

Shear Bond Strength of Porcelain Veneering to Nickel-Chromium, Chromium-Cobalt, Zirconia and Lithium Disilicate

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Abstract

Background and Aim: High chipping rates of the veneering porcelain in zirconia ceramic restorations have been reported in many clinical studies. However, information on the bonding behavior of veneering porcelain to zirconia and lithium disilicate frameworks is limited. The purpose of this study was to evaluate the bonding strength of porcelain veneering to zirconia, lithium disilicate, nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr) alloys.

Materials and Methods: In this in vitro experimental study, core specimens were fabricated with 12 mm height and 11 mm diameter, and veneering specimens were fabricated with 7 mm height and 5 mm diameter according to the manufacturer's instructions in four groups (n=12) as follows: Group I: Ni-Cr alloy, group II: Co-Cr alloy, group III: lithium disilicate, and group IV: zirconia. The shear bond strength (SBS) test was performed in all samples with a universal testing machine with a crosshead speed of 0.5 mm/min. The fractured samples were examined under a stereomicroscope (×10) to determine the mode of failure. The results were analyzed by one-way ANOVA (P<0.05).

Results: Maximum SBS was recorded in group IV (zirconia; 34.6 MPa) followed by groups II (Co-Cr; 30.66 MPa), I (Ni-Cr; 30.58 MPa), and III (lithium disilicate; 20.05 MPa). One-way ANOVA revealed no significant difference between the study groups (P=0.174).

Conclusion: The SBS of porcelain veneering to zirconia, lithium disilicate, Ni-Cr, and Co-Cr alloys was not significantly different.

Key Words: Dental Porcelain, Dental Bonding, Zirconium Oxide, Shear Strength

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Introduction

Nowadays, with the development of dental materials and the variety of ceramic materials, veneers and their bonding methods to the metal core are highly diverse. Furthermore, sufficient

bond strength between the veneering and the core is imperative [1-3]. Despite the success of metal-ceramic restorations in the recent years due to their optimal strength and fracture resistance, the demand for restorations with

high level of esthetics and biocompatibility has led to the common use of restorations with ceramic framework [4]. Currently, various ceramic materials such as reinforced leucite ceramics, glass-infiltrated ceramics, lithium disilicate, alumina and zirconia are used [5]. Mechanical features of the framework and porcelain must be compatible with each other to achieve the required bond strength. A strong bond is an important requirement for the structural integrity of the restoration under functional forces, and is needed to prevent separation and chipping of the veneering [6].

The bonding between the porcelain and metal substructure in porcelain fused to metal restorations has been widely investigated [15]. However, information on the microstructure, mechanism, and strength of the bond between the ceramic core and porcelain veneering in full-ceramic restorations is scarce. Despite various studies concerning the bond strength between many different surfaces, researchers have not achieved a unified acceptable protocol on this subject. Bond strength measurement tests are another issue for which a unified protocol has not been agreed upon, and different methods are used among which the shear test is the most common [16-19].

The strength and quality of the bond between the veneering and the core play important roles in success of bilayer restorations, an issue that needs more investigations. Therefore, the aim of this study was to compare the shear bond strength (SBS) of two types of metal alloys namely nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr), as well as zirconia, and lithium disilicate to the veneering porcelain. The null hypothesis was that there would be no significant difference between the SBS of the tested materials.

Materials and Methods

In this in vitro experimental study, 4 materials were investigated in 4 groups (n=12) as follows (Table 1):

*Group I: Ni-Cr alloy core (Meganium CS, Mega dental GmbH, Germany) with Noritake porcelain veneering (Noritake, Dental supply Co., Ltd, Miyoshi, Japan)

*Group II: Co-Cr alloy core (Bego, Wirobond SG, Wironit, Germany) with Noritake porcelain veneering

*Group III: Lithium disilicate core (IPS e.max press Ivoclar Vivadent AG, Schaan, Lichtenstein) with IPS e.max Ceram porcelain (IPS e.max Ceram, Ivoclar Vivadent AG, Schaan, Lichtenstein)

*Group IV: Zirconia core (Dental direct GmbH, Germany) with Vita VM9 porcelain veneering (Vita Zahnfabrik, Bad Sackingen, Germany)

