 9)\), cohesive in hybrid layer, with a significant difference for Group 2P \((n = 1)\) and Group 2B \((n = 4)\), where two layers of SB were applied, and also for Group 3B \((n = 0)\), where the LVCR was applied. There was no statistical difference among the other groups. Type 2 failure, cohesive in composite resin, was remarkably prevalent for Group 3B \((n = 11)\), where Protect Liner F was applied.

4. Discussion

The critical moment for the restorative technique, associating composite resin and adhesive systems, is the application and polymerization of the adhesive layer and the stress generated by the shrinkage of the first increment of composite resin, placed on the adhesive surface, using either a direct or an indirect technique [25]. In indirect restorations, the stress produced by the composite resin used for luting, the so-called resin cements, may disrupt the hybrid layer and open microscopic spaces that could induce post-operative sensitivity [18,32]. The incorporation of an adhesive layer to seal dentin prior to molding and temporary luting, followed by another adhesive layer application at the moment of the final luting of the restoration, has been demonstrated to reduce marginal leakage, to improve the dentin-adhesive-composite resin bond strength values and also to be effective in reducing the post-operative sensitivity [20,21].

This study employed an adhesive layer (Group 2) and a low elastic modulus LVCR placed on the adhesive layer (Group 3), using the technical procedure of sealing dentin prior to the final luting of the indirect restoration, before the molding procedures. This method was used to evaluate the effect of the internal cavity walls on bond strength, and was compared with the conventional technique for luting an indirect restoration (Group 1).

The evaluation of the results for marginal adaptation showed a higher dye penetration in margins of Group 3 restorations, which were statistically significant when compared to Groups 1 and 2 (Table 2). Possibly, the presence of four different materials composing the bonded interface at the cave-surface margin provoked higher irregularity on the
Table 4 – Failure modes: same letters indicate no statistical difference

<table>
<thead>
<tr>
<th>Groupsa</th>
<th>Type Ib</th>
<th>Type IIc</th>
<th>Type IIId</th>
<th>Specimens</th>
<th>Kruskal-Wallis p&lt; 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1P</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>13</td>
<td>B</td>
</tr>
<tr>
<td>G2P</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>A</td>
</tr>
<tr>
<td>G3P</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>14</td>
<td>AB</td>
</tr>
<tr>
<td>G1B</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>AB</td>
</tr>
<tr>
<td>G2B</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>A</td>
</tr>
<tr>
<td>G3B</td>
<td>0</td>
<td>11</td>
<td>4</td>
<td>15</td>
<td>A</td>
</tr>
</tbody>
</table>

a P: pulpal wall; B: buccal wall.
b Type I: cohesive in hybrid layer.
c Type II: cohesive in composite resin.
d Type III: mixed.

For this technique, dentin was acid-etched, followed by the application of the adhesive and LVCR prior to molding procedures. For the luting procedures of the restoration another layer of the adhesive was applied and followed by the resin cement. This sequence of different materials thickened the bonded interface and resulted in more irregularities at the cavo-surface region enabling a higher dye impregnation.

Conversely, the SEM analysis of fractured specimens of Group 3 showed a prevalence of Type 1 fracture (n=8), cohesive within the hybrid layer, for the pulpal wall (G3P) and Type 2 fracture (n=11), cohesive in composite resin, for the buccal wall (G3B). Although not statistically significant (Table 4), it may be speculated that an improved conversion of the adhesive monomers inside the demineralized dentin, guided the fracture within the hybrid layer in pulpal walls (Fig. 4) and within the composite resin in buccal walls (Fig. 5). In pulpal walls, the effect of an improved polymerization of the adhesive can be observed in Fig. 4, where portions of dentin are bonded to the base of the resin tags and even after the μTRS test it is possible to visualize intact anastomoses among the resin tags. The presence of a layer of LVCR covering the thin layer of adhesive neutralized the effect of the exposition to oxygen, leading to a higher conversion of the monomers [33,34]. In addition, the orientation of the dentin tubules in buccal region provided a more mineralized area for diffusion of the adhesive monomers, in the body of the longitudinally cut dentin tubules, as is shown in Fig. 6, and as reported by Marshall et al. [35]. Thus, the area for bonding was larger and the disruption occurred cohesively in the body of low modulus LVCR.

Consistent with these characteristics in the fracture pattern, the mean values of μTRS between the two regions (pulpal and buccal) did not present any statistical difference (Table 3). Probably, the application of the adhesive and LVCR, which have low elastic modulus, is responsible for this physical-mechanical behavior due to the formation of a higher thickness resilient bonded interface, created by the sequence of materials with low elastic modulus. Thus, the LVCR Protect Liner F, a low modulus composite resin, absorbed part of the tensile stress produced by the shrinkage of the resin cement during its polymerization and the axial stress during the test. This characteristic reinforces the concept of an “elastic stress breaker along the cavity wall” [36], and the thickness of this layer reaches 200 μm. Thus, the low elastic modulus associated to the higher thickness of the layer determined the

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Fig. 4 – SEM photomicrograph (4000 ×) illustrating a Type I failure in a specimen of Group 3 pulpal wall (G3P). Note the resin tags connected by the adhesive through the anastomoses of the dentin tubules (arrows).

