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Effect of Different Veneering Techniques on Shear Bond Strength and Translucency of Bi-layered Zirconia Ceramics

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ABSTRACT

Purpose. This study was designed to compare the effect of different veneering techniques (CAD-on, Press-on and manual layering) on the shear bond strength of veneering ceramics to zirconia framework and translucency of bi-layered zirconia based ceramics. **Materials and Methods:** A total of forty-eight zirconia samples were fabricated and were divided into three equal groups (n=16) according to the veneering technique used: Group (I): samples veneered using CAD-on technique. Group (II): samples veneered using Press-on technique and Group (III): samples veneered using manual layering technique. The samples of each group were subdivided into two equal subgroups (n=8) according to the testing procedure: Subgroup (A): for translucency parameter (TP). Subgroup (B): for shear bond strength. All samples were thermocycled in thermocycling device. Samples of subgroup (A) were tested for translucency parameter (TP) by using a reflective spectrophotometer. Samples of subgroup (B) were tested by using a universal testing machine. Failure modes of fractured samples were evaluated using stereomicroscope and scanning electron microscope (SEM).Data were statistically analyzed. **Results:** CAD-on veneered samples, group (1), recorded higher mean translucency parameter (11.099±0.452) than manual layering veneered samples, group (3), which recorded lower translucency parameter (5.463±1.255). CAD-on veneered samples, group (1), recorded higher mean shear bond strength (16.262±4.492) than Press-on veneered samples, group (2) which recorded lower shear bond strength (8.584±1.606). **Conclusions:** CAD-on veneered samples showed superior translucency parameter and shear bond strength than Press-on veneered samples.

KEYWORDS

Zirconia core,
Shear bond strength,
Translucency parameter,
Digital veneering method

INTRODUCTION

Ceramics have been the mainstay of esthetic dentistry for more than 100 years. Originally in the naturally occurring feldspathic form,

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ceramics were used primarily for anterior teeth as high fusing porcelain jacket crowns and denture teeth [1]. Now, newly introduced CAD/CAM systems are widely used to produce zirconia restorations, either as frameworks or monolithic restorations. However, when zirconia framework is fabricated using a CAD/CAM process, final restorations are completed by veneering zirconia frameworks using "esthetic ceramics"to achieve optimum esthetics [2]. Esthetic ceramics are glass-containing materials with high translucency and moderate flexural strength including feldspar-based and leucite-based ceramics [3]. At ambient pressure, unalloyed zirconia can assume three crystallographic forms depending on the temperature. At room temperature and upon heating up to 1170 ºC, the symmetry is monoclinic. The structure is tetragonal between 1170oC and 2370 ºC and cubic above 2370ºC and up to the melting point [2]. The transformation from the tetragonal (t) phase to the monoclinic (m) phase upon cooling is accompanied by a substantial increase in volume (~4.5%), sufficient to lead to catastrophic failure. This transformation is reversible and begins at 950 ºC on cooling. Alloying pure zirconia with stabilizing oxides such as CaO, MgO, Y_2O_3 or CeO_2 allows the retention of the tetragonal structure at room temperature and therefore the control of the stress-induced t□m transformation, efficiently arresting crack propagation and leading to high toughness [4]. When zirconia is used for esthetic dental restorations such as crowns and bridges, it is generally veneered with veneering ceramic, because zirconia has an insufficient Translucency [5]. However, the strength of the veneering porcelain is not enough to act as dental restoratives, especially for posterior teeth. Clinical failure has been reported to be mostly due to chipping or fracture of porcelain [5, 10]. Zirconia-veneer adhesion and bond strengths can be affected by several factors such as veneering methods, mechanical properties of the framework and veneering ceramic, wettability of the framework by the veneering ceramic and residual stresses at the Interface [11]. Various techniques have been developed over the years for veneering zirconia frameworks with glassy matrix ceramics. According to the traditional layering technique, the mixed ceramic powder and its liquid are built on the sintered zirconia framework larger than the final dimensions to compensate for the shrinkage of the veneering ceramic [12]. On the other hand, the "overpressing" veneering technique method requires a wax up model with the final contour of the veneer on the sintered zirconia framework to be invested under heat-pressed vacuum with pressable ceramics [13]. In addition to these commonly used veneering methods for zirconia frameworks, a relatively new method, the so-called "file-splitting" has been introduced based on improvements in computer-aided design/computer-aided manufacturing (CAD/CAM) [14]. In the file-splitting (CAD-on) technique, zirconia framework and veneering ceramic are designed together with the CAD software. Following the milling process through CAM units, the two parts are then combined using glass [15] or resin cement [16] depending on the ceramic-system manufacturer. The bond between the framework and the veneering layer and translucency of the final restoration are important factors for the overall success of the restoration, therefore both should be thoroughly investigated. Therefore, the purpose of the present study was set to compare the effect of different veneering techniques (CAD-on, Press-on and manual layering) on the shear bond strength of veneering ceramics to zirconia framework and translucency of bi-layered zirconia based ceramics. The null hypotheses assumed that shear bond strength between zirconia core and veneering ceramics and final translucency of bi-layered zirconia ceramics will not be affected by the veneering techniques used.