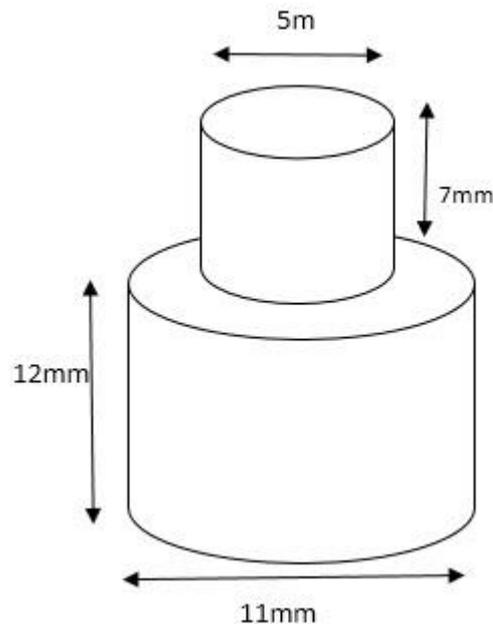
The specimens were prepared in the form of cylinders with core dimensions of 12 mm height and 11 mm diameter. The porcelain veneering samples had 5 mm diameter and 7 mm height (7) (Figure 1).

Preparation of metal core/porcelain veneering specimens (groups I and II):

Ni-Cr and Co-Cr specimens were prepared by wax-up (cylindrical wax pattern measuring 12 mm × 5 mm). After wax burn-out and casting according to the manufacturers' instructions, the specimens were sandblasted with 250 μm aluminum oxide particles with 0.4 MPa pressure for 10 s at 10 mm distance from the nozzle. Next, their surface was completely cleaned in an ultrasonic bath containing 70% ethanol for 5 min [8]. Eventually, they were degassed, and porcelain was applied to the prepared surfaces. Application of the first layer of opaque porcelain as a thin wash on the core was an important point that was followed for all specimens. After firing the opaque layer at 940°C, dentin layers (A2 shade; Noritake Dental Supply Co., Miyoshi, Japan) were applied and fired at 920°C for the first layer and 910°C for the next layers according to the manufacturer's instructions [20]. A metal cylindrical mold (5 mm diameter and 7 mm height) was used to standardize the dimensions of the veneering. The porcelain veneering specimens were fabricated slightly larger to compensate for the shrinkage during the firing procedure. After completion of condensation, excess moisture was removed with absorbent paper, and the mold was carefully removed. The specimens were fired in a furnace (AT300; KFP Dental, Tehran, Iran) for dentin firing. After the first firing cycle, another layer of ceramic was

Table 1. Materials used in this study

| Material | Manufacturer | Lot number | Composition |
|--|--|------------|---|
| (Brand name) Ni-Cr alloy | Meganium CS | 140604 | Ni:53%,Cr:23%,Mo:10%,Fe:1.5% |
| (Mega Dental) Co-Cr alloy | Mega dental GmbH, Germany | | Ce<1%,Si:2% |
| (Bego) Lithium disilicate | Bego, Wirobond SG, Wironit Germany | | Co:61.5%,Cr:26%,Mo:6%,W:5% |
| (IPS e.max) Zirconia | IPS emax press Ivoclar Vivadent AG | U41128 | SiO ₂ :57%,Li ₂ O:11%,K ₂ O:6.5% |
| (Direkt Dental) Feldspathic porcelain | Schaan, Liechtenstein Direkt dental GmbH Germany | 5011839002 | P ₂ O ₃ :5.5%,ZnO:4% ZrO ₂ :94.4%,Y ₂ O ₃ :5.4% |
| For base metal alloy Noritake Feldspathic porcelain | Noritake Dental Supply Co., Ltd | DUODA | SiO ₂ :57%-61%, AL ₂ O ₃ :13%-16% |
| For zirconia VM9 Feldspathic porcelain | Miyoshi, Japan | | |
| For lithium disilicate IPS e.max Ceram | Vita Zahnfabrik Badsackingen, Germany | 41030 | SiO ₂ :59%-63%, AL ₂ O ₃ :13%-16%, K ₂ O:9%-11%,Na ₂ O:4%-6% |
| | Ivoclar vivadent AG Schaan, Liechtenatein | L09526 | SiO ₂ :50%-60% ,AL ₂ O ₃ :16%-22% Na ₂ O: 6%-11%, K ₂ O: 8%,CaO,P ₂ O ₅ ,F:2%-6%,other oxide:1.5%-8%, Pigments:3% |

**Figure 1.** Schematic drawing of sample dimensions

applied and excess water was removed again. Then, they were fired for the second time at 910°C. Finally, excess veneering material was removed by a high-speed diamond bur and handpiece under cool water to reach 5 mm diameter and 7 mm height. This process was carried out for each of the four groups, except when applying the opaque layer for groups III and IV.

