Fracture Strength of Indirect Resin Composite Laminate to Teeth with Existing Restorations: An Evaluation of Conditioning Protocols

Mutlu Özcan, Ayse Mese

**Purpose:** This study evaluated the fracture strength and failure types of indirect resin-based composite laminates bonded to teeth with aged Class III composite restorations that were conditioned according to various protocols.

**Materials and Methods:** Maxillary central incisors (N = 60) with window-type preparations received laminates made of a highly-filled resin composite material (Estonia) (10 per group). On the mesial and distal side, Class III cavities (3 x 3 mm) were prepared using ultrasonic burs and filled with resin composite (Quadrant Anterior Shine). The un-restored teeth served as a control group (group 6). All restored teeth (n=50) were thermocycled (5°C to 55°C, 6000X) and subjected to one of the conditioning protocols: (1) air-particle abrasion with alumina particles coated with silica (30-μm SiO2, ColJet); (2) silanization; (3) 9.5% hydrofluoric acid (HF) for 90 s (Ultradent); (4) silanization and (4) protocol of Clearfil Repair Kit, (5) adhesive resin (Quadrant Unibond Sealer). A three-step bonding procedure and dual-polymerizing resin cement (Panavia F 2.0) were employed. The inner surfaces of the laminates were conditioned (ColJet-Sand, 30 μm SiO2) and silanized (ESPE-Sil). All specimens were stored in water at 37°C for one month prior to the fracture test.

**Results:** A significant difference was observed in fracture strength values between the groups (ANOVA, p = 0.0261). The only significant difference was between group 2 (299 ± 103 N) and group 3 (471 ± 126 N) (p = 0.0239) (Tukey's test, α = 0.05). The majority of failures were type C (35/60) (chipping of the laminate with enamel exposure), followed by type B (21/60) (cohesive failure within the composite laminate).

**Conclusion:** The fracture strengths of the laminates tested did not show significant differences, whether they were bonded to existing, aged Class III composite restorations or to intact teeth. The failure types, however, varied between the groups. The lowest strengths were obtained from the air-particle abraded (50 μm, Al2O3) and silanized group.

**Keywords:** indirect composite, fracture strength, laminates, surface conditioning.

J Adhes Dent 2009; 11: 391-397. Submitted for publication: 10.02.08; accepted for publication: 12.06.08.

With the advances in adhesive technologies, polymerization systems, and improvement in mechanical and physical properties of the resin systems, the use of resin composites have become routine practice in restorative dentistry. Unfortunately, during their service life in the oral environment, resin-based composite materials are prone to degradation, due to water absorption, softening and decomposition of the monomer matrix, filler detachment from the matrix, or microcrack formation. Clinically, this may lead to compromised esthetics due to wear, discol- oration, or loss of surface properties of the resin-based restorations, especially in the anterior region. In such situations, laminate restorations made of resin-based composite fabricated directly or indirectly, or ceramics serve as a good alternative to reestablish esthetics in a minimally invasive manner. When a laminate is indicated for a tooth that contains multiple discoloured resin restorations, with a history of several restoration cycles, the replacement of underlying pre-existing resin composite restorations first requires their removal by drilling. This may also result in the removal of sound enamel and dentin tissues. Clinical evidence indicates that failures related to adhesively bonded ceramic laminates are more frequent on existing composite restorations. These failures were mainly due to the difference in thermal expansion coefficient between ceramic and the composite. Such failures could be observed in the form of severe marginal defects and marginal discoloration at the transition between ceramic and composite restoration.
In general, adhesion between two composite layers is achieved in the presence of an oxygen-inhibited layer of unpolymerized resin. Pre-polymerized or aged resin restorations contain no or less unreacted monomers on the surface layer. Although surface conditioning methods have been proposed to facilitate composite-composite adhesion, such studies were conducted on specimens with standard geometries, ignoring the effect of enamel or dentin surrounding them. The surface conditioning protocols were not practiced on existing restorations of the tooth in question that was to receive a laminate. When a laminate is to be bonded to a tooth with existing composite restorations, clinicians are challenged with conditioning of three main substrates, namely, the resin composite, enamel, and dentin.

