Failures of porcelain laminate veneers using different techniques of bonding (A comparative in-vitro study)

Dr. Safa Adnan Gaeed B.D.S, M.Sc and Ammar Atta-Allah Ali B.D.S, M.Sc, Ph.D, Iraq
Corresponding author:
e.mail: sophy.luna@yahoo.com

Abstract:
Introduction: Esthetic dentistry (as a concept) and adhesive materials development (as a functional element) make the new dawn of dentistry, especially with the continuous development of adhesive techniques. Aim: To evaluate the failure patterns of porcelain laminate veneers used to esthetically restore maxillary first premolar by bonding them to enamel and dentin with two different techniques. Materials and Methods: A Forty eight extracted human maxillary first premolar were divided into three groups. Group (A): The preparation was limited to enamel with (0.5 mm) depth. Group (B): The preparation was in dentin (1 mm) depth and their veneers were bonded by delayed dentin sealing (DDS) technique. And Group (C): The preparation was in dentin (1 mm) depth and their veneers were bonded by immediate dentin sealing (IDS) technique. All the experimental groups were restored with the same type of veneer which was lithium disilicate ceramic CAD/CAM blocks and were milled by CAD/CAM technology. For all the experimental groups, veneer cement was used for the luting of veneers and all the specimens were stored in distilled water in 37°C for one week. Results: the statistical analysis have showed that the highest mean of load failure was recorded for the control group (548.1 N ± 93.2) with high significant difference (p <0.001) between the control group and all of the experimental groups. Conclusion: The development of bonding techniques like IDS made dentin as acceptable tooth substrate for indirect adhesive restorations when it becomes unavoidable.

Key words: Laminate veneers, CAD/CAM, lithium disilicate ceramic, delayed dentin sealing (DDS). Immediate dentin sealing (IDS), Load failure.

Introduction:
Dentistry has sound, unquestionable evidence affirming adhesive approach which considered as the most predictable, least invasive, and most conservative way to restore teeth to normal strength, function, form, and esthetics when tooth-colored materials are applied, as well as to protect a great amount of tooth structure while fulfilling patients’ restorative and esthetic requirements (Strassler, 2007; McLaren and Whiteman, 2010).
The enamel bond strength is beyond reproach, and is the least invasive, strongest, most predictable, and most conservative bond available. Magne (2005) stated that it duplicates the natural bond between enamel and dentin or dentino-enamel junction (DEJ). The same is untrue when it comes to dentin bonding. However, even dentin bonding is favored over non-adhesive restorations (Van Meerbeek et al, 2003).
Nakabayashi et al (1982) proposed the concept of dentin bonding that are well established nowadays. The principle of which was to create an inter-diffusion layer or interphase, which also named the hybrid layer by the introduction of monomers into the hard tissues immediately after tooth preparation (Nakabayashi et al, 1991). This technique was remarkable because once the polymerization of the infiltrating resin is done; it would generate a “structural” bond rather similar to the (DEJ) interphase (Lin and Douglas, 1994).

The technique where bonding agent is applied after tooth preparation and right before impression taking is termed immediate dentin bonding or immediate dentin sealing (IDS). In addition, to differentiate standard dentin adhesive technique from IDS, it is termed delayed dentin sealing (DDS) (Magne, 2005).

Materials and Methods:
48 caries-free maxillary first premolars teeth were extracted for orthodontic purposes, gathered from private clinics and dental health centers. The occluso-cervical and mesio-distal dimensions were measured according to the study’s standards. To evaluate that the crown is free of cracks, the teeth were visually examined with blue light transillumination. Teeth were cleaned from any attached soft tissue then were hand scaled and polished with fluoride-free pumice and stored in saline solution at room temperature until the time of the experiment (Abdo et al., 2012).

Teeth were randomly divided into one control group and three experimental groups of 12 teeth each as:

**Control group:** Intact teeth.

**Group A:** Teeth were prepared within the enamel to a depth of 0.5 mm depth and were restored with lithium disilicate ceramic CAD/CAM blocks (IPS e.max CAD, Ivoclar/Vivadent, Germany).

**Group B:** Teeth were prepared to a depth of 1mm with exposure of dentin and were restored with lithium disilicate ceramic CAD/CAM blocks (IPS e.max CAD, Ivoclar/ Vivadent, Germany) and were treated as the delayed dentin sealing with the Veneer cement (Choice™2,Bisco, USA).