Preparation of lithium disilicate core/porcelain veneering specimens (group III):

IPS e.max cylindrical specimens were fabricated with the desired dimensions using the press technique (after wax-up and burn-out) according to the manufacturer's instructions. Wax burn-out was accomplished in a specialized press furnace (Vita, Vident, CA, USA) at 870°C temperature. After the furnace's temperature reached 700°C, the lithium disilicate ingots were pressed by an Alox plunger. This process took about 25 min. Surface preparation was then carried out by distilled water rinse and immersion in an ultrasonic bath containing 70% ethanol for 5 min to eliminate the contamination. Finally, e.max Ceram porcelain veneering was applied according to the manufacturer's instructions. At first, a wash layer of porcelain was applied on the core and fired at 760°C (Programat P510; Ivoclar, Vivadent, Schaan, Lichtenstein), and then another layer of dentin ceramic with the desired dimensions was applied and fired at 450°C starting temperature, 45°C/min heating rate, and 750°C ending temperature (for 1 min before cooling) [8].

Preparation of zirconia core/porcelain veneering specimens (group IV):

Zirconia cores were fabricated from presintered Dental Direkt blocks (Dental Direkt GmbH, Germany) which undergo shrinkage. Therefore, zirconia cores were fabricated 20% larger to reach the ideal dimensions after the firing process. Zirconia cores were sintered at 1450°C temperature for 10 h in a specialized furnace (Sirona in lab MC XL; Cerec, Germany) after cutting by a computer-aided design and computer-aided manufacturing device (M1, Zirkozahn GmbH, Bruneck, Italy). Then, surface preparation was carried out by

sandblasting with 50 µm aluminum oxide particles at 0.4 MPa pressure, rinsing with distilled boiling water to remove contamination and lipids, and using an ultrasonic bath containing 70% ethanol for 15 min. The porcelain veneering (Vita VM9, Vita Zahnfabrik, Germany) was applied as follows: a wash layer of porcelain and then a layer of dentin ceramic were fired at 930°C according to the desired dimensions [9]. All specimens were stored at 37°C temperature for 24 h after preparation.

To assess the SBS of specimens, they had to be mounted in the test device's specialized copper molds. For this purpose, the molds were filled with auto-polymerizing acrylic resin (Acropas, Tehran, Iran), and the specimens were mounted in the molds in such a way that the core was mounted in the acrylic resin and the porcelain veneering-core interface positioned 3 mm above the acrylic surface [6]. The interface was exactly parallel to the mold surface because any angle between the mounted specimen's interface and the force application axis would lead to wrong measurement of SBS. Therefore, each specimen was first connected to the analyzing rod of a surveyor and was placed in the acrylic while the specialized mold was on the surveying platform. At 24 h after self-curing of acrylic resin, the specimens were placed in a universal testing machine (Z050; Zwick Roell, Ulm, Germany) and the machine's chisel-shaped vertical arm was set to apply the force exactly to the veneering-core interface. The crosshead speed was 0.5 mm/min, and load was applied continuously until failure (Figure 2). The force at failure of specimens was measured and recorded in Newtons and converted to megapascals (MPa) using the following formula: $SBS (MPa) = Load (N) / surface\ area (mm^2)$. After the SBS test, the mode of failure was investigated under a stereomicroscope at X10 magnification and categorized as follows:

- Adhesive failure: if the veneering layer was completely separated from the core.
- Cohesive failure: if the ceramic veneering or the core mass fractured.
- Mixed (adhesive/cohesive) failure: if both fractures occurred at the same time.

