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Abstract

Purpose: To investigate the influence of immediate dentin sealing (IDS) vs delayed dentin sealing (DDS) on the marginal gaps of machinable monolithic zirconia vs pressable lithium disilicate laminate veneers.

Materials and Methods: A total of 40 maxillary lateral incisors were used and received butt-joint laminate veneer preparation. The samples were divided into two groups (n = 20 each) according to ceramic material: pressable lithium disilicate ceramic (PLD) was used in the first group, and machinable monolithic zirconia (MMZ) was used in the second. Each group was then divided into two subgroups according to the bonding protocol: IDS was employed in one, and DDS in the other (n = 10 each). The marginal gap widths were measured using digital microscopy and statistically analyzed. Results: The smallest marginal gaps were observed in MMZ-DDS (57.2 ± 8.4 µm), followed by PLD-DDS (62.4 ± 2.7 µm) and MMZ-IDS (63.5 ± 1.9 µm). The largest marginal gaps were observed in PLD-IDS (81.5 ± 6.3 µm). Two-way ANOVA revealed that the bonding technique (P < .001) and ceramic material (P < .001) both showed significant differences.

Conclusions: MMZ produced better marginal accuracy than PLD. IDS seems to have a predisposition to significantly wider marginal gaps than DDS, but these gaps are within the clinically acceptable range. The marginal accuracy of ceramic veneers appears to be related to the bonding technique as well as the material of construction. Int J Prosthodont 2022. doi: 10.11607/ijp.8008

Keywords: Immediate dentin sealing, delayed dentin sealing, lithium disilicate, monolithic zirconia, laminate veneers, marginal gaps

1 Introduction

Laminate veneers are not only used to correct esthetic derangements but also are reliable and more conservative alternatives for restoring the biomechanical and esthetic integrity of teeth than classical full-coverage restorations.1 Improvements in ceramic materials, manufacturing technologies and bonding protocols optimized the quality and clinical performance of ceramic restorations.2,3 The esthetic quality in terms of color and translucency, as well as adhesive strength and retention quality, are among the major factors influencing the success of laminate veneers. The adhesive strength and retention quality are
outcomes of a complex of contributing components of the ceramic surface, luting cement and tooth surface.\textsuperscript{4,5}

Different ceramic materials have been used to fabricate laminate veneers, such as feldspathic, leucite-reinforced and lithium disilicate-reinforced glass ceramics. Because of the glass matrix, these materials showed satisfactory translucency and esthetic quality. Excellent adhesion to luting cement can be achieved with these materials because they can be hydrofluoric acid etched followed by silanization.\textsuperscript{6} The recent introduction of monolithic zirconia polycrystalline ceramics has enabled the fabrication of thin and ultrathin restorations that maintain the necessary flexure strength and fracture toughness. The material ranges from traditional tetragonal opaque zirconia to high-translucency cubic zirconia.\textsuperscript{7,8}

Since their introduction, tremendous modifications of monolithic zirconia has enhanced their translucency and improved their esthetic quality.\textsuperscript{7} This development was coupled with endeavors for manufacturing suitable bonding materials and developing genuine technologies for intaglio surface treatment to upgrade the bonding of zirconia polycrystalline ceramics because these materials are typically neither acid etchable nor silanizable.\textsuperscript{9-12} Because zirconia veneers are generally less translucent than glass-ceramics, they are particularly indicated for restoring teeth with deep discoloration.\textsuperscript{13} The principal idea for improved and sustainable adhesive bonding relies on providing a maximal surface area of enamel bonding rather than dentin.\textsuperscript{14} However, eventual dentin exposure after preparing anterior teeth is inevitable in many clinical situations even when conservative preparation is intended.\textsuperscript{15,16}

