A comparative evaluation of the effect of liners on the shear bond strength of veneered zirconia block: An in vitro study

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Abstract

Aim: This study aims to evaluate the effect of lithium disilicate glass–ceramic liner, silicon dioxide based liner, and glass–ceramic interlayer on the shear bond strength (SBS) of a commercially available veneered zirconia block and to study fractographic behavior of the samples using universal testing machine, scanning electron microscope (SEM).

Setting and Design: In vivo – comparative study.

Materials and Methods: 60 samples were fabricated from VITA (vita zahnfabrik, Bad sackingen, Germany) zirconia discs. Samples were divided into 4 groups with 15 samples each. First is the control group, second is lithium disilicate glass–ceramic liner group, third is silicon dioxide based liner, and fourth is glass–ceramic interlayer group. SBS of samples was recorded using universal testing machine. Samples were further analyzed for fractographic behavior using SEM.

Statistical Analysis Used: One Way ANOVA test, and Chi-Square test.

Results: The intergroup comparison of mean SBS (Mpa) was done using the post hoc Bonferroni test. The mean SBS (Mpa) was significantly more among lithium disilicate and glass–ceramic interlayer groups in comparison to silicon dioxide-based liner group. Fractographic analysis was done using the Chi-square test.

Conclusion: It was concluded that maximum SBS was obtained for lithium disilicate liner. Maximum adhesive failures were found with lithium disilicate liner, and silicon dioxide-based liner group showed cohesive failures.

Keywords: Adhesive failure, cohesive failure, fractographic analysis, glass–ceramic liners, shear bond strength, zirconia

INTRODUCTION

All ceramic dental restorations composed of porcelain veneer on a zirconia substructure are nowadays being commonly used as an alternative to metal ceramic restorations. Chipping and fracturing of layered porcelain (lithium disilicate) applied to zirconia frameworks continue to be a problem with a reported incidence between 0% and 30%. Type of fracture can be adhesive or cohesive.
The adhesive fracture of layered porcelain indicates its poor shear bond strength (SBS). Lithium disilicate with coefficient of thermal expansion (CTE [25°C –800°C]: $\sim9.3–9.9 \times 10^{-6} \text{ K}^{-1}$) is a type of glass ceramic which offers thermal shock resistance, thus leading to a more stable CTE even after multiple firings. The SBS indicates interceramic bond between zirconia core and veneering ceramics. Strong discrepancies in CTE between veneering porcelains and zirconia significantly affect their bond strength. Considerable refinement is required to estimate the interfacial stress at the junction to prevent the fracture and chipping of the restoration. To resolve the problem, researchers have explored various surface treatment methods to improve the bond strength between zirconia and resin-based luting agent, such as airborne particle abrasion, laser treatment, elective infiltration etching, silica coating, and functional monomer application. Sandblasting is the most widely used surface treatment...
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The Journal of Indian Prosthodontic Society | Volume 19 | Issue 4 | October-December 2019

method in dentistry. However, it may initiate some surface defects and compromise the mechanical strength of the ceramic. Liners are proprietary ceramic materials that are suggested by some manufacturers to be applied as an intermediate layer between the zirconia core and the veneer to maximize bond strength, shade effects, fluorescence, and to increase the wetting property on the zirconia surface.

Zirconia surface can be layered with two commercially available glass ceramic that is feldspathic porcelain or feldspathic porcelain with leucite crystal. Use of interlayer liquid suspension of ceramics as liner between zirconia substructure and veneered porcelain can enhance bond strength to great extent.

Bond strength evaluation of layered porcelain over zirconia substructure can be done using shear bond strength test, three and four point flexure, tensile and microtensile bond test. Shear bond tests have been reported as one of the most established bond strength tests in literature. SBS measurements showed that veneering porcelain on zirconia with lithium disilicate glass–ceramic liner fired at 85°C (vitali850) had the highest mean SBS. Failure modes has been classified as cohesive failure within veneering porcelain, adhesive failure between glass–ceramic liner and zirconia substructure, and combined failure with both cohesive and adhesive failure, although the fractographic behavior of zirconia blocks veneered with ceramic is still not very well understood.

The purpose of present study was to evaluate the efficacy of lithium disilicate glass–ceramic liner as a liner and to compare it with various other commercially available liners to increase the SBS of veneered zirconia block and to study its fractographic behavior.