The data were analyzed using SPSS version 25,

and a comparison between the groups was carried out using one-way ANOVA. The significance level was set at $P < 0.05$ in all tests.



Figure 2. Sample placed in a universal testing machine for measurement of shear bond strength

Results

Table 2 shows the mean SBS of porcelain veneering to the core material in the four groups. The maximum SBS was recorded in group IV (zirconia; 34.6 MPa) followed by groups II (Co-Cr; 30.66 MPa), I (and Ni-Cr; 30.58 MPa) and finally III (lithium disilicate; 20.05 MPa). One-way ANOVA revealed that there was no significant difference between the study groups ($P = 0.174$).

Microscopic observations at X10 magnification revealed that 7 samples in group I (Ni-Cr) showed mixed (adhesive/cohesive) failure and 5 samples showed adhesive failure. In group II (Co-Cr), fracture of 6 samples was mixed (adhesive/cohesive) and 5 samples showed cohesive failure. In group III (lithium disilicate), 8 samples showed cohesive failure and the others showed mixed (adhesive/cohesive) failure. In group IV (zirconia), almost all specimens showed adhesive failure and, a small amount of adhesion between the ceramic and

core was seen at some parts of the discs' edges (Figure 3).

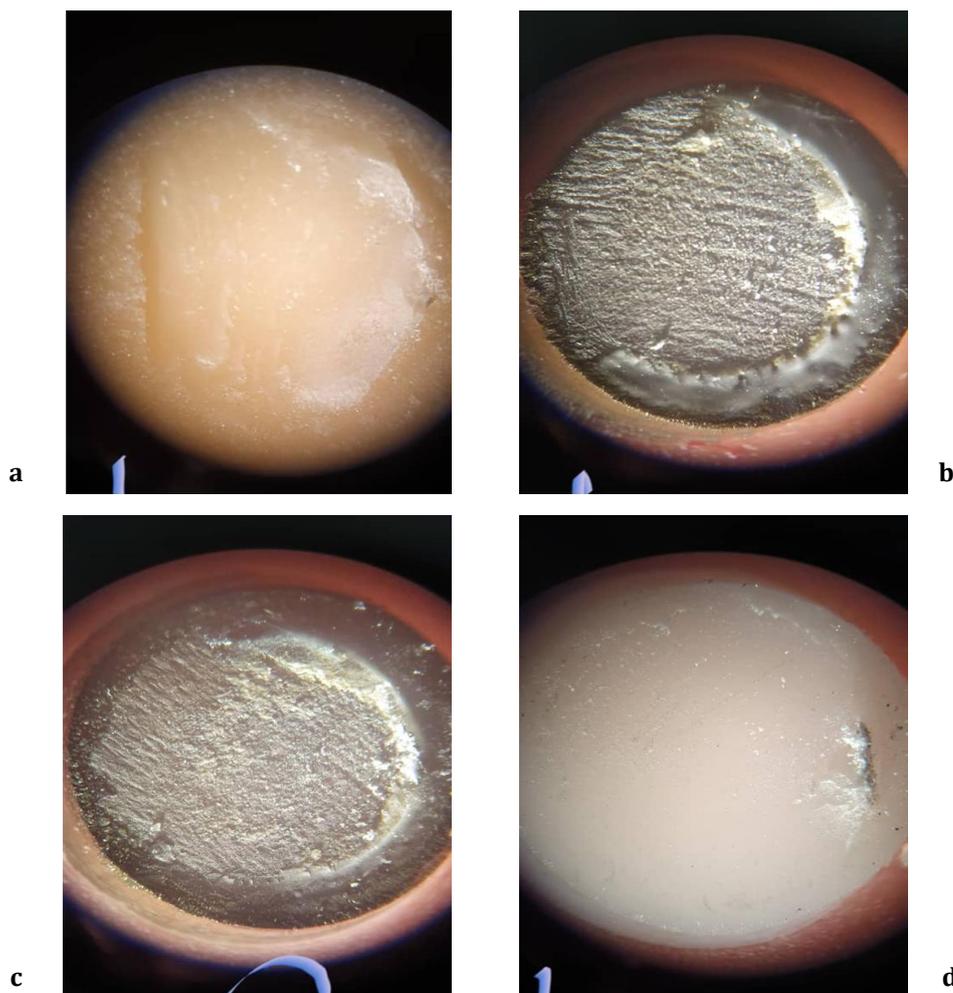
Discussion

In the present study, the mean SBS of the study groups was not significantly different although the SBS of zirconia core group (34.06 MPa) was slightly higher than that of other groups while that of lithium disilicate (25.05 MPa) group was minimum. Therefore, the null hypothesis was accepted. Part of our results was similar to the findings of Eriefej et al, [10] and Al-Dohan et al [11]. Eriefej et al. [10] assessed the SBS of zirconia (ZirCAD/Ceram) and lithium disilicate (LS/Ceram) and reported that the difference in their SBS was not significant (28.8 MPa for zirconia and 29.1 MPa for lithium disilicate).

Al-Dohan et al. [11] compared various veneering and core compounds including IPS Empress 2, Procera all Zircon, and DC Zircon, and suggested the use of veneering by the same manufacturer as the core and found no significant difference between them (lithium disilicate group and two zirconia groups). In the present study, because of technical errors in two specimens, the mean SBS of the e.max group (lithium disilicate) was found to be slightly lower than that of other groups. The SBS of the veneering to the zirconia core was 34 MPa and did not have a statistically significant difference with that of other groups. Choi et al. [12] compared the SBS of zirconia, base metal alloys, and high noble alloy cores and showed a significant difference between the zirconia cores with the other two groups of base metal (35.87 MPa) and high noble (38 MPa) alloy cores. The