The immediate dentin sealing (IDS) technique was suggested in the early 90s to avoid early exposure of dentinal tubules to contaminants after preparing teeth for indirect restorations and ingress of bacteria before final cementation.\textsuperscript{17,18} The technique is employed as an alternative to delayed dentin sealing (DDS) to develop a resin-collagen hybrid layer following dentin exposure directly after tooth preparation using either etch and rinse or self-etch bonding approaches.\textsuperscript{19} The procedure has been reported to improve bond strength, mechanical behavior,\textsuperscript{4,20} and long-term performance of indirect bonded restorations.\textsuperscript{21} This technique was used to boost bonding and protect the freshly exposed dentin surface before impression taking, thus preventing bacterial invasion of dentinal tubules and reducing dentin hypersensitivity during the provisional phase.\textsuperscript{4,21-23} A recent prospective clinical trial over 11 years indicated that laminate veneers in
teeth with greater than 50% exposed dentin showed a significantly higher survival rate when IDS was performed.\textsuperscript{24}

The optimum biomechanical and esthetic integrity of ceramic restorations, including laminate veneers, necessitate close marginal and internal fit that are key elements for long-term superior clinical performance.\textsuperscript{25} The clinical manifestations of ill-fitting restoration and increased marginal gaps include soft tissue irritations and inflammation, hypersensitivity, marginal discoloration and loss of retention.\textsuperscript{13,26} The literature indicates that marginal gaps of 50 µm or less are considered ideal.\textsuperscript{27} However, marginal gaps in the range of 100 µm can be satisfactory,\textsuperscript{28} while others consider gaps up to 150 µm to be clinically acceptable.\textsuperscript{29} On the other hand, the fabrication technique of ceramic veneers was found to influence the adaptation and marginal gap of laminate veneers.\textsuperscript{30}

Different methods have been reported to assess the marginal gaps of restorations. This includes either direct-view, cross-sectional or replica techniques\textsuperscript{31} in addition to microcomputed tomography.\textsuperscript{32} Among the previously mentioned methods, direct view was the most predominant, utilizing in vitro direct assessment of marginal gaps with the aid of high-power microscopy.\textsuperscript{31} Various examples of microscopy with direct view include light microscopy, scanning electron microscopy,\textsuperscript{33} stereomicroscopy,\textsuperscript{34} and digital microscopy.\textsuperscript{35} A combination of the techniques was also implemented, such as the replica technique together with scanning electron microscopy assessment.\textsuperscript{36}

This in vitro study aimed to investigate first, the influence of IDS versus DDS on the width of the marginal gap of ceramic laminate veneers, and second, the effect of ceramic material - pressable lithium disilicate and machinable monolithic zirconia – on the marginal gap of laminate veneers. The null hypotheses were that, in comparison with DDS, IDS does not affect the marginal gap width of laminate veneers and that PLD and MMZ veneers have similar marginal gap widths.

\section{Materials and Methods}

\subsection{Sample preparation}

Forty maxillary lateral incisors (average in size) were used in this study that were extracted from patients above 30 years old due to periodontal reasons. The research ethics committee of the College of Dentistry, xxx has approved the use of extracted human teeth in anonymized form (014/2020) and all study participants provided informed consent. All methods were carried out in accordance with relevant guidelines.
and regulations. The roots of the teeth were embedded in self-cure acrylic resin blocks to a level of 2 mm below the cementoenamel junction. A silicon index was prepared for each tooth to aid in obtaining standardized and uniform preparation.

The samples were randomly assigned to two groups according to the ceramic material used for laminate veneer fabrication. In the first group, the control group, pressable lithium disilicate glass ceramic (PLD, IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) was used. In the second group, the test group, machinable monolithic zirconia (MMZ, UTML, Kuraray Noritake Dental Inc., Aichi, Japan) was used. Each group was divided into two subgroups (n = 10) according to the employed conditioning procedure of the prepared tooth surface. In subgroup DDS, etch and rinse conditioning was performed directly before cementation; in the literature, this procedure is referred to as delayed dentin sealing (DDS). In subgroup IDS, immediate dentin sealing was performed on the freshly prepared tooth surface following dentin exposure. The materials used in the present study are listed in table 1. A sample size of n = 10 for each study group was employed based on the previously reported KISS approach after referring to previous similar studies to determine a provisional sample size that was then confirmed by power analysis.37