MATERIALS AND METHOD

Construction of IPS e.max ZirCAD frameworks:

Forty-eight IPS e.max ZirCAD (Ivoclar Vivadent AG, Schaan, Liechtenstein) samples with (12mm length,12mm width and 0.6mm thick), were cut from IPS e.max ZirCAD blocks using diamond micro-saw (IsoMet 4000 precision cut, Microsaw

(Buehler USA)) [17,18] with cutting speed 2500 rpm, with a diamond disc 0.6 mm thick under cooling system; water coolant: anticorrosive agent(30:1). Partially sintered IPS e.max ZirCAD framework samples were fully sintered according to the manufacturer's instructions in Sintramat furnace (Ivoclar Vivadent AG, Schaan, Liechtenstein), sintering temperature 1500°C/ 2732°F.

All samples were divided into three equal groups (n=16) according to the veneering technique used: group (I): IPS e.max ZirCAD frameworks veneered using CAD-on veneering technique. Group (II): IPS e.max ZirCAD frameworks veneered using Press-on veneering technique. Group (III): IPS e.max ZirCAD frameworks veneered using manual layering technique. The samples of each group were subdivided into two equal subgroups (n=8) according to the testing procedure: Subgroup (A): samples were tested for translucency parameter (TP). Subgroup (B): samples were tested for framework/ veneer shear bond strength.

Veneering of IPS e.max ZirCAD frameworks:

In group (I); CAD-on samples with (7 mm length, 6mm width and 0.7mm thickness) were fabricated by sectioning IPS e.max CAD block (Ivoclar Vivadent AG, Schaan, Liechtenstein) using a slow-speed diamond saw. CAD-on veneering samples were fused to IPS e.max ZirCAD frameworks by fusion glass (IPS e.max CAD Crystall/Connect) (Ivoclar Vivadent AG, Schaan, Liechtenstein) which was vibrated in the Ivomix vibrator for10-15 seconds. Samples (IPS e.max ZirCAD framework/CAD on veneer) were inserted into the Programat P300 furnace (Ivoclar Vivadent AG, Schaan, Liechtenstein), and fired according to the manufacturer's recommendation, Firing temperature at 840°C. In order to achieve standardized shape and size of the veneers in the other groups, silicon index was made for the sectioned CAD-on veneering sample.

In group (II); Press-on group, Zirliner (Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to the surface of the framework sample and fired at 960°C,After firing the thickness of IPS e.max Ceram ZirLiner was approximately 0.1 mm then wax-up with (7 mm length, 6mm width and 0.7mm thickness) using modeling wax (FC ModellingWax;Bego, Bremen,Germany) of the veneer through the constructed silicon index was done, invested by IPS Press Vest special investing material(Ivoclar Vivadent AG, Schaan, Liechtenstein), subjected to wax elimination at 700°C, IPS e.max ZirPress ingot (Ivoclar Vivadent AG, Schaan, Liechtenstein) pressed into the mold using Program at Ep3000 (Ivoclar Vivadent AG, Schaan, Liechtenstein) according to the manufacturer's instructions and divestment was carried out with polishing beads at 4 bar for rough fine divestment and at 2 bar for fine divestment . After divesting, the sprue was cut using a diamond disc (Acurata, Thurmans bang, Germany) and burs.

In group (III); Manual layering group, Zirliner was applied to the framework surface and fired, After firing the thickness of IPS e.max Ceram ZirLiner was approximately 0.1 mm then the previously fabricated silicon index was used to build up dentin, enamel and glaze of IPS e.max Ceram with (7 mm length, 6mm width and 0.7mm thickness).

Thermocycling: All samples were thermocycled in a thermocycling device (Robota automated thermal cycle; BILGE, Turkey). Samples were subjected to 1500 thermal cycle (50°C-55°C) with 30 seconds dwell time in each water bath and a lag time 10 seconds.

