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Effect of Surface Treatment and Veneering Method on the Shear Bond Strength between Zirconia and Veneering Ceramics

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ABSTRACT

Purpose: The current study was aimed to assess the effect of various surface treatments: liner, silica coating and laser treatment, and veneering technique on the zirconia veneering ceramic sheer bond strength. **Materials and Methods:** Sixty four zirconia discs were prepared from Y-TZP ceramic blocks. According to surface treatment, the discs were divided into four groups (n=16); Group I: Control (without any treatment), Group II: liner application, Group III: silica coating, Group IV: laser irradiation. Then they sub grouped into subgroup A (n=8): layering technique and subgroup B (n=8): press–on technique according to the used veneering technique. Two additional specimens from every group were inspected by scanning electron microscope. To stimulate the thermal changes all samples were thermocycled for 1500 cycles. Shear test was done using a universal testing machine**. Results:** The highest mean sheer bond strength value was noted in the laser group and the control group showed the lowest in case of veneering by layering. While in case of press-on veneering sub group the lowest mean sheer strength value was recorded in the liner. **Conclusions:** surface treatments and veneering technique had an effect on the zirconia-veneer sheer bond strength.

KEYWORDS

Y-TZP,
Veneering ceramics,
Laser,
Shear bond strength.

INTRODUCTION

All-ceramic restorations have won a great acceptance because of their biocompatibility and brilliant esthetic performance with the increasing esthetic request of the community [(1)].

Dental ceramics are classified into: glass-matrix ceramics, polycrystalline ceramics and resin matrix ceramics according to their microstructure. Glass-matrix ceramics are ceramic materials having a glass

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phase e.g IPS emax cad. Polycrystalline ceramics are ceramic materials that don't have a glass phase e.g, Procera allceram and ICE zirconia blocks, and a resin matrix ceramics: polymer matrices having predominately inorganic refractory compounds as glasses or ceramics e.g, Vita enamic[2].

Polycrystalline ceramics consist of a crystalline phase and don't contain a glass phase so they are opaque in comparison to the glass ceramics. These materials are unsuitable as monolithic materials due to their poor translucency [3].

Zirconia ceramics have been used instead of metal ceramic restoration as a core material for veneered fixed restorations owing to their white color, biocompatibility, good mechanical properties, comparative translucency and specific transformation toughening criteria [4].

Pure zirconia has a three crystal structures primarily based at the temperature. These crystal structures are monoclinic from room temperature to 1170˚C , tetragonal at 1170˚C till 2370° C and cubic beyond 2370˚C to the melting point[5].

The addition of 2 - 3% yttrium oxides insures a stabilized tetragonal zirconia poly-crystal (TZP) at room temperature. This TZP has characteristics, such as: high elastic modulus and compressive strength which are advantageous in the medical and dental fields [6].

One of most important characteristics of TZP is the 3% -4 % volumetric expansions owing to the reversible phase transformation from tetragonal to monoclinic phases. The stresses on the crack tip will transform the tetragonal to the monoclinic phases that followed by a 3% to 4% volumetric growth which creates a compressive stresses that shields crack tips and prevents further crack propagation and this is referred as transformation toughening [7].

For esthetic reasons, the white color zirconia core substructure must be veneered with esthetic veneering ceramics [3] which may be done using a layering, a press-on, CAD-on veneering techniques or a combination of these techniques [8].

The coefficient of thermal expansion of the veneering materials should be somewhat lower than the zirconia one as great difference resulting in residual stress which reduce the restoration reliability [9].

The bonding between the zirconia and ceramic veneer could be increased by surface treatments which may be chemical or mechanical treatments that modify the surface properties of the treated surface. The wettability of the dental ceramic is improved by the surface treatment which promoting a rise in the surface roughness of the dental ceramic[10].

The color of underlying zirconia core can be masked through liner application which in turn can be used for adjusting the porcelain color. There are different reports about the effect of liner on the zirconia veneer bond strength and these reports are differing, however, some was found that the bond strength was increased [11,12], while others founding a decrease[13].

There were several methods used to coat zirconia ceramic surfaces with silica. Silicate ceramics are used for veneering the zirconia surface. The zirconia veneer bond can be enhanced by the silica coating [14].