All three of these substrates require different adhesion protocols; therefore, variations can be expected in the fracture strength of the laminates. Furthermore, due to the possible degradation phenomena in resin-based materials, it can be hypothesized that adhesion of laminates may be impaired on aged composites as opposed to their adhesion on intact teeth. In terms of adhesive strengths of laminates, to the author’s knowledge, there is no study available which evaluated the effect of surface-conditioning methods on existing composite restorations.

The objectives of this study were thus twofold: a) to compare the fracture strength of indirect composite laminates on teeth containing differently conditioned, aged resin composites, and b) to evaluate the failure types after fracture strength testing. The null hypothesis tested was that fracture strength of laminates bonded on existing restorations would be less than those bonded on intact teeth.

MATERIALS AND METHODS

Tooth Selection
Sixty intact caries-free human maxillary central incisors of similar size stored in distilled water with 0.1% thymol solution at room temperature were selected from a pool of recently extracted teeth. To ensure that the enamel was free of crack lines, all teeth were examined under blue light transillumination. The teeth were stored in distilled water for up to 3 months until the experiments began. The enamel surfaces were cleaned and polished using water and fluoride-free paste (Prophy Paste COS; Borlänge, Sweden) with a prophylaxis brush, rinsed with water, and dried using an air syringe.

Class III Preparations and Composite Restorations
The brand names, manufacturers, chemical composition and batch numbers of the materials used in this study are listed in Table 1. In 60 specimens (groups 1 to 5), mesio- and distobuccal Class III box preparations were made at standard dimensions of 3 x 3 mm using ultrasonic burs (Sonicsys approx, size 3, Kavo; Biberach, Germany) (Fig 1). Preparation surfaces to be bonded were acid etched with 35% H₃PO₄ (Ultra-etch, Ultradent Products; South Jordan, UT, USA) for 30 s. After rinsing with water and air drying, primer (Quadrant Unibond Primer, Cavex; Haarlem, The Netherlands) and bonding agent (Quadrant Unibond Sealer, Cavex) were applied onto the labial surfaces of the teeth according to the manufacturer’s instructions. This was performed due to possible exposure of dentin. All Class III restorations were made using a microhybrid resin composite (Quadrant Anterior Shine, Cavex; shade A2) that was applied into the box incrementally. Each layer was light polymerized for 40 s (Demetron LC, SDS Kerr; Karlshruhe, Germany) at a light intensity of 500 mW/cm² and then finished using finishing burs (Swiss Dental Products, FG-2309; Grancia, Switzerland) and polished (Sof-Lex discs, 3M ESPE; St Paul, MN, USA).

All specimens (N = 60) were subjected to thermocycling (Willytec; Grafelfing, Germany) for 6000 cycles between 5°C and 55°C in distilled water. The dwell time in each bath was 30 s and the transfer time from one bath to the other was 2 s.

Laminate Preparation
Before preparation for laminates, an impression was taken of each tooth using a high-precision condensation silicone (Zhermack; Marl, Germany) in order to obtain molds for creating the laminates of the original form and shape of the teeth. In order to keep the size of the restorations standard, window-type tooth preparations without incisal overlap were made with a depth cutting bur especially designed for laminate preparations (Intensiv SA, Swiss Dental Products; batch #M-9306). After the depth cuts of 0.7 mm were made, preparation was finalized using a round-ended tapered diamond chamfer bur (Swiss Dental Products; batch #S-4180, FG-2309). The preparations ended 1 mm above the cementoenamel junction. Smooth margins were created to prevent stress concentration zones. All prepared teeth were randomly assigned to 6 experimental groups (N=60, 10 per group).
Table 1: Brand names, manufacturers, chemical composition and batch numbers of the materials used in this study