results of the present study were in contrast to those of Choi et al [12]. This difference can be due to multiple factors such as the study design, methodology, operator's skills and experience, and preparation and shape of specimens. The minimum bond strength for metal-ceramic systems reported by the standardization organizations is 25 MPa [13]. Due to the ceramic cores' brittleness, some tests such as three-point bending and biaxial flexural tests cannot be used for multilayer full-ceramic systems [13]. Al-Dohan et al. [11] stated that the

Table 2. Mean shear bond strength (MPa) of different materials (n=12)

| Group | Mean (MPa) | Max. | Min. | Std. deviation |
|-------|------------|-------|-------|----------------|
| I | 30.58 | 40.74 | 0.00 | 13.08 |
| II | 30.66 | 39.77 | 5.19 | 9.51 |
| III | 25.05 | 50.25 | 19.19 | 8.88 |
| IV | 34.67 | 42.59 | 19.06 | 6.66 |

**Figure 3.** Failure modes under a stereomicroscope (X10 magnification): (a) lithium disilicate, (b) Co-Cr, (c) Ni-Cr, and (d) zirconia

SBS of commercially available core-veneer full-ceramic systems is 22-31 MPa. In the present study, high SBS of zirconia core group (34 MPa) can be a result of the core surface's preparation for porcelain veneering application

or a result of coordination of the coefficients of thermal expansion (CTE) of the core and the veneering. The zirconia core's surface was prepared by sandblasting with 50 μm aluminum oxide particles at 0.4 MPa pressure which

increased the bond strength. The sandblasting procedure has an important effect on bond strength, and other factors including the particle size, pressure, and duration of sandblasting affect the surface roughness and SBS. Other studies have pointed out that large sandblasting particles or high-level of zirconia surface roughness do not increase the SBS [14,15]. Another effective factor is the removal of surface contamination that must be done for all cores to have a suitable veneering connection. Using lipid solvents such as acetone or 70% ethanol for 10 min, ultrasonic bath, and boiled distilled water help to eliminate surface contaminations and improve the bond strength. Furthermore, heat treatment (regeneration firing) was performed at 1000°C for 15 min for the zirconia surface preparation, before the application of porcelain, to modify the zirconia surface after sintering according to the manufacturer's instructions to remove the tension between the frame and the veneering [9]. The proper bond strength between the veneering and the core depends on factors including chemical bonding, mechanical bonding (mechanical interlocking), type and accumulation of interface defects, wetting properties, degree of compressive stress, and the difference in the CTE of the veneering and the core [15].