The silica coating may be in the form tribochemichal silica coating[15] using Cojet or Rocatec devise (blasting with silica coated alumina),plasma technology, flame coating device [16] or application of silica layer by using sol dip coating in silica or aluminosilicate solution[17]. Using of laser irradiation for surface roughening is considered as new method for enhancing the integration and bonding between zirconia and veneer ceramic [18].

The aim of present study was to assess various surface treatments and veneering technique effects on the zirconia veneering ceramic sheer bond strength.

MATERIAL AND METHODS

Sixty four zirconia discs with final dimensions (3mm thickness x7mm diameter) were constructed from pre-sintered ICE zirconia based ceramic blocks using diamond micro saw (IsoMet 4000 , Buehler, USA). The discs were cut with 20 % increase in the dimension to compensate the volumetric changes which will occur after zirconium samples firing. Partially sintered zirconia discs were placed on firing tray and transferred to sintering furnace (Tabeo, Germany) where they were sintered according to manufacturer's recommendation.

Surface treatments for the samples:

According to surface treatment the sintered samples were haphazardly divided into four groups with sixteen samples for each group:

Group I: Control, discs were not subjected to any surface treatment and left after firing to be ready for veneering.

Group II: Zirconia discs subjected to the liner application, the samples were coated with IPS e.max ZirLiner (Ivoclar Vivadent, Liechtrnstein Germany). Powder and liquid were mixed to a creamy consistency. Then the liner was applied by a brush and the disc was vibrated until an even greenish color effect was achieved. The applied zirliner was fired as the manufacturer's instructions in the Programat EP3010 firing furnace (Ivoclar Vivadent, Liechtrnstein Germany).

Group III : Zirconia discs subjected to silica coating, a specially prepared silica solution was prepared through addition of tetraethyl orthosilicate (Sigma-Aldrich, Egypt) nitric acid solution (Morgan speciality chemicals co, Egypt) (55%) and ethyle alcohol (El nasr pharmaceutical chemical co, Egypt) 100% under stirring. Then distilled water was added after ten minutes which then was stirred for 1 hour in the room temperature. Then the discs were dip-coated by the silica sol and heat treated at 400°C for 2 hours.

Group IV : Zirconia discs subjected to laser surface treatments. Discs were subjected to laser irradiation. The laser used for this study was Er-YAG laser (Pluser Erbium laser, Italy). Each sample was irradiated with 2.5 W output power, the pulse energy was 250 mJ, with repetition rate of 10 Hz and the duration was 20 seconds. The irradiation was done under copious water cooling at 1mm tip-sample distance.

Veneering of zirconia core discs

According to ceramic veneering technique each group was then sub-grouped into: Sub group A: Zirconia discs veneered by conventional layering technique and Sub group B: Zirconia discs veneered by press-on technique with eight samples for each subgroup.

A specially designed split teflon mold (3mm thickness x 5mm diameter) was constructed for standardization of the veneer ceramic thickness. It was fixed over the zirconia disc through other teflon mold (3 thickness x 7 diameter) the two molds were fixed with each other using a metal ring.

Sub group A: Zirconia discs veneered by conventional layering technique: IPS emax ceram (Ivoclar Vivadent, Liechtrnstein Germany) powder was mixed with its liquid in a proper proportion with plastic spatula on glass slab. The first layer that applied was a wash layer through application of dentine material in a thin coat then fired into a firing furnace (Programat EP3010 Ivoclar Vivadent, Liechtrnstein Germany) at 750°C. The veneering ceramic material was built up incrementally into the mold using a brush until the mold was completely filled. Hand vibration and removal of the excess moisture by absorbent paper was done for each increment then the mold was removed gently. Then the samples were placed on the firing tray and fired in the firing furnace (Ivoclar Vivadent, Liechtrnstein Germany) at 750°C as manufacturer recommendations.

Sub group B: Zirconia discs veneered by press-on technique: Wax pattern was constructed with dimensions (3mm thickness x 5mm diameter) and the spruing was done after its hardening. The wax pattern and the zirconia were invested using IPS Press Vest special investment material (Ivoclar Vivadent, Liechtrnstein Germany). After setting of the investment, the ring was transferred to the preheating furnace. The pressing furnace was heated from room temperature to stand by point of 700 °C.