<table>
<thead>
<tr>
<th>Brand name</th>
<th>Manufacturer</th>
<th>Chemical composition</th>
<th>Batch number</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMA</td>
<td>AutoPlast, Candulor; Wangen, Switzerland</td>
<td>Polymethylmethacrylate</td>
<td>F42028</td>
</tr>
<tr>
<td>Estenia</td>
<td>Kuraray; Osaka, Japan</td>
<td>Urethane tetramethacrylate (UTMA), 92% lanthanum oxide fillers</td>
<td>00002A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluoride containing fillers, containing fillers, 75.6% w%, polymerization catalysts 0.6% w%, inorganic pigments 0.1% w%</td>
<td>00003A/00004G/00005E</td>
</tr>
<tr>
<td>Quadrant Anterior</td>
<td>Cavec; Haarlem, The Netherlands</td>
<td>Methacrylate-based monomers 23.7% w%, silica, silicate glass and fluoride containing fillers 75.6% w%, polymerization catalysts 0.6% w%, inorganic pigments 0.1% w%</td>
<td>010035C/010037C</td>
</tr>
<tr>
<td>Shine (QA)</td>
<td></td>
<td>Alumininum trioxide particles coated with silica, particles size: 30 μm</td>
<td>165092</td>
</tr>
<tr>
<td>CoJet®-Sand</td>
<td>3M ESPE; Seefeld, Germany</td>
<td>3-methacryloxypropyltrimethoxysilane, ethanol</td>
<td>152745</td>
</tr>
<tr>
<td>ESPE®-Sil</td>
<td>3M ESPE; Seefeld, Germany</td>
<td>MDP, HEMA, dimethacrylate monomer, water, photo-initiator</td>
<td>00262A</td>
</tr>
<tr>
<td>Clearfil SE Bond</td>
<td>Kuraray; Osaka, Japan</td>
<td>Bisphenol a polyethylene dimethacrylate, 3-methacryloxypropyltrimethoxysilane</td>
<td>001248</td>
</tr>
<tr>
<td>Primer</td>
<td></td>
<td>Ethanol, (2-hydroxyethyl)-methacrylate, maleic acid</td>
<td>9572</td>
</tr>
<tr>
<td>Clearfil Porcelain</td>
<td>Kuraray; Osaka, Japan</td>
<td>Poly-functional methacrylate-based monomers 2.5% w%, bis-GMA, UDMA, TEG-DMA 22% w%, barium aluminium silicate glass fillers, mean 5 lm 14% w%, barium, aluminium, silicate glass fillers, mean 0.7 μm 43% w%, porous SiO2, mean 8 μm 18% w%, polymerization catalysts 0.4% w%, inorganic pigments 0.1% w%</td>
<td>9650</td>
</tr>
<tr>
<td>Bond Activator</td>
<td></td>
<td>Poly-functional methacrylate-based monomers 2.5% w%, bis-GMA, UDMA, TEG-DMA 22% w%, barium aluminium silicate glass fillers, mean 5 lm 14% w%, barium, aluminium, silicate glass fillers, mean 0.7 μm 43% w%, porous SiO2, mean 8 μm 18% w%, polymerization catalysts 0.4% w%, inorganic pigments 0.1% w%</td>
<td>9650</td>
</tr>
<tr>
<td>Quadrant UniBond</td>
<td>Cavec; Haarlem, The Netherlands</td>
<td>Ethanol, (2-hydroxyethyl)-methacrylate, maleic acid</td>
<td>9572</td>
</tr>
<tr>
<td>Primer</td>
<td></td>
<td>Poly-functional methacrylate-based monomers 2.5% w%, bis-GMA, UDMA, TEG-DMA 22% w%, barium aluminium silicate glass fillers, mean 5 lm 14% w%, barium, aluminium, silicate glass fillers, mean 0.7 μm 43% w%, porous SiO2, mean 8 μm 18% w%, polymerization catalysts 0.4% w%, inorganic pigments 0.1% w%</td>
<td>9650</td>
</tr>
<tr>
<td>Quadrant UniBond</td>
<td>Cavec; Haarlem, The Netherlands</td>
<td>Poly-functional methacrylate-based monomers 2.5% w%, bis-GMA, UDMA, TEG-DMA 22% w%, barium aluminium silicate glass fillers, mean 5 lm 14% w%, barium, aluminium, silicate glass fillers, mean 0.7 μm 43% w%, porous SiO2, mean 8 μm 18% w%, polymerization catalysts 0.4% w%, inorganic pigments 0.1% w%</td>
<td>9650</td>
</tr>
<tr>
<td>Sealer</td>
<td></td>
<td>Poly-functional methacrylate-based monomers 2.5% w%, bis-GMA, UDMA, TEG-DMA 22% w%, barium aluminium silicate glass fillers, mean 5 lm 14% w%, barium, aluminium, silicate glass fillers, mean 0.7 μm 43% w%, porous SiO2, mean 8 μm 18% w%, polymerization catalysts 0.4% w%, inorganic pigments 0.1% w%</td>
<td>9650</td>
</tr>
<tr>
<td>Panavia F 2.0</td>
<td>Kuraray; Osaka, Japan</td>
<td>Silanated barium glass, silanated silica, surface treated sodium fluoride, bis-phenolA, polyethylene dimethacrylate, MDP, hydrophilic dimethacrylate, benzoyl peroxide, sodium aromatic sulfinate, N,N-diethanol, p-toluidine, photo-initiator</td>
<td>00168A</td>
</tr>
</tbody>
</table>