Applying liner to increase the SBS should be according to the manufacturer's instructions. However, using liner can significantly increase the bond strength in some systems such as Cercon and Ceram S while some other systems like Lava Dentine and Rondo Shoulder do not recommend a liner [16]. In the present study, according to the manufacturer's instructions, liner was not used. Heat treatment before porcelain application has an important effect on the oxide layer formation in metal-ceramic restorations [17]. If this oxide layer is not formed during ceramic layer sintering, or is thin, a weak bond is resulted. On the other hand, a heavy oxide layer must be avoided because it leads to weak cohesive strength and disrupts the mechanical bonding [17]. According to the manufacturer's instructions, oxide layer formation occurs in nickel and cobalt base

alloys. In the present study, the SBS of Ni-Cr and Co-Cr groups was similar (30 MPa). Base metal alloys' failure has been reported to be at the interface; therefore, it is believed that the oxide layer is weaker than the veneering porcelain.

Another important factor that affects the bond strength is the CTE coordination of the veneering and porcelain. Generally, the CTE of the veneering must be approximately 10% to 15% less than the core. The reasonable CTE difference between metal and porcelain is almost $1.0 \times 10^{-6} \text{C}$ [18]. Komine et al [7] showed that porcelain veneering/ceramic cores' CTE difference was similar to that of metal-ceramics which leads to compression of the porcelain veneering on the ceramic core after firing. A higher CTE discrepancy between the core and porcelain veneering causes a considerable decrease in SBS. Aboushelib et al, [16] also showed that a narrow positive mismatch between the core and the veneering is effective in success of full-ceramic restorations.

Various tests have been mentioned in the literature for bond strength investigation such as biaxial flexural strength test, three- and four-point loading tests, SBS test, and micro-tensile bond strength test [12,20]. Al-Dohan et al. [11] believed that the shear test is the best test for porcelain bond investigation. In the present study, SBS test was chosen due to its simple protocol and specimens' preparation but it has some limitations such as high standard deviation, non-uniform interfacial stress, and influence of specimen geometry. Therefore, standardization of prepared specimens, cross-sectional surface area, magnitude of load application, and the crosshead speed of the universal testing machine are important factors in this test. Higher force application rates lead to nonhomogeneous stress distribution and higher possibility of cohesive fracture. In the present study, this rate was set at 0.5 mm/min [21].

To investigate the failure type, a stereomicroscope at X10 magnification was used and the resulting failures were divided into 3 groups of adhesive, cohesive and mixed. In the lithium disilicate group, failures were mainly cohesive in the veneering ceramic. This

shows that the veneer/core bond was stronger (adhesive) than the cohesive strength of porcelain veneering. Ereifej et al. [10] reported the same result. Some other samples in lithium disilicate group showed a combination of adhesive and cohesive failures.

In the alloy groups, a combination of adhesive and cohesive failures was observed. Adhesive failure at the center of the discs and cohesive failure at the specimen margins were also noted such that some parts of porcelain remained on the metal frame. Cohesive failure was observed more in the Co-Cr alloy than the Ni-Cr alloy. It seems that the bond strength between the veneering and Co-Cr alloy is more than that of Ni-Cr alloy. In the zirconia group, the failure was mainly adhesive and this shows that the veneer/core zone is the weakest.

Understanding failure development in dental ceramics is important to reinforce and improve ceramic properties. Fractography, which was not used in this study, is a strong tool in understanding the mechanics of brittle materials' failure such as dental ceramics. According to Lopez-Molla et al [3], fracture development in restorations with zirconia cores differs from restorations with lithium disilicate cores. In restorations with lithium disilicate cores, the fracture starts at the surface, passes through the veneering thickness, and after passing the interface, continues in the core in the same path. But in zirconia core restorations, the fracture either deviates or stops after reaching the interface [3].

The present study had some limitations. Thermal changes, chewing forces, fatigue phenomenon, and aging, which were not investigated in this study, are other important factors in evaluating the bond strength. Also, the investigated specimens in this study could not reflect the intraoral restorations' conditions completely. Thermocycling and cyclic loading should be performed in future studies.

Conclusion

Within the limitations of this study, it can be concluded that:

1-The SBS of the four study groups was not significantly different.

2-The mode of failure in the lithium disilicate group was mainly cohesive in the veneering. However, it was adhesive in the zirconia group and occurred at the interface of the veneering porcelain and the core. A combination of adhesive/cohesive failures was noted in alloys.

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