After the removal of the ring from the preheating furnace, the IPS e.max Zirpress ingot (Ivoclar Vivadent , Liechtrnstein Germany) was placed then the Alox plunger after that this assembly was placed in the center of the press furnace**.** Pressing program was selected and activated as manufacturer's instructions. During the pressing procedure the vacuum and heating process run automatically. After cooling of the investment ring divesting was done first at 4 bar pressure then fine divesting at 2 bar pressure then the sprues were separated.

Scanning electron microscope analysis for each group

After surface treatments, two samples from all groups were scanned using Scanning electron microscope (FEI company, Netherlands) to analyze surface properties and surface treatment effect of the zirconia surface.

Thermocycling

Specimens were thermocycled in order to mimic the thermal changes in the oral cavity. All samples were regularly dipped in a water bath of 5°C and 55°C with dwell times 25 seconds in each water bath and a lag time 10 seconds using a thermal cycle device (BILGE, Turkey) for 1500 cycles.

Shear bond strength test

Samples were fixed to specially designed sample holder (hollowed metal tube with central hole for sample housing) tightened to the lower compartment of the machine (Instron Industrial Products, Norwood, USA) by tightening screws. The samples were loaded till failure at the interface with a crosshead speed of 0.5 mm/min. Calculation of bond strength through dividing the force that causes the bond failure by the cross-section of the bonded area.

Mode of failure analysis

The failure mode evaluation was done using digital stereomicroscope (Scope Capture Digital microscope, Guangadong, China) for all the fractured samples.

RESULTS

I. Scanning electron microscope analysis for each group:

Figures 1 A - D showed the SEM images for the surface treated groups. SEM examination for the control group showed a blank image for zirconia surface, for liner group showed a homogenous, smooth and uniform zirliner layer, in case of silica treated group the zirconia surface showed a homogeneous silica layer on it while in case of laser group showed surface irregularities (pitted areas) the blue arrows, the surface roughness in the form of abrasion, microcracks and voids.

II. Statistical analysis of the shear bond strength:

The collected data were computerized and statistically analyzed using SPSS program. All statistical comparisons were two tailed with significance level of P-value ≤ 0.05 significant while, $P > 0.05$ indicates non-significant difference.

Within subgroup A (layering veneering technique), the highest shear bond strength value recorded in laser group and the control group was the lowest. Within subgroup B (press-on veneering technique) the highest mean value recorded in laser group while the liner group was the lowest (table 1).

When comparing the veneering technique all the surface treated groups showed a non-statistically increase in the mean bond strength value while when the control group showed statistically increase in mean bond strength value at $P=0.01$ (table 1).