Translucency Parameter (TP): Samples of subgroup (A) were tested by using a reflective spectrophotometer, (X-Rite, model RM200QC, Neu-Isenburg, Germany).The aperture size was set to 4 mm and the samples were exactly aligned with the device. The TP values were calculated by using the following equation:

$$TP= [(L_b^* - L_w^*)_2 + (a_B^* - a_w^*)_2 + (b_B^* - b_w^*)_2]^{1/2}$$ [19]

Where letters "B" refer to color coordinates over the black backgrounds and "w" refer to those over the white backgrounds.

Shear Bond Strength test: Samples of subgroup (B) were tested for shearing test by applying compressive mode of load at framework-veneer interface using a universal testing machine (Model 3345; Instron Industrial Products, Norwood, USA) at cross-head speed of 0.5mm/ min. The load required for debonding was recorded in Newton. Shear bond strength (MPa) was calculated according to the following equation: The load at failure was divided by bonding area to express the bond strength in MPa : $\tau = P/A$ Where; τ=shear bond strength (MPa), P=load at failure(N), A=area of bonding

Failure mode analysis after shear bond strength test: Each fractured sample was examined and photographed using USB digital stereomicroscope (Scope Capture Digital Stereo Microscope, Guangdong, and China) with a built-in camera (Carl Zeiss, Aalen, Germany) connected to an IBM compatible computer. One sample, representing the prevalent mode of failure was examined under Scanning Electron Microscope (Quanta 250 FEG (Field Emission Gun) FEI Company, Netherlands) under magnification (150X and 500X).

Statistical analysis:

Data were analyzed by SPSS 16 (Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA) for Windows using Tukey's post hoc test for pairwise comparison when ANOVA test revealed a significant difference. The significance level was set at $P \leq 0.05$.

RESULTS

I- Results of Translucency parameter (TP):

The highest mean value was recorded for CAD-on veneered samples, group (I), (11.099±0.452), while the least mean value was recorded for manual layering veneered samples, group (III), (5.463±1.255). ANOVA test revealed a statistically significant difference between the tested groups. **(Table 1)**

II- Results of Shear bond strength test (MPa):

The highest mean value was recorded for CAD-on veneered samples, group (I), (16.262±4.492), while the least value was recorded for Press-on veneered samples, group (II), (8.584±1.606). ANOVA test revealed a significant difference between the tested groups at ($P<0.05$). **(Table 2)**

III. Mode of failure analysis:

On examination of fractured samples, it was noticed that the mixed failure was the prevalent type in all groups. Group (1) IPS e.max ZirCAD veneered usin CAD-on technique was (6) Samples mixed failure, (2) Adhesive failure. In group (2) IPS e.max ZirCAD veneered using Press-on technique was (5) Samples mixed failure, (3) Adhesive failure Group (3) IPS e.max ZirCAD veneered using manual layering technique was (5) Samples mixed failure, (3) Adhesive failure.

Table (1): *Mean values of translucency parameter (TP) for subgroup (A) of the three tested groups.*

Groups	Group (1) IPS e.max ZirCAD veneered using CAD-on technique	Group (2) IPS e.max ZirCAD veneered using press-on technique	Group (3) IPS e.max ZirCAD veneered using manual layering technique
NO of samples	8	8	8
Mean	11.099[a]	9.263[b]	5.463[c]
SD	0.452	1.295	1.255
P Value	<0.0001*		

** Significant at P<0.05*

Table (2): *The mean shear bond strength (MPa) for subgroup (B) samples of the three tested groups:*

Groups	Group (1) IPS e.max ZirCAD veneered using CAD-on technique	Group (2) IPS e.max ZirCAD veneered using Press-on technique	Group (3) IPS e.max ZirCAD veneered using manual layering technique
NO of samples	8	8	8
Mean	16.262[a]	8.584[b]	15.120[a]
SD	4.492	1.606	4.579
P Value	<0.000152*		

** Significant at P<0.05*

DISCUSSION

Zirconia, and particularly partially stabilized tetragonal zirconia (TZP), are known for their excellent strength and resistance to fracture, superior biocompatibility, and good esthetic properties, making them a popular choice in constructing frameworks for all-ceramic restorations of crowns and fixed partial dentures in the molar area [20]. However, veneering ceramics used on TZP frameworks showed a chipping rate of 13% within 3 years and 15.2% within 5 years [21]. In contrast, the fracture rate of metal ceramics at 10 years was reported to be only 8-10% [22]. This was attributed to the weak bond between veneering ceramics and TZP compared to their bond with metal alloys as well as the lower strength of veneering ceramic itself [20]. Different veneering techniques were therefore introduced aiming at improving both; core/veneer bond and the inherent strength of the veneering ceramics [14].