2.2 Veneer preparation

Butt-joint laminate veneer preparation was performed with an incisal reduction of 1.5 mm and a facial reduction of 0.5 mm.38-40 Preparation was accomplished using a laminate veneer preparation kit (ceramic veneer 4388, Komet Dental, Lemgo, Germany). A Chamfer finish line with a 0.5-mm width was prepared cervically 1 mm above the cementoenamel junction. The preparation of all teeth was accomplished using a high-speed air turbine with a coolant spray. To standardize the preparation, guided depth grooves of 0.4 mm were established using a depth marker (868B.314.020 ceramic veneer 4388, Komet Dental, Lemgo, Germany) and the preoperative silicone index. Facial reduction was completed by the removal of the remaining islands between the depth grooves using tapered diamond abrasive stone (868.314.016, ceramic veneer 4388, Komet Dental, Lemgo, Germany). Finishing was performed using a fine-grain diamond stone (8868.314.016, ceramic veneer 4388, Komet Dental, Lemgo, Germany).

2.3 Immediate dentin sealing

Immediate dentin sealing was performed in subgroup IDS. Directly after tooth preparation and before final impression taking, phosphoric acid etching 37% (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein) was
applied on the prepared tooth surface for 10 s followed by water rinsing and drying with cotton pellets. Next, the filled adhesive (Single bond Universal, 3M ESPE, USA) was applied for 20 s, followed by air thinning for 5 s and light-curing for 20 s. The light-curing unit (Elipar, 3M ESPE, USA) a light intensity of 1,470 mW/cm², and the light intensity was regularly monitored using a dental radiometer (Bluephase Meter II, Ivoclar Vivadent, Schaan, Liechtenstein). Glycerin was painted over the cured adhesive, followed by additional curing for 10 s to polymerize the superficial oxygen inhibited layer. The margins were refined to remove excess adhesive resin from the enamel margins with a very fine-grain diamond (852EF.314.014, ceramic veneer 4388, Komet Dental, Lemgo, Germany).

2.4 Laminate veneer fabrication

For the fabrication of PLD veneers, impressions were taken using polyvinyl siloxane one-step dual mix putty and light consistency (Express, 3M ESPE, USA), followed by pouring with improved stone (Easy mix BEGO, Germany). The veneers were waxed-up on the stone dies with an adjusted thickness of 0.5 mm facially and 1.5 mm incisally using the preoperative index and wax gauge. Wax patterns were embedded in the ceramic investment material (IPS press VEST, Ivoclar Vivadent, Liechtenstein). The pressing procedures were completed using LT A2 ingots (IPS e.max Press, Ivoclar Vivadent, Liechtenstein) in the pressing porcelain furnace (EP 3000, Ivoclar Vivadent, Liechtenstein). The sprues were separated, then the veneers were checked for thickness and were finished and glazed (IPS e.max Ceram, Ivoclar Vivadent, Liechtenstein).

For the fabrication of MMZ veneers, the teeth were scanned before preparation to help standardize the veneer thickness for all the milled restorations. The teeth were directly scanned using an optical laboratory scanner (inEos X5, Sirona Dental Systems, Bensheim, Germany) before and after tooth preparation. The files (stl format) of the scanned teeth were exported to dental designing software (exocad Dental CAD, Exocad GmbH, Darmstadt, Germany) to design the veneers. The veneer thickness was adjusted digitally using a preoperative scan. The cement space was fixed at 0.05 mm, and then the restoration file was progressed forward to mill the EA2 ultra translucent multi layered block (UTML, Kuraray Noritake Dental Inc., Aichi, Japan). Milling was accomplished using a five-axis milling machine (InLab MC X5, Sirona Dental Systems, Bensheim, Germany). Milled veneers were separated from the blank and cleaned with isopropanol 99% in an ultrasonic cleaner for 30 s. A drying lamp (Bredent Medical GmbH & Co.KG, Senden, Germany) was used to dry the zirconia veneers for 2 min. The zirconia sintering furnace (Nabertherm
GmbH, Lilienthal, Germany) was adjusted to 1560 °C along a 9-h sintering cycle and then was glazed (IPS e.max Ceram, Ivoclar Vivadent, Schaan, Liechtenstein).