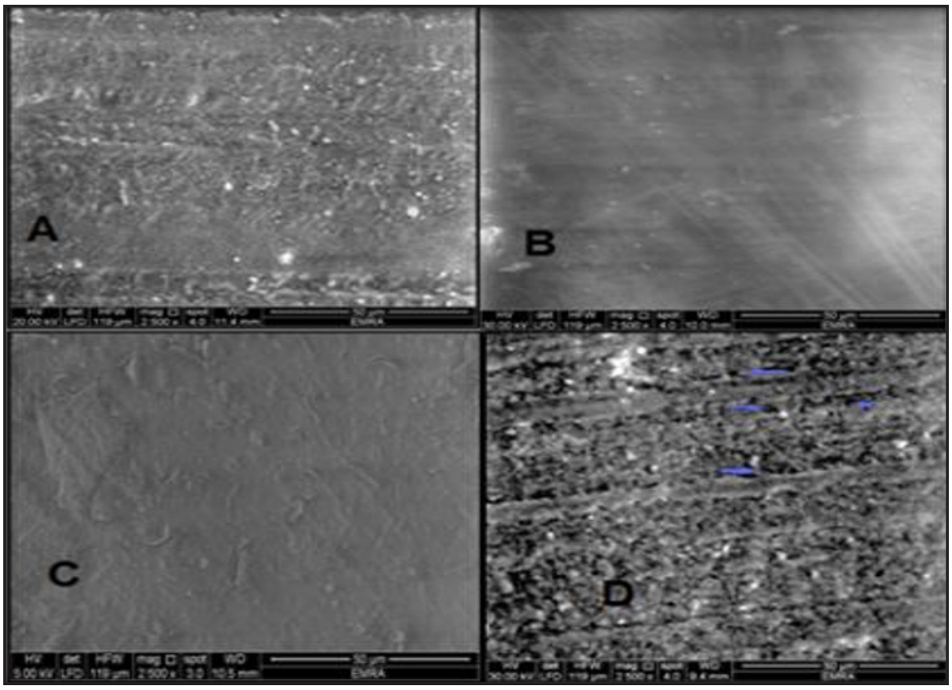

Figure (1) Representative scanning electron microscopic images of surface treated groups (x2500): (A) control, (B) liner treated, (C) silica coating then (D) laser treated groups (blue arrows show surface irregularities).

Table (1) *Comparison between groups as regade veneering method used*

Groups	Veneering	N	Mean	SD	Minimum	Maximum	Mean Difference	T	Sig.
Control	Layering	8	13.90	2.16	11.32	18.16	-3.20	-3.00	**0.01***
	Pressing	8	17.10	2.11	14.85	20.45			
liner app	Layering	8	16.19	2.81	14.02	22.65	-2.48	-1.81	0.091
	Pressing	8	16.93	2.66	14.89	23.54			
silca coat	Layering	8	17.16	3.22	11.57	20.78	-0.55	-0.31	0.76
	Pressing	8	17.72	3.86	10.80	22.80			
Laser	Layering	8	17.42	2.07	14.43	20.52	-1.07	-0.89	0.391
	Pressing	8	18.48	2.71	14.70	22.39			

P-value ≤ 0.05 significant while, P> 0.05 indicates non-significant difference

III. Analysis of failure mode for the fractured specimens after sheer test using stereomicroscope :

Among all the surface treated sub groups, three modes of failure were noted: adhesive between zirconia and its veneer, cohesive within the veneering materials or mixed failures (both failure modes).

DISCUSSION

The introduction of Y-TZP zirconia core allowed the application of a more successful and reliable restorations. Currently more complex restorations are probable due to the unique and excellent properties of zirconia [19].

The major causes of failure of zirconia fixed restoration usually were owing to chipping-off or delamination of the ceramic veneer. Primarily this will be the veneering ceramic which need to be with adequate strength to resist the mastication stresses so prevents its delamination [20], or the bond strength between the core and ceramic veneer [21].

The change in thickness ratio, coefficient of thermal expansion mismatch between the core and veneering material , their mechanical properties and thermal conductivity have an effect on the durability of these bilayered restorations [22].

Regarding the surface treatment effect on the zirconia veneering ceramic bond strength the results were the control group showed the statistically significant lowest mean value (13.90±2.16MPa). This may be justified because the untreated zirconia smooth surface is unsuitable for bonding; this data was supported by SEM image in which the control group didn't show any retentive surface features on the zirconia surface in comparison with the other surface treatments Figure1A. This results were concomitant with other studies [15,17,23, 24] which found that the untreated zirconia group showed lower mean shear bond strength value.

No statically significant effect on the sheer bond strength between The surface treated groups, however the laser group had the highest mean value (17.42±2.07 MPa) Table 1 for layering sub-group and (18.67±2.66 MPa) Table 1 for press on subgroup, followed by the silica coating group (17.16± 3.22MPa) Table 1 for layering sub-group and (17.2 ±3.86 MPa) Table 1 for press on subgroup then liner group (16.29±2.1MPa) Table 1.

In the current study the highest bond strength value for laser group could be possibly due to the rough zirconium surface and this is supported by SEM evaluation for the samples that treated with laser in which distinctly rough surface with sharp boundaries, surface scratches and irregular surface texture throughout the zirconia surface were observed Fig(1).

This was in accordance with other studies [23,25,26] which found that there was a significant increase in the zirconia-veneer bond strength of laser treated zirconia. This explained by the increased surface roughness which results in micromechanical retention. It was found that Er: YAG laser evaporates the water content of the lased surface moreover, micro-explosions result in the formation of micro-porosities and increased micromechanical retention. So that the surface treatment using laser application has been used to increase roughness of zirconium surface and enhance the bonding with the veneering ceramics.