**MATERIALS AND METHODS**

The study was approved by institutional board (ref no: SGTU/FDS/24/1/717). Total of 60 samples were fabricated from VITA (Vita Zahnfabrik, Bad Sackingen, Germany) zirconia discs (ADA Standard No. 131-2015), measuring 7 mm diameter and 3 mm height [Figure 1]. Samples were fabricated using computer-aided design and computer-aided manufacturing technology and finished with ultrasonic cleaner and steam cleaner. 60 samples were divided into four groups based on application of liner at the time of layering of zirconia samples with porcelain; group 1 (control group - no liner), group 2 (lithium disilicate glass ceramic liner), group 3 (silicon dioxide-based group) & group 4 (glass ceramic interlayer) (ADA Standard No. 64-2010). [Figure 2 and Table 1].

Fabrication of customized jig

To standardize the thickness of liner, layered dentin, and enamel over zirconia block, a custom-made metallic jig of stainless steel was fabricated [Figure 3]. Jig comprised of one 3 mm thick base metal plate and three metal plates with 0.5 mm thickness. All four metal plates had a 7 mm diameter hole in center.

Purpose of base metal plate was to fabricate zirconia block of 7 mm diameter and 3 mm height and three metal plates
were used to standardize the thickness of liner, layered dentin, and enamel over zirconia block of 0.5 mm thickness.

**Layering and veneering of zirconia samples**

60 samples were divided into 4 groups with 15 samples each.
- **Group I** - Control group
- **Group II** - Lithium disilicate glass–ceramic liner group
- **Group III** - Silicon dioxide-based liner
- **Group IV** - Glass–ceramic interlayer group.

The prepared samples from Group 1 to IV will be steam cleaned and taken up for ceramic layering.

**Group I**

Samples were fabricated using custom-made metallic jig to obtain samples of uniform thickness. Dentin powder was mixed with modelling liquid as per manufacturer's instruction. A custom made zig was used for application of dentin over zirconia core to achieve a uniform thickness of 0.5 mm and fired at 910°C. This was followed by application of 0.5 mm of enamel layer fired at 900°C. Samples were finished with a diamond bur to achieve a final uniform thickness of 4 mm.

**Group II**

In lithium disilicate glass–ceramic liner group, samples were placed in the custom jig and then 0.5 mm thick lithium disilicate glass–ceramic liner (IPS e.max Press) was layered and fired at temperature 930°C followed by 0.5 mm dentin layer (VITA VM9 [Vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 910°C and then 0.5 mm enamel layer (VITA VM9 [vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 900°C. Fifteen samples were veneered in the same pattern. Finally, samples were finished with a diamond bur to achieve a total uniform thickness of 4.5 mm. Chairside polishing of samples of each group was done using Komet Ld 0707 polishing kit.

**Group III**

In silicon dioxide-based liner, sample is placed in the custom jig and then 0.5 mm thick silicon dioxide-based liner (Vita Zahnfabrik. Bad Sackingen, Germany) was layered and fired at temperature 930°C and 0.5 mm dentin layer (VITA VM9 [vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 910°C and then 0.5 mm enamel layer (VITA VM9 [vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 900°C. Fifteen samples were veneered in the same pattern. Finally, samples were finished with a diamond bur to achieve a total uniform thickness of 4.5 mm.

**Group IV**

In glass–ceramic interlayer group, samples were placed in the custom jig and then 0.5 mm thick dentin (dentin interlayer) was layered and fired at temperature 930°C and 0.5 mm dentin layer (VITA VM9 [vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 910°C and then 0.5 mm enamel layer (VITA VM9 [vita Zahnfabrik. Bad Sackingen, Germany]) was applied and fired at temperature 900°C. Fifteen samples were veneered in the same pattern. Finally, samples were finished with a diamond bur to achieve a total uniform thickness of 4.5 mm.

**Testing of samples for shear bond strength**

60 samples were loaded under a standard shear load at a crosshead speed of 0.5 mm/min, and load was recorded using universal testing machine (Asian Universal Testing Machine, LRX 2K5, Hants, UK) [Figure 4]. A chisel load applicator was used to direct a parallel shearing force to the substructure/veneer ceramic interface.

**Testing of samples for fractographic behavior**

60 samples were also analyzed for fractographic behavior (adhesive and cohesive) using scanning electron microscope (SEM) (LEO Evo 40X VP; Carl Zeiss AG, Oberkochen, Germany). Sample was taken for evaluating the fracture mode. SEM study was done at 49 X, 350 X and 1000 X. Statistical analysis was done.

**RESULTS**

**Evaluation of shear bond strength**

Sixty samples were loaded under a standard shear load at a crosshead speed of 0.5 mm/min, and load was recorded using universal testing machine (Asian universal testing machine, LRX 2K5, Hants, UK). The values obtained were recorded in mpa which form the basic data of the study. Data were subjected to statistical analysis (one-way ANOVA test). The SBS of 4 groups is shown in Table 2.