2.5 Intaglio surface treatment of veneers (PLD and MMZ)

The intaglio surface of the PLD veneers was conditioned by buffered hydrofluoric acid gel 9.5% for 20 s (Porcelain Etch, Bisco, Schaumburg, USA), followed by the application of a silane coupling agent (Porcelain Primer, Bisco, Schaumburg, USA). The MMZ veneers were conditioned by air particle abrasion with 50-μm Al₂O₃ particles at 3 bars for 10 s, followed by ultrasonic cleaning 41. All the MMZ veneers were coated with a filled adhesive resin containing MDP (Single Bond Universal, 3M ESPE, USA), followed by air thinning for 5 s.

2.6 Conditioning of the prepared surface

The prepared tooth surfaces for the IDS subgroup were cleaned by polishing with a soft brush and pumice for 10 s (Pumice Oral Extra Fine, Kemdent, Swindon, United Kingdom). The prepared tooth surfaces were then etched with phosphoric acid 37% (Total Etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 15 s, rinsed with water for 10 s, and gently dried using cotton pellets. Next, the adhesive was applied (Single Bond Universal, 3M ESPE, USA) for 20 s, followed by air thinning for 5 s.

2.7 Cementation procedure

All the fabricated veneers were cemented with a dual-cure resin cement (Rely X Ultimate, 3M ESPE, USA) in shade A3. The luting cement was applied on the intaglio side of the veneer, fixed in place on the prepared tooth using gentle finger pressure and light-curing for 20 s as an initial curing at the center of the facial surface. Excess cement was removed with a lancet followed by additional light-curing for 30 s. The margins were finished by polishing with an intraoral ceramic rubber polisher (Kenda Nobilis, Kenda AG, Liechtenstein).

2.8 Marginal gap measurement

The marginal gap was defined as the perpendicular measurement between the external margin of the restoration and preparation fishing line as described by Holmes et al. 42 In the clinical situation, this distance accounts for the thickness of the luting cement exposed to the oral environment with vulnerability to dissolution and bacterial leakage. 43 The marginal gaps were measured at four specified points using a digital microscope (Scope Capture Digital Microscope, Guangdong, China) and image processing software.
(Scope Capture 1.1.1.1. Ltd. Co.) at a magnification of $\times 40$. Before the beginning of the study and at different study intervals, the software was calibrated to confirm accuracy. The four reference points for the marginal gap measurements were located mid cervical, mid mesial, mid distal, and mid incisal (Fig. 1), and measurements were performed using a digital caliper. Each measurement was repeated three times for each respective reference point, and then an average of the three readings was calculated and recorded.

2.9 Statistical analysis

Means and standard deviations were calculated. Data were tested for normality using the Shapiro–Wilk test. One-way ANOVA with post-hoc Tukey’s test was performed for differences between the groups. Two-way ANOVA was performed to test the effect of different study variables: ceramic material and bonding technique. All the tests were performed at a level of significance of $p < 0.05$ using Graph-Pad InStat statistics software for Windows.

3 Results

The means ($\mu m$) and standard deviations, minimum, maximum and 95% confidence intervals (low and high) values are presented in table 2. None of the study groups was completely free of marginal gaps. Among all groups, the smallest marginal gaps were observed in MMZ-IDS ($57.2 \pm 8.4 \mu m$), with statistical significance ($p = 0.025$), followed by PLD-IDS ($62.4 \pm 2.7 \mu m$) and MMZ-IDS ($63.5 \pm 1.9 \mu m$) ($p = 0.052$). The largest marginal gaps were observed in PLD-IDS ($81.5 \pm 6.3 \mu m$), with statistical significance ($p < 0.001$). Two-way ANOVA revealed that the bonding technique ($p < 0.001$) and the ceramic material ($p < 0.001$) showed significant differences: IDS resulted in greater marginal gaps than DDS and PLD resulted in larger marginal gaps compared to MMZ.