**Group C:** Teeth were prepared to a depth of 1mm with exposure of dentin and were restored with lithium disilicate ceramic CAD/CAM blocks (IPS e.max CAD, Ivoclar/ Vivadent, Germany) and were treated as immediate dentin sealing with the Veneer cement (Choice™2,Bisco, USA).

With the help of the analyzing rod of dental surveyor (Jelenko Dental Surveyor, Dentaurum, Germany), the teeth were mounted into specially designed locally- manufactured rubber mold (30 mm height × 30 mm diameter) filled with cold cure acrylic (Vertex, Netherlands) (Fig. 1). The center of the occlusal surface of each tooth was attached to the vertically moving arm of the surveyor with sticky wax, where the long axis of the tooth perpendicular to center of the mold. Each tooth was suspended in the center of the mold. All specimens were embedded up to 2mm apical to the CEJ to simulate the natural biologic width (Versluis et al., 2011).

Silicone Index Fabrication
A sectional index made of putty polyvinyl siloxane impression material (Zhermack,
Italy) of 2 mm thickness in a bucco-palatal direction was fabricated for each tooth in the experimental group before the preparation in order to be able to evaluate the amount of tooth reduction since the index can be remounted on the tooth (Fig. 2).

**Figure 1: Tooth mounted in acrylic block.**

**Figure 2: Silicon in dex repositioned on the tooth**

**Teeth preparation:**
The outlines of the preparation were painted with waterproof color marker according to the following limits:

**For facial reduction:** the boundaries extend from the cusp tip to the cervical line.

**For the occlusal reduction:** from the cusp tip to a point 1 mm on the slope of the buccal cusp palatally and a point of 1.4 mm bellow the cusp tip facially.

**For the proximal reduction:** The preparation was extended to the proximal contact areas which represent the areas of highest contour as determined by the digital caliper. (Prasanth et al, 2013). The preparation carried out with the ceramic veneer burs set (Komet, Germany). Magnification loupes (2.5 x) were used during the whole tooth preparation procedure which was done under constant water irrigation.

**For group A:** The entire preparation was confined within enamel were a 0.4 mm depth preparation in the cervical third and 0.5 mm preparation in the middle and occlusal thirds, which was controlled by the use of depth limiting bur creating tooth bridges which were then removed with tapered diamond fissure bur. Creating a preparation that is entirely in enamel, the preparation ended 1 mm occlusal to the cement-enamel junction (Prasanth et al, 2013; Abdul Khaliq and Al-Rawi, 2014).
For groups B and C: The preparation was entirely in dentin which was checked by two ways; first by differentiating the color of dentin from the color of enamel under a magnifying lens with light, and secondly by performing a short etching process (2 to 3 seconds) and thorough washing and drying of the prepared surfaces. Dentin can be easily recognized because of its glossy appearance, whereas enamel is frosty white (Magne, 2005). The preparation was done as for the group A with additional step done with the depth limiting bur creating a final facial preparation of 1mm depth in the occlusal and middle thirds and 0.9 mm in the cervical third which was checked with the silicon index.

The buccal cusp was reduced 1.5 mm occluso-cervically and 1 mm bucco-palatally with butt joint cavosurface margin. Proximally, the preparation was extended without destroying the contact area which represents the area of highest contour that the preparation was located at the facio-mesial line angle mesially and facio-distal line angle distally. Finally the preparation was finished using fine diamond finishing bur for all the preparation surfaces then the silicon index which was previously fabricated was repositioned on the tooth to check for the depth and uniformity of the preparation (Fig. 3).

Immediate dentin sealing (IDS) for group C: After preparation and prior to taking impression, the samples of group C were sealed with the bonding agent (all bond 3, Bisco, USA) according to manufacturers instructions.

• Teeth were etched with 32% phosphoric acid (UNI-ETCH®, Bisco, USA) for 15 seconds, then rinsed thoroughly and dried.
• Application of bonding was by 2 coats were applied to the preparation and gently air dried with oil-free air flow to evaporate the solvent for 10 seconds and light cured with LED Light curing light (radii plus, SDI, Australia) for 10 seconds.

Final impression was taken by two step putty wash technique, the impression then prepared for pouring the stone by boxing the impression with sheet wax and the stone die was prepared using dental stone type IV.