On the other hand another study found that the bond strengths of the laser group were not higher than the control one. They explained that this was due to the inherent reflective property of the ceramic and the low level of laser energy absorption within its surface. Also the alternate warming and cooling phases cause internal tension in the material, which is likely to negatively affect its mechanical properties [27].

In the silica treated group, the mean sheer bond strength was statistically higher than the control group. It might be interpreted by the chemical bond formed between the veneering ceramics and silica coated zirconia core which was supposed to be higher than the effect of sandblasting [17].

The result regarding to the silica coating application was in agreement with other study [17] which found that silica coating of zirconia by sol-gel leading to an increase the core veneer bond strength. They explained that the interaction between hydroxyl group in both silica particles and zirconia surface resulting in formation of silica layer on the zirconia surface. Also the chemical bond formed as a result of formation of $ZrSiO_4$, zirconium aluminum oxide and intermetallic compounds leading to enhancement of the zirconia veneering ceramic bond strength. Moreover the large cell volume of $ZrSiO_4$ which is fourfold greater than zirconia resulting in creation of compressive stresses in the coat which can enhance the bonding between zirconia ceramic veneer. This was concomitant with other studies [15,18] which found that the silica coating increase the bond strength of zirconia and veneering ceramic.

Regarding the liner application in case of layering veneered ceramic the bond strength was statically higher than control group. It was assumed that liner application may form an intermediate layer at the zirconia-veneer interface that formed through integration of the particles of both core and veneering material. These particles increase wetting properties that optimize bond strength between zirconia core and its ceramics veneer [28].

These results were concomitant with previous studies [11,13,24,29,30] which found that the application of liner on sintered zirconia increase the bond strength with its layered veneering ceramics. They found that the liner application increase the wettability which affect the bond strength of the veneered restorations.

While in case of liner application in case of press-on veneered ceramic, the bond strength was non statistically lower than the control group with mean value (16.93 ±2.66 MPa)(Table1).

This could be supported by other studies [27,31-33]which found that the liner application decrease the zirconia veneering ceramics bond strength. It was found that the liner application leading to the formation of an intermediary layer with incorporated porosities attributed to brush on technique of application which declining the bond strength of the veneered restorations.

Regarding the effect of veneering technique the results of shear bond strength for control group showed that press-on technique had the statistically significant higher mean shear bond strength (17.10±2.11MPa) than the layering technique (13.90±2.16MPa) at P =0.01 Table 1. While in case of surface treated group there was no statistically significant difference (Table1) .

A possible explanation for this result might be due to better surface contact with core. This is due to applied external pressure which decrease the possibility of micro gap formation at interface between the core and its veneer as result of cooling stresses is limited[22]. Also the strength of the veneering material and its bonding quality to the underlying core are affected by structural defects and air bubble incorporation which decreased by the heat pressing that achieved under controlled conditions and improved the wettability of the zirconia surface by those molten ceramic [23,34].

Our findings were in agreement with a previous studies [31,35] that found that pressing produce a superior bond in comparison to layering veneering technique and it is the technique of choice instead of layering technique.

On the other hand the layering technique is more sensitive and subject to variability due to incremental building, firing procedures, differences in powder to liquid ratio and mixing technique which affect the density, structural defects and the amount of air bubbles with in the veneering material after firing [35].

On the other hand, our results were in contrast to a previous study [36] which found that the bond strength of press-on veneered ceramic was significantly lower than layered one .This possibly clarified by the kinds and composition of the veneering materials in the two sub-groups were different. Also the higher ceramic pressing temperature that was used result in higher tetragonal to monoclinic transformation rate with concomitant higher coefficient of thermal expansion mismatch between the monoclinic zirconia and overlying veneer which in turn create higher tensile stresses at the interface.

CONCLUSIONS

1. Zirconia-veneer bond strength can be enhanced by surface treatments while the surfaces treated groups showed non-statistically difference.
2. Liner application resulting in decrease in the core-veneer shear bond strength for press-on veneering ceramic.

3. Press-on veneering technique represents a reliable method for enhancing the core-veneer shear bond strength.

4. For layering veneering technique the surface treatments have the advantages for enhancing bonding between zirconium core and veneering ceramic.

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