4 Discussion

The results of our study indicated that both proposed null hypotheses could be rejected because the marginal gap width was affected by both the bonding technique and ceramic material. Ceramic laminate veneers are commonly selected as conservative restorations for correcting esthetic derangements that do not require sacrificing considerable tooth structure as is the case with full-coverage restorations.$^{1,44,45}$ The preparation of teeth to receive laminate veneers is confined to their labial surface, part of their proximal surfaces and occasionally includes the incisal edges with or without palatal overlap. Incisal butt-joint
preparation was performed in our study because it confirms better veneer seating, enhances esthetics by producing better incisal translucency and affords a more conservative approach than palatal overlap preparation. Furthermore, it produces better adhesive and cohesive failure resistance. The average facial reduction for laminate veneers is between 0.5 and 0.7 mm. The thickness of the enamel in central incisors is in the range of 0.4 mm cervically and 1 mm incisally or less; in the lateral incisor, the facial enamel thickness is 0.3 mm cervically and 0.9 mm incisally. Because the validation of IDS was a part of the current study design, the upper lateral incisors were selected because preparing them for laminate veneers imparts unavoidable exposure of dentin facially, particularly at the cervical one third. The literature indicates that bonding to enamel is more stable and clinically durable than bonding to dentin. For direct restorations, several attempts have been proposed to improve bond durability to dentin. Although laminate veneers provide excellent esthetic restorative options that conserve tooth structure and might not need preparations deep to dentin, unavoidable exposure of the dentin surface can be the eventual outcome following tooth preparation in many cases in routine clinical practice. IDS has been proposed to stabilize the bonding interfaces of exposed dentin surfaces and promote bonding strength until the time of final cementation. The technique was reported to prevent the collapse of the collagen plexus of the hybrid layer and contamination of freshly cut dentin. Furthermore, it reduces postcementation hypersensitivity, and the need for local anesthetic agent administration during cementation following the removal of interim restorations. In the case of in-office digital fabrication, the need for IDS might be eliminated because the teeth are prepared and final restorations are produced and permanently cemented in the same clinical session. However, it is not infrequent that esthetic rehabilitation involves time-consuming technical challenges, modifying procedures and characterization that make it difficult to deliver the final prosthesis in one clinical session with achievable desired results. For the optimum outcomes of treatment, IDS is a considerable approach when there is an interval between tooth preparation and final cementation. Therefore, CAD/CAM versus pressable fabricated laminate veneers were included in our study design to assess the possible influences of the fabrication method. Pressable lithium disilicate reinforced glass-ceramic was selected as a control group due to the common use of the material and fabrication technique for producing laminate veneers. Monolithic zirconia has been utilized recently in the different esthetic restorations designs including laminate veneers. As one of available esthetic
machinable materials, the improved esthetics coupled with enhanced bonding procedures and possibility of using the materials in thin and ultrathin sections increases its chances as one of the options for conservative bonded restoration as laminate veneer. Consequently, assessing the performance of MMZ in terms of marginal gaps width has a considerable clinical significance.

Several studies have investigated the influence of IDS on the bond strength, adaptation and mechanical behavior of indirect restorations. One recent in vitro investigation showed the benefits of IDS compared with DDS when microcomputed tomography was employed to study the marginal and internal adaptation of class II ceramic inlay restorations. A recent clinical study demonstrated the superior performance of laminate veneers employing IDS that included assessing marginal adaptation using the Modified United States Public Health Services criteria.

The direct view method for assessing of marginal gap is a commonly used assessment. Our marginal gap assessment method was the guided by Holmes et al., who used the perpendicular measurement between the external margin of the restoration and preparation fishing line to quantify and grade marginal gaps. The microscopic direct visual evaluation of the gap filled with luting cement identifies the tooth-restoration marginal gap. Previous investigations used different number of points for marginal gaps assessment. Similar to the previous work of Lin et al., our study used a four point measurement of the marginal gaps research.

The results of the present study confirmed the previous findings that marginal gaps could not be eliminated regardless of the material of construction or method of fabrication of the restoration or dentin sealing or bonding technique, IDS or DDS. Marginal integrity is essential for the long-term reliability of restorations. Large marginal gaps would allow leakage of saliva, bacteria and bacterial by-products with degradation of the luting cement leading to plaque accumulation, recurrent caries and failure of restorations. Our own data showed that the deterioration in marginal gap width was greater in the PLD group than in the MMZ group. This indicates that the material of construction and the fabrication technique both influence the marginal fitness of laminate veneers.