CAD/CAM Veneers fabrication: Veneers fabrication was done using (Sirona Dental Systems, Bensheim, Germany) program (CEREC in-Lab (4.02)), the milling process have taken 10 minutes to complete producing the veneer in its gray-bluish pre-crystallized phase that needs glazing and sintering as instructed by the manufacturer, so the veneer was glazed then placed in the sintering furnace (Ivoclar/Vivadent/technical, Germany) and fired in a short 30 minutes firing cycle. This process was to present the glass-ceramic with its final strength and esthetic properties.

Veneer cementation: Cementation was carried out with (choice™2) veneer cement, with etch and rinse technique. The translucent shade cement was used for all of the samples. The veneers were held with the aid of OptraStick (Ivoclar/ Vivadent, Germany). The cementation process was carried out in three phases: First the internal side of the porcelain veneer was etched with 9.5 % hydrofluoric acid for 90 seconds, then rinsed with water and thoroughly air dried, then two equal parts of BIS-SILANE™ A and B were mixed in a ratio of 1:1 and two coats were applied to the and left for 30 seconds, then dried with air syringe. Secondly the prepared teeth were cleaned with pumice slurry, rinsed and dried. Then were etched with 32% phosphoric acid UNI-ETCH® for 15 seconds then rinsed thoroughly and lightly air dried while leaving the preparation visibly moist. After that, equal parts of ALL-BOND 3® which is an acetone based bonding agent, A and B were mixed and 2 consecutive coats were applied on
the tooth for group A and three coats were applied on the tooth for groups B and C as recommended by the manufacturer instructions. Then air dried for 10 seconds to evaporate the solvent, and light cured for 10 seconds. Lastly, a thin layer of PORCELAIN BONDING RESIN was applied to the inner side of the veneer and left without curing, and then the inner side of the veneer was lined with the translucent shade of Choice 2™ veneer cement and was seated gently and light cured for 3 seconds to tack the veneers into place and remove the excess cement. Then each veneer was light cured for 40 seconds from facial, mesial, distal, and occlusal aspect. Finally the margins were finished and polished with Optidiscs finishing and polishing system (Kerr, Switzerland), and the Samples were stored at 37°C in distilled water in an incubator for one week before subjecting them to the failure test (Mobilio et al, 2015) (Fig. 4).

**Failure test:** The test was done with universal testing machine (LARYEE Universal testing machine, China). The block was mounted on a custom-made jig, where the load was applied in at 45° to the long axis of the tooth (Abdul Khaliq and Al-Rawi, 2014). The angle was standardized by the locally manufactured custom-made jig, and then the load was applied at crosshead speed of 0.5mm/min (Al-Joboury and Zaka-ria, 2015) with a 3.2 mm in diameter flat end moving vertical rod of the machine that exerted the load at a point 1mm from the cusp tip palatally. The maximum load to produce failure was recorded in Newton (N) using computer software (Sphor et al, 2013). Modes of failure were assessed with stereomicroscope at 20x magnification.

**Results:**
The means and standard deviation of load failure were calculated for each group shown in (Table 1). It can be seen that the highest mean of load failure was recorded for the control group (548.167 N), followed by group A (393.417N), then group C (318 N) and the lowest mean of failure load was recorded for group B (237.833 N). Shapiro-wilk test was conducted to assess the normality of distribution of the analyzed data that have shown that the data are normally distributed as shown in (Table 2). The ANOVA test has revealed that there is a high significant difference among the groups at P≤ 0.001, as we can see in (Table 3). The results of the LSD test showed that there were high significant difference between the control group and all three experimental groups (p < 0.01), also there was
high significant difference in the load failure between groups A and B, and there was significant difference in the load failure between both groups A and C and between B and C as we can see in (Table 4). The failure patterns resulted in the study have varied from 58% of samples debonded, 33% of the samples suffered tooth fracture without debonding and 8% of samples were fractured.

Table 1: Descriptive Statistics. Mean values and standard deviation values of fracture strength for each group in Newton (N)

<table>
<thead>
<tr>
<th>Groups</th>
<th>No.</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>12</td>
<td>548.167</td>
<td>93.270</td>
</tr>
<tr>
<td>Group A</td>
<td>12</td>
<td>393.417</td>
<td>84.206</td>
</tr>
<tr>
<td>Group B</td>
<td>12</td>
<td>237.833</td>
<td>91.673</td>
</tr>
<tr>
<td>Group C</td>
<td>12</td>
<td>318</td>
<td>82.25</td>
</tr>
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</table>