Production of Laminates

Sixty indirect laminate veneers using a highly-filled indirect composite material (Estenia, shade E1, Kuraray; Kurashiki, Japan) were prepared according to the manufacturer's instructions. Standard thickness of the laminates in the original form of the teeth was achieved using the impression molds made prior to tooth preparation. For each tooth, an individual laminate was produced. After the initial light polymerization for 40 s (Demetron LC, SDS Kerr) at a light intensity of 500 mW/cm², both light and heat polymerization was achieved at 110°C for 15 min using the polymerization unit advocated by the manufacturer (Tecnomedica; Bareggio, Italy). Excess composite around the laminate margins was removed during adjustment and the laminates were finished using finishing burs (Swiss Dental Products, FG-2309) and polished (Sof-Lex discs, 3M ESPE; St Paul, MN, USA).

Surface Conditioning Protocols

Group 1

Class III composite restorations were air-borne particle abraded using alumina particles coated with silica (CoJet-Sand, 30-μm SiO₂ particles, 3M ESPE; Seefeld, Germany) from a distance of approximately 10 mm at a pressure of 2.0 bar for about 4 s, using an Intracure air-abrasion device (Dento-PrepTM, RØNVIG; Daugaard, Denmark).

Table 2: Distribution of failure types

<table>
<thead>
<tr>
<th>Group</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>1/10</td>
<td>6/10</td>
<td>3/10</td>
</tr>
<tr>
<td>Group 2</td>
<td>2/10</td>
<td>0/10</td>
<td>8/10</td>
</tr>
<tr>
<td>Group 3</td>
<td>0/10</td>
<td>2/10</td>
<td>8/10</td>
</tr>
<tr>
<td>Group 4</td>
<td>0/10</td>
<td>6/10</td>
<td>4/10</td>
</tr>
<tr>
<td>Group 5</td>
<td>0/10</td>
<td>6/10</td>
<td>4/10</td>
</tr>
<tr>
<td>Group 6</td>
<td>1/10</td>
<td>3/10</td>
<td>6/10</td>
</tr>
<tr>
<td>Total</td>
<td>4/60</td>
<td>21/60</td>
<td>35/60</td>
</tr>
</tbody>
</table>

Type A: complete adhesive failure between the tooth and the laminate; type B: cohesive failure within the composite laminate; type C: mixed failure; chipping of the laminate with enamel exposure.
Group 2
Class III composite restorations were air-borne particle abraded using alumina particles (Korox-Sand, 50-μm Al₂O₃ particles, Bego; Bremen, Germany) using the same protocol as in group 1. Following both surface conditioning methods, the remnants of sand particles were gently blown off with air.

Group 3
9.5% HF acid gel (Ultradent Porcelain Etch, Ultradent) was applied on the Class III composite restorations for 90 s in accordance with the manufacturer’s recommendations.

After applying the conditioning protocols in groups 1-3, the surrounding enamel/dentin was acid etched with 35% H₃PO₄ (Ultra-etch) for 30 s. After rinsing with water and air drying, an MPS silane coupling agent (ESPE-Sil, 3M ESPE; Seefeld, Germany) was applied on the composite resin parts and let react for 5 min. Then the dental tissues were conditioned using a three-step bonding procedure to ensure good adherence of the resin cement in case dentin was exposed, especially at the cervical areas. Primer (Quadrant Unibond Primer) was applied with a brush for 30 s and gently air blown. Then bonding agent (Quadrant Unibond Sealer) was applied with scrubbing movements using a brush, air thinned, and light polymerized for 20 s according to the manufacturer’s instructions.