In the present study, IPS e.max ZirCAD was used as core material due to its high flexural strength (more than 900 MPa), fracture resistance and fracture toughness (twice that of glass-infiltrated ceramics) [23]. IPS e.max ZirCAD is available as presintered yttrium-stabilized zirconium oxide blocks (Y-TZP). The blocks are milled in green stage with enlarged dimensions to compensate for material shrinkage (20-25%) that occur during the final sintering stage [24].

IPS e.max CAD, a lithium disilicate glass ceramic designed for the CAD/CAM technique, was used as a veneering material for samples of group (1) as recommended by the manufacturer as well as by Beuer et al in (2009) [25] and Schmitter et al in (2012). [14] It has a coefficient of thermal expansion (CTE) that matches that of IPS e.max ZirCAD (CTE of IPS e.max ZirCAD (100-400oC) is 10.75×10-6 K-1, CTE of IPS e.max CAD (100-400oC) is (10.25×10-6 K-1) [25]. According to the manufacturer instructions, the milled veneering layer was subjected to the crystallization procedure after being joined to the zirconia framework using the fusion glass IPS e.max CAD Crystall./Connect [14].

IPS e.max CAD Crystall./ Connect is a predosed, ready to use powder/liquid system. The precisely adjusted powder/liquid mixture of IPS e.max CAD Crystall./Connect turns liquid when vibrated with the Ivomix vibrator.Without vibration, IPS e.max CAD Crystall./Connect returns to a firm state, which enables the joined restoration to be checked in the articulator; a special property known as thixotropy. It forms a homogeneous glass-ceramic bond between core and veneer during the IPS e.max CAD-on Fusion/Crystallization firing [26].

To achieve a standardized shape and size of the veneering layer in all groups; a special transparent silicone key was recorded for the CAD-on veneering layer. The silicon mold was subsequently used to construct the veneering layer in manual layering and Press-on groups.

In the present study, IPS e.max Ceram, a low fusion, nano- fluorapatite glass ceramic was used for veneering of zirconia frameworks using manual layering technique, (group 3), as its coefficient of thermal expansion [CTE (100-400 °C) is 9.5 ± 0.2510-6 K^{-1}] [27] matches that of IPS e.max ZirCAD [CTE (100-400 °C) is 10.75×10-6 K^{-1}) [23]. In addition, IPS e.max ZirPress, a fluorapatite glass-ceramic ingot, was used for veneering zirconia frameworks using Press-on technique, (group 2). It has a matching CTE [(100-400°C) is 9.8 ± 0.2510^{-6} K^{-1}] [28] to that of IPS e.max ZirCAD [(100-400°C) is 10.75×10^{-6} K^{-1}) [23] to reduce tensile stresses within ceramic materials.

In order to simulate in-vivo condition and test the durability of the achieved bond between zirconia substructure and the veneer layer; all samples of the present study were subjected to thermal cycling for 1500 cycle in two water baths, between 5oC to 55oC with dwell times 30 second and lag time 10seconds according to the procedure followed by Beuer et al [29] and Vidotti et al [30].

The highest mean translucency parameter value was recorded for CAD-on veneered samples, group (I) (11.099±0.452), whereas the least mean translucency value was recorded for samples veneered by manual layering technique, group (III) (5.463±1.255). The difference between translucency parameter values (TP) of different groups was statistically significant, (table (1)). The first proposed null hypothesis was thus rejected.

The obtained results are in accordance with other studies, [18,31] which on comparing the translucency of zirconia substructures veneered by either manual layering technique or Press-on technique, a significantly higher translucency was recorded for restorations veneered using heat pressing fluorapatite glass-ceramic ingots compared to those veneered using the layering technique. It has been suggested that Y-TZP core material is hardly affected by additional firings after it is fully sintered, without a change of optical properties [18]. Thus, the difference of final translucency obtained in the veneered samples can be attributed to the veneering methods themselves.

In samples veneered using the Press-on, and CAD-on techniques, glass ceramic ingots/blocks of industrially manufactured homogenous structure were used. Crystals are proportionally distributed within the veneer glass matrix without an obvious porous structure. Furthermore, the Press-on technique uses high pressure in association with high temperature to press the material inside the mold; this eliminates the possibility of pore formation within the substructure. The same applies to CAD-on veneering in which high strength lithium disilicate glass ceramic is machined, with no possibility for pores formation [32].