Although all our measured gap widths were within the clinically acceptable value of 100 μm, IDS caused the marginal gaps to increase in all the study groups, which varied in effect in both ceramic materials. Our results indicate that IDS could be implemented without compromising the marginal accuracy of machinable
monolithic zirconia and pressable lithium disilicate beyond the clinically acceptable range denoting that IDS is a clinically acceptable procedure. The IDS protocol involves applying a layer of bonding agent to the prepared tooth surface immediately after tooth preparation and another layer at the time of final cementation. This accounts for a corresponding increase in the marginal gap width compared with that in the DDS group where only one single application of the bonding agent is completed at the time of final cementation. Previous findings have demonstrated that cured dentin bonding agent can add a layer of 60- to 80-μm thickness for convex surfaces and approximately 200 μm or more for concave surfaces at the chamfer finishing line. Our findings that marginal discrepancy is greater with PLD than with MMZ, regardless of the bonding technique IDS or DDS, contradict with earlier outcomes that pressable restorations provide better marginal fitness than milled restorations and differ from other reports that pressable and machinable restorations provide similar marginal discrepancy. This controversy might be related to variations in the employed methodology, preparation design and materials. In our study, the inlab mc x5 milling machine was used for the milling of monolithic zirconia CAM blanks. This five-axis milling machine was found to produce better marginal fitting than the heat pressable technique. Previous findings have indicated that the five-axis milling machine improves marginal fitting. The zirconia CAM blanks used in this study are partially sintered, relatively soft material known as low brittleness index (BI) with enhanced precise machinability. The BI is known for its direct correlation with the marginal chipping factor (CF) and, in turn, on the marginal integrity. Even with different brands of zirconia material, differences in fitting were noticeable. In addition to the film thickness of the luting cement, polymerization shrinkage, hygroscopic expansion, thermal and load cycling have been reported as factors influencing the marginal fitness. The current study did not measure marginal gaps after immersion of samples in water and without testing the influence of thermal and/or mechanical cycling which might be considered as one of the study limitations. Although visualizing marginal gaps with digital microscopy is among the reliable assessment methods included in the literature, increasing the number of assessment points and providing a cross sectional analysis of the internal fitness could have magnified the validity of the study outcome. Future research should consider the role of the resin luting cement and elucidate the influence of its shrinkage behavior and film thickness on the marginal gaps of differently constructed laminate veneers of
different materials. Using three-dimensional microcomputed tomography might provide a more comprehensive analysis of the marginal and internal fitness of laminate veneers considering the different influencing factors.\textsuperscript{73,74}

5 Conclusions

Under the circumstances of this in vitro investigation and considering its limitations, IDS predisposes to significantly wider marginal gaps than DDS. Machinable monolithic zirconia produces better marginal accuracy than pressed lithium disilicate glass ceramic veneers. The marginal accuracy of ceramic veneers appears to be related to the material of construction as well as the bonding technique.

6 Acknowledgments

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7 References

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46. Mark SK: Comparison of veneer preparation design and fracture strength: a thesis [Masters in Oral Biology]. Bethesda, Maryland, USA, Uniformed Services University of the Health Sciences, 2017
Table 1 Materials used in this study

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<th>Material</th>
<th>Details</th>
<th>Lot no.</th>
<th>Manufacturer</th>
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<td>KATANA™ Zirconia UTML (EA2)</td>
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<td>DMZMG</td>
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Table 2 Means, standard deviation, minimum, maximum and 95% confidence interval of the marginal gap results (µm) for both ceramic groups as a function of cementation

<table>
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<tr>
<th>Groups</th>
<th>Mean ± SD (µm)</th>
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<th>Maximum</th>
<th>95% confidence interval</th>
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</table>

Fig. 1 Diagram representing the measurement points (arrows) from the labial, the proximal (a) and the palatal side (b).