There was a significant difference in mean SBS (Mpa) between control group [Figure 5], lithium disilicate group [Figure 6], glass–ceramic interlayer [Figure 7], and silicon dioxide-based liner groups [Figure 8].

| Group                  | Mean (mpa) | SD    | F     | P       |
|------------------------|------------|-------|-------|---------|
| Control group          | 21.21      | 10.13 | 50.55 | <0.001* |
| Lithium disilicate group| 62.40      | 11.39 |       |         |
| Glass-ceramic interlayer| 61.07      | 12.38 |       |         |
| Silicon dioxide-based liner | 33.55   | 10.58 |       |         |

*Significant difference. SD: Standard deviation, SBS: Shear bond strength.
Evaluation of fractographic behavior
The fractographic behaviour of fractured samples was studied using SEM (LEO Evo 40XVP; Carl Zeiss AG, Oberkochen, Germany) and observed as adhesive failure, cohesive failure and combined failure. The distribution of mode of failure was obtained using Chi-square test.

The distribution of mode of failure was compared between control group, lithium disilicate liner, glass–ceramic interlayer, and silicon dioxide-based liner groups using the Chi-square test. A significant difference was found in the distribution of mode of failure between control group, lithium disilicate liner, glass–ceramic interlayer, and silicon dioxide-based liner groups.

DISCUSSION
Bond strength of zirconia with veneered ceramics is influenced by many factors such as strength of chemical bonds, mechanical interlocking, type and concentration of defects at the interface, inappropriate framework support for the layering porcelain, wetting properties, and the degree of residual compressive stress in the veneering layer due to a difference in the CTE between zirconia and the veneering ceramic. For veneering zirconia, silicate ceramics are used. Silica coating of zirconia, therefore, may be considered to enhance bond strength.\[7\]

The purpose of present study was to evaluate and compare the SBS of various commercially available liners and to study their fractographic behavior. Various commercially available liners used in the study are lithium disilicate glass–ceramic liner, silicon dioxide-based liner, and glass–ceramic interlayer.

Lithium disilicate glass–ceramic, in particular the Li$_2$O–SiO$_2$ system, is the first material classified as glass ceramic discovered by stokey as having better mechanical properties over base glass.\[8\] Mean SBS between veneering porcelain and zirconia substructure was significantly improved with lithium disilicate glass–ceramic liner. Factor which led to improved SBS is good cohesion between glass–ceramic liner and veneering porcelain. Al-Dohan et al.\[9\] demonstrated that most of the studies that performed macro shear bond test showed that most fractures occurred in the veneering layer (cohesive failure). The SBS of veneering ceramics was higher than SBS between core and veneering ceramics, and the failure mode observed was mainly combined as adhesive at the interface and cohesive in the veneering ceramic.\[10,11\] SBS between zirconia core and veneering ceramics was not affected by thermocycling.\[12\]

Glass–ceramic interlayer is a liquid suspension used between zirconia substructure and veneering porcelain to enhance their adhesion. Glass–ceramic interlayer is either feldspathic porcelain or a mixture of feldspathic porcelain and leucite crystals.\[13\] Silicon dioxide-based liner is a VITA VM9 effect liner (VITA Zahnfabrik Bad Sackingen Germany) which has been used in the study as a test group. Aboushelib et al. pointed out that the core–veneer interface is the weakest part of the all-ceramic restorations and plays a significant role in the success of all ceramic restorations.\[14–16\]

The present study compared the efficacy of three commercially available liners which consisted of 60 samples of zirconia blocks which were divided into 4 groups with 15 samples each. First is the control group, second is lithium disilicate glass–ceramic liner group, third is silicon dioxide-based liner, and fourth is glass–ceramic interlayer group.

From the results obtained, Table 2 and Graph 1 depict the mean SBS of each group of zirconia samples. The maximum and minimum SBS was obtained for lithium disilicate liner and control group, respectively. With one-way ANOVA test, there was a significant difference in mean SBS (Mpa) between control group, lithium disilicate group, glass–ceramic interlayer, and silicon dioxide-based liner groups. In the case of lithium disilicate, CTE mismatch would be less of a consequence since it has a low CTE, which is also compatible with both feldspathic porcelain and zirconia. Therefore, the CTE of lithium disilicate glass–ceramic liner tends to be stable after multiple firings.

Wattanasirikit et al.\[17\] concluded that the highest SBS of vital850 was a result of lithium disilicate glass–ceramic forming good adhesion to zirconia and the two veneering porcelain layers.