On the other hand, in the manual layering technique, multiple factors can affect the final translucency of the structure due to the introduction of human variation, such as the ratio of powder/liquid, vibration and condensation techniques, and firing temperature, which may result in insufficient grain growth, contributing to the asymmetric size and inhomogeneous distribution of crystals and high pore volume thus altering the final translucency and color of the samples [18, 33]. Human variation during application of the manual layering procedure can account for an inhomogeneous structure affecting the final translucency of the samples.

Differences in grain size, amount of porosity, second phase inclusions, and the discontinuity of refractive indices at the grain boundary are the primary factors affecting the translucency of polycrystalline ceramics [34,35]. Moreover, the number of firing is another determinate factor affecting the final translucency of the restorations [36].

According to **recent study**, [37] shear test measurements have been reported as the most prevalent in literature to evaluate the bond strength between two phases. However, some researchers prefer modified tensile tests to eliminate the occurrence of non-uniform interfacial stresses.

In the present study, all samples were loaded to failure in a universal testing machine where shearing test was done by compressive mode of load applied at core-veneer interface using a mono-beveled chisel shaped metallic rod attached to the upper movable compartment of the testing machine, traveling at cross-head speed of 0.5 mm/min, as recommended by many authors(12,38,39).

Values of shear bond strength obtained in this study ranged between (8.5MPa-16.2MPa), which lies within the same value ranges obtained in other studies (40,41). Direct comparison among shear bond strength values obtained in different studies is however difficult due to wide diversity of methods applied which in turn can affect shear bond strength values (i.e, the shape of the samples, area of the contacting surface and type of surface treatment). This could explain higher values obtained in other studies (12, 42, 39).

The highest mean shear bond strength value was recorded for CAD-on veneered samples, group (1), (16.262 MPa±3.492), whereas the least value was recorded for Press-on veneered samples, group (2), (8.584MPa±1.606). The difference between tested groups was statistically significant (table (2)). Therefore, the second null hypothesis was rejected.

Samples veneered with CAD-on technique, group (1) resulted in the significantly highest shear bond strength values (16.262MPa±3.492) among other groups. The obtained results are in accordance with other studies (15, 39).This result can be explained as that; in this technique an industrially manufactured block is milled then fused to zirconia substructure. The veneering cap thus has fewer inherent flaws with subsequent higher resistance to failure. Furthermore, ceramics tend to fail as a result of the propagation of flaws and cracks (43). In a ceramic restoration, the number and size of the flaws are associated with the material and fabrication method (26). Hence, a digital veneering system, in which the veneering process is simple and the number of firings is minimized, is predicted to have the least number of flaws.

In the present study, samples veneered using the manual layering technique, group (3), resulted in a significantly higher shear bond strength values(15.120 MPa±4.579) compared to samples veneered using the Press-on technique, group (2) (8.584 MPa±1.606). This result is in accordance with another study (42) which attributed the less favorable results obtained with the Press-on veneering technique compared with the manual layering technique to the difference in fabrication procedures among both techniques (44).

According to the manufacturer (Ivoclar Vivadent) recommendations, a layer of a liner material (ZirLiner) was applied before the application of IPS e.max ZirPress and IPS e.max Ceram on ZirCAD surfaces. Yet it was previously reported that the use of a liner at the core/veneer interface weakens the bond strength (45). Pressable veneer ceramics should be directly applied over sandblasted zirconia substrate as using a liner material becomes a weak link in the bilayered structure. Furthermore, a previous research recommended sandblasting the liner material before application of the veneer to reduce chances of delamination of the veneer ceramic (46).

The present study was not free from limitations. Investigating the shear bond strength of the framework/veneer structure would have been more clinically relevant if a cyclic loading procedure was included in the study, which needs to be investigated as they may have probable influence on bond strength under clinical circumstances. In addition, no surface treatment for the ZirCAD framework was conducted which may affect the final performance of the restorations.

CONCLUSIONS

Within the limitations of this in vitro study the following conclusions could be drawn:

1. Transluceny of bilayered zirconia based restorations is affected by the veneering technique and material.
2. The shear bond between zirconia framework and veneering ceramic is affected by the veneering technique used; CAD-on technique providing better bonding when compared to Press-on and manual layering technique with benefits of time saving and standardization.
3. CAD-on and Press-on veneering techniques yield a higher translucency parameter values than manual layering technique.

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