Group 4
In this group, both the Class III composite restorations and the surrounding enamel/dentin were conditioned employing the protocol of Clearfil Repair Kit (Kuraray) only. First, 40% H₃PO₄ etchant gel (K-etchant, Kuraray) was applied to the surface with a microbrush for 10 s, rinsed thoroughly with water, and air dried. One drop of primer and coupling agent (Clearfil SE Bond Primer and Clearfil Porcelain Bond Activator, Kuraray) were mixed and applied to the tooth surface and composite, left in place for 20 s, and air dried. Bonding agent (Clearfil SE Bond, Kuraray) was applied to the tooth surface and the composite with a microbrush, thinned to a uniform layer, and light polymerized for 10 s.

Group 5
Both the Class III composite restorations as well as the surrounding enamel/dentin were conditioned employing using primer (Quadrant Unibond Primer) and bonding agent (Quadrant Unibond Sealer) only according to the manufacturer’s instructions as described in group 3.

Group 6
This group received no composite restorations simulating the laminates cemented onto intact teeth.

Cementation of the Laminates
Dual polymerized resin composite cement (Panavia F2.0, Kuraray) was used for the cementation of the laminates. The inner surfaces of the laminates were conditioned with alumina particles coated with silica (CoJet-Sand, 30 μm SiO₂, 3M ESPE) using a chairside air-abrasion device (Dento-Prep; Béro, Czech Republic) from an approximate distance of 10 mm until the surface became matte, and then silanized (ESPE-Sil). Silane coupling agent was allowed to react with the surface for 5 min.

Cement was mixed by the principal investigator (MÖ) throughout the experiment. All specimens were cemented employing the ultrasonic cementation technique (Amdent; Nynäshamn, Sweden). The tip of the cementation device was held perpendicular to the surface after seating the laminate veneer on the prepared tooth surface. Excess cement was removed from the margins using an explorer followed by a microbrush. The restoration was then light polymerized (Demetron LC) for 40 s from the mesial, distal, labial, and cervical directions. Oxygen inhibition gel (Oxyguard, Kuraray) was applied around the margins of the laminates to ensure complete polymerization of the cement, and then rinsed thoroughly.

Fracture Strength Test
The teeth with the cemented laminate veneers were embedded perpendicular to the bottom of the mold in polymethylmethacrylate (Autoplast, Condular, Wangen, Switzerland) up to their cementoenamel junction in the middle of plastic rings (PVC, diameter 2 cm, height 1 cm). The specimens were stored in water at 37°C for one month prior to the fracture test that was performed in a universal testing machine (Zwick ROELL Z2.5MA, 18-1/3/7, Zwick; Ulm, Germany). In order to simulate the clinical
situation as closely as possible, the specimens were mounted to a metal base, and load was applied at 137 degrees at a crosshead speed of 1 mm/min from the incisal direction to the laminate/tooth interface (Fig 2).\(^5\) The maximum force to produce fracture was recorded.

**Failure Analysis**

Following fracture strength tests, digital photos were taken of the specimens. Using a software program (CorelDRAW 9.0, Corel; Ottawa, Canada) failure types were determined by two calibrated operators at 20X magnification. Failure types were classified as: type A: complete adhesive failure between the tooth and the laminate; type B: cohesive failure within the composite laminate; and type C: mixed failure, chipping of the laminate with enamel exposure.

**Statistical Analysis**

Statistical analysis was performed using the SAS System for Windows, release 8.02/2001 (Cary, NC, USA). The means of each group were analyzed with one-way ANOVA. P values less than 0.05 were considered to be statistically significant in all tests. Multiple comparisons were made with Tukey’s adjustment test.