Table 2: The normality of distribution test (Shapiro-Wilk test)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Shapiro-Wilk</th>
<th>d.f.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.944</td>
<td>12</td>
<td>0.555 (NS)</td>
</tr>
<tr>
<td>A</td>
<td>0.886</td>
<td>12</td>
<td>0.105 (NS)</td>
</tr>
<tr>
<td>B</td>
<td>0.892</td>
<td>12</td>
<td>0.125 (NS)</td>
</tr>
<tr>
<td>C</td>
<td>0.939</td>
<td>12</td>
<td>0.481 (NS)</td>
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</tbody>
</table>
Table 3: One-way ANOVA test

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Sum of Squares</th>
<th>d.f.</th>
<th>Mean Square</th>
<th>F-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>628634.729</td>
<td>3</td>
<td>209551.576</td>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>340556.250</td>
<td>44</td>
<td>7739.915</td>
<td>27.074</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>969210.979</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4): SD test

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean Difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>134.750</td>
<td>0.000 (HS)</td>
</tr>
<tr>
<td>B</td>
<td>310.333</td>
<td>0.000 (HS)</td>
</tr>
<tr>
<td>C</td>
<td>230.167</td>
<td>0.000 (HS)</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>155.583</td>
<td>0.000 (HS)</td>
</tr>
<tr>
<td>C</td>
<td>75.417</td>
<td>0.042 (S)</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>-80.167</td>
<td>0.031 (S)</td>
</tr>
</tbody>
</table>
Discussion

Bonding a restoration to dentin is questionable since exposed dentin is subjected to contamination due to temporization, sensitivity, and micro leakage that reduces the life of the restoration (Cohen and Razzano, 2006). Magne et al (2005) proposed a technique to improve the bond strength to dentin by sealing the freshly –cut dentin immediately after preparation. This will provide the highest bond strength to dentin by protecting the hybrid layer that will reduce sensitivity by sealing the dentinal tubules, reducing the chance of pulpal damage by bacterial habitation, and reducing dentin contamination by (microorganisms, blood, or chemicals) during the temporary phase. It has been translated effectively to clinical testing.

For this technique to be fully advantageous, the use of etch and rise (total-etch) type of bond that still considered as «gold standard» is essential, since this type provide the deepest, strongest, most predictable, and long-term bond to the tooth (Hashimoto et al., 2003; Duarte et al., 2009). In this study we focused on the failure of the laminate veneer, both fracture and deboning when the restoration is entirely on enamel and when dentin is involved using DDS and IDS techniques. IPS e.max CAD was used not only for its strength (360 Mpa), but also for its esthetic properties that mimics natural tooth appearance and its excellent translucency and brightness (Ivoclar Vivadent, 2011). Various techniques for accurate tooth reduction have been proposed, including silicone matrices and depth limiting burs (Cherukara et al, 2005; Mizrahi, 2007).

The type of tooth preparation selected for this study was a modified form of incisal wrap where for the premolar it’s a buccal cusp wrap, one suspects that completely covering the buccal cusp when applying porcelain laminate veneers to premolars provides the set with greater retention and strength, increasing the predictability of success (Archangelo et al., 2011). A standardized buccal reduction was done in all teeth by using depth-marking burs (Ceramic Veneer Set, Komet, Germany). By using this diamond standardized diameter burs, equal preparations of about 0.4 mm depth cervically and 0.5 mm in occlusal two thirds of samples in (group A) were done to ensure that the whole preparation was confined to enamel (Friedman, 1998; Lin et al., 2012). In order to make the preparation in dentin, we had to remove 0.9 mm cervically and 1 mm of the occlusal two thirds for groups (B and C). The preparation was continuously checked with the help of the silicon index (Lesage and wells, 2011).

After cementation of the veneers, the failure test was carried out by mounting the samples at 45° to the long axis of the tooth, simulating the dental contact between the arches during lateral shift of the mandibular movement (Archangelo et al., 2011). As during function, the occlusion generates non-axial forces resolved into their horizontal and vertical vectors along the cuspal side, the horizontal vector of the load has much more influence on teeth than the vertical vector. To provide allowance for these aspects in the present study, the load was applied at a 45° angle to simulate a worst case scenario (Sorrento et al., 2007; D’Arcangelo et al., 2008).