The mode of failure of fractured samples was observed as adhesive, cohesive and combined failures. The distribution of mode of failure (Chi-square test) was compared between control group, lithium disilicate liner, and glass–ceramic interlayer.

Table 3: Mode of failure was compared between control group, lithium disilicate liner, glass–ceramic interlayer, and silicon dioxide-based liner groups

| Groups                      | Mode of failure |
|-----------------------------|-----------------|
|                             | Cohesive | Adhesive | Combined |
| Control group (%)           | 11 (73.3) | 0 (0.0)  | 4 (26.7)  |
| Lithium disilicate liner (%)| 0 (0.0)  | 15 (100.0) | 0 (0.0)  |
| Glass–ceramic interlayer (%)| 0 (0.0)  | 13 (86.7) | 2 (13.3)  |
| Silicon dioxide-based liner (%)| 12 (80.0) | 0 (0.0)  | 3 (20.0)  |

\*Significant difference
interlayer, and silicon dioxide-based liner groups. Table 3 and Graph 2 depict that a significant difference was found in the distribution of mode of failure between control group, lithium disilicate liner, glass–ceramic interlayer, and silicon dioxide-based liner groups. Fischer et al.\[7\] concluded that the bond strength between zirconia and the veneering ceramic was higher than the cohesive strength of the veneering ceramic. In other words, the weakest link was not the interface but the veneering ceramic itself.

The results of the present study depict that SBS is improved by applying a layer of liner (lithium disilicate glass–ceramic liner, glass–ceramic interlayer, and silicon dioxide-based liner). Among these, lithium disilicate glass–ceramic liner showed maximum SBS but there are authors who contradict these theories. Aktas et al.\[17\] stated that the veneering ceramic properties affected the results of SBS to the zirconia core. Choi et al.\[18\] stated that the SBS test has some disadvantages such as high standard deviations, occurrence of nonuniform interfacial stresses, and the influence from specimen geometry. Therefore, the standardization of specimen preparation, cross-sectional surface area, and rate of loading application are important for improving the clinical usefulness of SBS test. Tashkandi\[19\] concluded that better bond strength of zirconia is achieved with air abrasion particles using an experimental primer and SEM study revealed predominantly cohesive failure. Tholey et al.\[20\] stated that veneering porcelain appears to wet and bond well to zirconia framework and on HF etching, moisture created grain faceting at surface of zirconia. López-Mollá et al.\[21\] stated that the lithium disilicate porcelain and their veneer porcelain achieved the highest shear strength. Aalaeeha et al.\[22\] said that there was no statically significant difference between the SBS of three tested veneering ceramics to the zirconia cores. Ozkurt et al.\[23\] concluded that none of the test groups demonstrated cohesive failure within the veneer. Eighty percent adhesive failure was demonstrated when veneered with Cercon ceram. Alghazzawi and Janowski\[24\] stated that pressing technique is considered technique of choice over layering on yttria-stabilized tetragonal zirconia polycrystals. Alsadon et al.\[25\] conducted a study to show that zirconia composite crowns showed similar occlusal load bearing as compared to zirconia porcelain crowns.

Hence, it can be concluded from the studies that SBS has improved maximum after applying lithium disilicate glass–ceramic liner followed by glass–ceramic interlayer and silicon dioxide-based liner. The fractographic behavior showed that zirconia samples lined with lithium disilicate glass–ceramic liner presented adhesive failures (failure between glass-ceramic liner), glass–ceramic interlayer presented adhesive and combined failures (combined failure is both cohesive and adhesive failures), silicon dioxide-based liner presented maximum cohesive failures (failure within veneering porcelain), and control group showed both cohesive and combined failures.

Despite many advantages of an in vitro study, some critical aspects must be taken into account when using an in vitro method to estimate the clinical performance of materials.\[26\]

Hence, the limitation of the present study was that in vitro information cannot be used as a direct, straightforward prediction for the clinical situation. Second, large variations exist in in vitro test results. In the case of the SBS test method, a concerted effort must be made to standardize the test method so as to improve the clinical usefulness of this in vitro test. Further, other important aspects that must be considered during an SBS test include storage conditions, type of specimen used and the preparation method, rate...
CONCLUSION

Under the limitations of the study, it can be safely concluded that SBS was maximum after applying lithium disilicate glass–ceramic liner at 930°C followed by glass–ceramic interlayer at 930°C and silicon dioxide-based liner at 930°C. The fractographic behavior showed that zirconia samples lined with lithium disilicate glass–ceramic liner presented with adhesive failures (failure between glass–ceramic liner). The use of silicon dioxide-based liner showed cohesive failures (failure within veneering porcelain) while the control group showed both cohesive and combined failures.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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