Fig. 5 – SEM photomicrograph (1500 ×) illustrating a Type II failure, cohesive in composite resin, prevalent in Group 3 pulpal wall (G3P). The sequence of arrows shows the interface of the fractured areas occurred between LVCR/resin cement (A), and resin cement/adhesive layer (B).
lack of statistical difference between the μTBS values of pulpal (16.07 ± 2.81 MPa) and buccal (17.54 ± 2.20) walls for Group 3.

For Group 2, dentin was sealed prior to molding and butting of the restoration with resin cement. The values for the marginal adaptation test referent to dye penetration in the margins were not statistically different between Groups 1 and 2. It is possible to conclude that the interface formed by one or two layers of adhesive and resin cement was more uniform, with fewer irregularities when compared to the restorations of Group 3. This result corroborates the study of Montes et al. [5] that used the association of an adhesive and a LVCR in Class I cavities with margins totally located in dentin, for direct restorations with composite resin.

In this study, the Class I cavity preparation was also totally in dentin, but with lateral walls lightly divergent to occlusal to enable the insertion of the indirect restoration. In this situation, the dentin tubules in lateral walls are almost parallel to the cut surface, while in pulpal wall the dentin tubules are cut perpendicular to the surface. This morphological difference in tubules' orientation was an important factor that influenced the bond strength between resin and dentin. The other factor is related to the thickness of the interface, due to the application of the LVCR on the adhesive surface. Both conditions could be evaluated in this study.

For the buccal wall, Group 2B had a statistically higher mean value of bond strength to those of Groups 1B and 3B, which were also statistically different to each other. In contrast, the pulpal wall bond strength was higher for Group 1P, and statistically different when compared to Groups 2P and 3P, which did not differ from each other (Table 3). Probably, when the adhesive was applied on lateral cavity walls, it naturally flowed towards pulpal walls, with an accumulation in the cavity deeper angles. Thus, the adhesive layer in buccal walls becomes thinner and facilitates the oxygen concentration effect on its surface, preventing its adequate polymerization, which resulted in lower bond strength for Group 1B. In pulpal walls, adhesive thickness seems to be adequate, since it resulted in high bond strength values. According to Zheng et al. [37] higher bond strength values were obtained when adhesive layer thickness ranged between 25 and 50 μm. The evaluation of the fracture pattern did not demonstrate any statistical differences and both in the pulpal and buccal walls there was a prevalence of Type 1 fractures, cohesive within the hybrid layer, as illustrated in Figs. 7 and 8. It may be speculated that the adhesive layer thickness on the pulpal wall may have ranged between 25 and 50 μm, an adequate thickness for higher bond strengths [37], but also that the penetration of the adhesive within the acid-etched dentin was incomplete, beneath the demineralize area. Thus, the most susceptible...
area for failure was located at the base of the hybrid layer, as shown in Table 4 and Figs. 7 and 8. When the second layer of adhesive or the LVCR layer was applied (Groups 2 and 3), the flow phenomena also occurred towards the pulpal wall, and the addition of successive layers resulted in a higher thickness on the pulpal wall surface, which probably compromised the bond strength in this region. On the other hand, for the buccal wall, the second layer of adhesive (Group 2) may have achieved an adequate thickness and provided a higher bond strength (Table 3). Another situation may have caused these higher bond strength values in buccal walls. The orientation of almost parallel tubules may have facilitated the adhesive penetration in peritubular dentin, creating a larger bonding area (Fig. 9), that resulted in higher bond strength for this area, corroborating Ogata et al. \[38\]. In the fracture pattern evaluation, the influence of the adhesive layer thickness could be observed. Although bond strength values were lower in the pulpal wall, the fracture pattern was not statistically different when compared to the buccal wall. There was a slight prevalence of Type 3 failure (mixed) in Group 2B, and a uniform distribution among the three fracture patterns for Group 2B.

Thus, prior sealing of dentin using adhesive, followed by another application at the moment of luting of the restoration was seen, in this study, to be an effective alternative technique with regards to marginal adaptation of indirect composite resin restorations and bond strength at the interface in buccal wall. These are, in fact, the most critical regions for the longevity of restorations. However, the structural variability due to the orientation of the dentin tubules in cavity walls, and the thickness of the adhesive layer or another low elastic modulus resinous material, are factors that determine the physical properties of the resin layer on the dentin surface.

Fig. 9 – SEM photomicrograph (2500×) illustrating a specimen of Group 2 buccal wall (G2B). Note the dentin impregnated by the adhesive. Note the structure of the tags formed by the adhesive and the irregularities due to the impression of collagen fibrils from inside the tubules (black arrows). Note also parts of etched but not hybridized dentin (white arrows). T: resin tags.

REFERENCES