The failure test carried out giving wide range of data for each group that had to be analyzed for normality of distribution so that any data affects the overall study should be repeated or excluded. The test came with a result that the data are normally distributed. The cause of this wide range of data is long to be the cause of different tooth substrate dealt with in this study from intact tooth to restoration in enamel then restoration in dentin (Chun et al., 2010). The ANOVA test carried out have revealed a highly significant difference in the mean of failure load among the groups. The dif-
ferences between control group and other test groups were found to be statistically highly significant. For the experimental groups the difference in the failure load was translated by the failure of the bonding strength of the laminates to different tooth substrate.

The highest mean of load failure of the experimental groups was recorded for group A (in which the veneer preparation was entirely on enamel) which was (393 N) mean load failure, this may be due to the strong interlocking of the luting cement into the retentive etch pits of both the porcelain and tooth enamel contributes to strong adhesion of porcelain veneers with good retention (Rezvani et al., 2012).

The next highest mean of failure load was recorded for group C (which was prepared in dentin and the veneer bonded by IDS technique), the fact that IDS with the adhesive system and low viscosity micro filled resin significantly improved the bond strength of indirect restorations bonded to dentin using the resin cement (Okuda et al., 2007; Sultana et al., 2007). Increasing the bond strength of the luting material helps to increase the fracture strength of the restorative material and therefore lowers the veneer failure (Furukawa et al., 2002). Fewer gaps were observed at the internal dentin – restoration interface in the specimens coated with an adhesive system compared with non coated specimens (Jayasooriya et al., 2003). Therefore, IDS techniques are based on the principle that adhesive systems bond better to freshly prepared dentin (Terata, 1993; Watanabe et al., 1997) thus protecting the dentin-pulp complex and preventing or decreasing sensitivity and bacterial leakage during the provisional stage (Hu & Zhu, 2010; Perugia et al., 2013).

On the other hand, when using immediate dentin sealing and restoration (intrinsic to indirect techniques) and postponed occlusal loading, the dentin bond can develop without stress, resulting in significantly improved restoration adaptation (Dietschi et al., 2002).

The lowest mean of failure load was recorded for group B (which was prepared in dentin and the veneer bonded by DDS technique). Several reasons have been given to explain why bonding to dentin still a challenge, despite of the improvements in dental adhesive technology and advances in bonding knowledge. These include the heterogeneity of the structure and composition of dentin, the dentin surface characteristics after bur cutting and chemical treatments, and bond strategy and physico-chemical properties of the adhesives, among other variables (Cardoso et al., 2011; Van Meerbeek et al., 2011).

According to the LSD test, there was high significant difference between groups A and B, as bonding strength to enamel is more reliable than bonding strength to dentin (Cardoso et al., 2011).

This comes in agreement with the result of a study by Kiremitçi et al. (2004). Although this disagree with the result of a study by Burrow et al. (2008). Probably because of using self-etching adhesive that have resulted in higher bond strength to dentin than enamel since total-etch technique to dentin followed by dryness lead to collapse of the collagen network leaving dentin as soft mineral free collagen collapse surface (Carvalho et al., 1996). In addition, there was a significant difference between the groups A and C in the LSD test, there are no previous studies comparing the bond strength between enamel and dentin treated with IDS technique. However, for comparison, it was stated that the principle of the IDS technique was to create an interphase or inter diffusion layer, also called the hybrid layer (Nakabayashi et al., 1991) by the interpenetration of monomers into the hard tissues.
This approach was landmark because once the infiltrating resin is polymerized; it can generate a “structural” bond somewhat similar to the interphase formed at the (DEJ) (Magne, 2005). In order to give a close comparison with what have previously studied, the comparison will be between the bond strength of enamel and DEJ. So in regard to that, our results disagree with the results of a study by Shimada et al. (2003) with no significant difference between the bond strength of enamel and DEJ probably due to the use of different bonding system (Clearfill SE bond). However, our results agree with results of a study by Li et al. (2011).

On the other hand, there was a significant difference in the mean failure of groups B and C, since the difference between IDS and DDS techniques was directed for the improvement of the bond strength of dentin to different indirect restoration by the preservation of the hybrid layer. Our results agree with the results of Magne et al. (2005) and the results of a study by Yu-Sung Choi and In-Ho Cho (2010). While our results disagree with the results of a study by Dalbey et al., (2012), this probably was due to the specimens were hand sanded with a 600-grit silicon carbide paper under water to create a smooth dentin surface and a smear layer, and the use of self-adhesive cement (Relyx Unicem), that may have resulted in the difference in results.

Conclusion: The development of bonding techniques like IDS made dentin as acceptable tooth substrate for indirect adhesive restorations when it becomes unavoidable.

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