**RESULTS**

A significant difference was observed in fracture strength values between the groups (ANOVA, p = 0.0261). There was only a significant difference between group 2 (299 ± 103 N) and group 3 (471 ± 126 N) (p = 0.0239) (Tukey’s test). The mean fracture strength values (in Newtons) in descending order were 471 ± 125, 416 ± 146, 363 ± 118, 352 ± 117, 339 ± 96, and 299 ± 103 for groups 3, 5, 4, 6, 1, and 2, respectively (Fig 3).

Failure types and their distribution for each group are presented in Table 2. Most of the failures in all groups were of the mixed failure type (type C), where chipping of the laminate was seen together with enamel exposure (35/60). The next most frequent failure type was B (21/60).

**DISCUSSION**

Direct or indirect laminates are restorations that improve the esthetics of the tooth by changing color, position, and form in a minimally invasive approach compared to their full-coverage crown counterparts. However, the most frequent failures associated with indirect laminate veneers are still reported to be debonding or fracture, and marginal degradation.\(^4,17\) This is an important clinical problem as it relates to the longevity of such restorations.

Different testing methods and the difficulty in measuring chewing forces result in a wide range of bite force values. The average chewing forces in the anterior region vary between 22 and 222 N.\(^2,6,8\) The results of the present study exhibited mean values in excess of these, ranging between 299 N and 471 N, indicating that composite laminates could be considered strong enough to withstand chewing forces when cemented with Panavia F 2.0 in combination with a three step etch-and-rinse adhesive system. It should also be stated that measurement of intra-oral forces is not an exact science.\(^11\) The given values can only be used as guidelines. Intra-oral forces during nonphysiological function may greatly exceed these values. On the other hand, no perfect tooth model presently exists for conducting fracture strength studies. Finite Element Analysis may be considered, but such tests to date have focused mainly on preparation techniques.\(^12,21,22\) Furthermore, they may not completely simulate the variations between the enamel and dentin factors in natural teeth. Prior to the experiments, selection of similarly sized teeth already led to elimination of a great number of teeth for this study. The size of the teeth, restoration type, preparation, and the amount of dentin or enamel left on the surface after preparation may certainly affect the results. Although it is not the most common method, in order to standardize the restorations, the window-type preparation was chosen. Other preparation types may change the results. In this study, preparations were made using standard depth cutting burs, since free-hand preparation has the distinct drawback of reducing too much or too little enamel. After preparation, a thin layer of enamel with partially exposed
islands of dentin was sometimes visible at the labial surface. For this reason, an etch-and-rinse, multiple-step dentin bonding procedure was employed during the cementation procedures.

In this study, 10-methacryloyloxydecdihydrogen-phosphate (MDP)-based cement (Panavia F 2.0) was used, since it has been previously reported to deliver the best microtensile bond strength results for the resin composite used (Estenia). The compatibility of the MDP monomer with the bis-GMA of the adhesive system requires further chemical analysis. Interestingly, the mean results obtained from group 3, where the adhesive system also contained MDP monomers, did not differ significantly from other groups, except group 2. This indicates that perhaps the preparation type was more influential than the monomer compatibility factor.

Yamaga et al. also reported that both hardness and fracture toughness of resin composites containing four-functional urethane methacrylate (UTMA) were greater than that of two-functional urethane methacrylate (UDMA). This composite is characterized by a high filler:matrix ratio of 92%, with the lanthanum oxide being the main filler. Other resin cements and composite laminate materials may present different results.

Since studies have often been conducted on either dental tissues or composite materials only, without considering the clinical situations in which usually the combination of the two substrates needs to be conditioned, this study sought to identify the best protocol for conditioning the existing composite restorations prior to laminate cementation. When a laminate is indicated on existing composite restorations in an oral cavity, it is likely that the restoration has been aged in the humid oral environment. This means that water saturation has been reached and less free radical activity could be expected. However, there is no consensus for the aging regimens simulating the oral conditions. It has been suggested that the greatest residual free radical activity of the substrate can be found on the surface of the substrate during the first 24 h after polymerization. In this study, the specimens were subjected to 6000 thermocycles prior to cementation for the purpose of aging the existing composite restorations. This process took approximately one week. Temperature alterations between 5°C and 55°C result in water absorption and further polymerization of the composite. Therefore, free radical activity of the monomer functional groups could be expected to be diminished. Nevertheless, fracture strength of laminates bonded to differently conditioned composite/tooth assembly showed no significant difference when compared to the control group, where laminates were bonded to intact teeth without composite restorations.

The only significant difference was obtained between alumina-abraded and HF-treated and silanized groups, with the HF/silanized group showing higher bond strengths. The results are in agreement with Özcan et al., who reported that siloxane bonds were weaker on alumina treated and silanized substrates compared to silica treated groups. The higher frequency of mixed failures observed in the alumina-treated groups supports this finding.

On the other hand, in another study, SEM analysis of the conditioned indirect composite surfaces revealed that HF acid gel dissolves the filler components and produces porous irregular surfaces. However, such microporosities were not found to contribute to micromechanical retention. In that study, composite-composite shear bond strength was tested, whereas in this study the composite-lamine complex involved the enamel/dentin tissues on the substrate and the cement at the interface. Nonetheless, micromechanical retention with HF followed by chemical adhesion obtained by silanization seems to be more effective than that of the micromechanical and chemical adhesion obtained with alumina-air abrasion and silanization.

From the clinical standpoint, while HF acid gel is considered hazardous, air-borne particle abrasion silica coating requires additional equipment in the dental practice. Taking this as well as the favorable failure types into consideration, applying an intermediate adhesive resin as used in this study provides a less expensive and more applicable option prior to laminate cementation in clinical practice.

For the purpose of this study, standardized composite restorations were made to simulate the clinical situation when indirect laminates are fabricated and cemented on previously restored teeth. These dimensions were dictated by the dimensions of the ultrasonic box burs that were used to standardize the size of the preparations and consequently the composite restorations. It can be argued that, from the clinical point of view, this design may not always necessitate a laminate restoration and could be restored with new Class III restorations. The results may therefore be different if the restorations are larger than the ones used in this setup. One could extrapolate from this study that a small composite material surface does not influence the fracture strength dramatically. The use of larger composite restorations in future experiments will probably improve the clinical relevance. On the other hand, in order to achieve a harmonious results, laminates are occasionally indicated on small composite restorations or even on intact teeth.

Unfortunately, laminated composites have relatively poor mechanism for absorbing energy due to local impact damage where loading is normal to the laminate planes. Failure analysis of the fractured laminates showed mainly the mixed failure type, where chipping of the laminate was seen together with enamel exposure, followed by type B failure with cohesive failures of the laminate restorations in the form of chipping. Cohesive failures within the laminate material indicates good adhesion of the laminate to either dental tissues or to the cement layer. The adhesive failure, on the other hand, shows the weak link between the cement/tooth and the laminate veneer. Although the incidence was low in groups 3 and 6, type B failures were not observed in group 2 at all.

Furthermore, type C failures, indicating chipping of the laminate and enamel, were more frequently observed in groups 2 and 3. Therefore, it can be stated that although surface conditioning protocols may not affect the final fracture strength of indirect composite laminates, they do affect the failure types. Future studies should not only report the fracture strength but also the failure types of such
restorations. Since there were no significant differences in fracture strength between the groups but variations in failure types, the hypothesis may be accepted partially.

Under the influence of compressive cyclic stresses, the damage associated with delamination may reduce the overall stiffness as well as the residual strength, leading to structural failure. Thus, the behavior of laminates requires further investigation under fatigue conditions. Such studies are under progress in our laboratories. Water sorption of the monomer matrix may also influence the fracture strength of the laminates. In this study, specimens were water stored for only 1 month and no thermocycling was performed. Hence, the results represent the early clinical failures, indicating that not only fatigue but also static stress could cause laminate failures.

CONCLUSIONS

- The fracture strength of composite laminates did not differ significantly when they were bonded either to the existing, aged Class III composite restorations or to intact teeth.
- Only surface conditioning of the composite restorations with 9.5% HF acid etching followed by silanization resulted in significantly higher fracture strengths than airborne particle abrasion with 50 μm Al₂O₃ particles and silanization.
- The most frequent failure type was mixed failure, where chipping of the laminate was seen together with enamel exposure.

REFERENCES


Clinical relevance: Application of adhesive systems tested could be sufficient for conditioning the existing resin composite Class III restorations prior to laminate cementation.