RESEARCH PAPER

An in vitro evaluation of shear bond strength of layered veneering ceramics to metals and zirconia

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ABSTRACT

The bonding integrity between veneering ceramic and core materials plays a crucial role in the clinical success and longevity of fixed prosthodontic restorations. This in-vitro study was designed to assess and compare shear bond strength of veneering ceramic to three core materials: conventional metal, direct metal laser sintering (DMLS) and zirconia. A total of 30 specimens were fabricated and divided into three groups (n=10 each). All specimens were surface treated, veneered with compatible ceramics, and subjected to shear bond strength testing using a universal testing machine. Fracture patterns were evaluated under a stereomicroscope and classified as adhesive, cohesive, or mixed failures. The mean shear bond strength was highest in the DMLS group (33.49 ± 7.68 MPa), followed by the zirconia group (27.81 ± 10.42 MPa) and conventional metal group (26.97 ± 4.01 MPa). One-way ANOVA showed no statistically significant difference among the three groups (p = 0.148). Tukey's post-hoc analysis also revealed no significant differences in pairwise comparisons. Mixed failure was the predominant failure pattern among all groups, with no significant difference in failure modes. Zirconia, DMLS, and conventional metal core materials demonstrated comparable shear bond strength with veneering ceramics.The shear bond strength of layered veneering ceramics to metal, DMLS and zirconia cores showed no statistically significant difference. Although the DMLS group demonstrated comparatively higher mean bond strength, all three materials exhibited comparable bonding performance with predominantly mixed modes of failure. Therefore, casted metal, DMLS and zirconia can all be considered reliable core materials for veneered ceramic restorations.

Keywords: Shear bond strength, Zirconia, Direct metal laser sintering, Cobalt-chromium alloy,..
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INTRODUCTION

The quest for combining strength and aesthetics in fixed partial dentures resulted in the evolution of metal ceramics in the 20th century [1]. Porcelain fused metal have long been considered the gold standard in fixed prosthodontics due to their proven longevity, mechanical strength, and reliable bond between metal cores and porcelain veneers [2]. The bond strength is achieved through a combination

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of mechanical interlocking and chemical bonding, facilitated by oxide layers forming on the metal surface during porcelain firing. Various alloys are used in metal-ceramic restorations.

Currently, base metal alloys (Co-Cr and Ni-Cr) are mainly used for the fabrication of fixed metal-ceramic restorations. Out of which, Co-Cr base alloy is an unfailing alternative since Ni has been found to cause allergic reactions in patients. The excellent mechanical properties such as high modulus of elasticity, and the high corrosion resistance of Co-Cr alloys, in combination with their significantly low cost, are factors that make these alloys the first choice for dental metal-ceramic applications [3].

Metal alloys have traditionally been cast using traditional techniques, but because of their accuracy and repeatability, modern milling and laser melting technologies are being used more.

Fabrication of the bond also has a profound effect on the bond integrity.

In recent years, there has been a shift in the focus of restorative dentistry towards materials with high aesthetic quality and excellent mechanical properties. The use of layered veneering ceramics in fixed prosthodontics is well suited to provide natural tooth like esthetics on a sound substructure. Although metal-ceramic restorations are designed, they are prone to porcelain fractures within the material, and at the metal-ceramic bond.

In recent years, though, metal-free restorations involving zirconia ceramics are more and more gaining popularity owing to their excellent aesthetic qualities, chemical stability and superior biocompatibility [4]. One of the most common materials for use as a core is yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), which has a high flexural strength and fracture toughness; it is a promising core material for all-ceramic restorations. Zirconia does have mechanical benefits, but it still presents many problems for the bond of veneering ceramic.

The surface chemistry of zirconia differs substantially from porcelain fused metal restorations; zirconia's inert, crystalline structure lacks a glassy phase and readily forms fewer chemical bonds with porcelain, resulting in weaker adhesion.

However, the bonding interface between veneering ceramics and core materials is still crucial despite major advancements in ceramic and core materials. Clinical complications such as veneer chipping and debonding are more frequently reported with both porcelains fused metal and zirconia-based restorations, impacting the restoration's longevity and patient satisfaction.

Shear bond strength testing is a key in vitro method to assess the quality and durability of the ceramic-to-core interface under forces simulating intraoral condition, measuring the maximum stress a material can endure before failing under shear forces.

Thus, the present in-vitro study was performed to compare the shear bond strength of layered ceramics to metal, DMLS and zirconia, and evaluated the associated failure modes.

MATERIALS & METHODS

This in-vitro comparative study included 30 standardized cylindrical core specimens. Each specimen measured 5 mm in diameter and in height. The specimens were allocated equally to three groups (n=10 per group), as summarized in Table 1.

Table 1. Study groups, fabrication procedures and veneering protocol

Core material	Core fabrication and surface preparation	Veneering protocol
Metal	CAM-designed wax patterns; phosphate-bonded investment; induction casting; finishing; 110μm aluminium oxide abrasion at 2-3 bar pressure; ultrasonic cleaning for 10 minutes	Degassing; two opaque layers and dentin porcelain (VITA VMK Master) to 3 mm veneer height
DMLS	Layer-by-layer DMLS using Co-Cr powder under inert gas; 20-30 micrometre layer thickness; 110μm aluminium oxide abrasion at 2-3 bar pressure; ultrasonic cleaning for 10 minutes	Degassing; Two opaque layers and dentin porcelain (VITA VMK Master) to 3 mm veneer height
Zirconia	Five-axis CAD-CAM milling; sintering at 1450-1500 °C; 110μm aluminium oxide abrasion at 2-3 bar pressure; ultrasonic cleaning for 10 minutes	Dentin porcelain (VITA VM9) layered to 3 mm veneer height

Specimen geometry for core fabrication was generated using computer-aided design software and exported as Standard Tessellation Language files. Cast specimens were produced from milled wax patterns and a Co-Cr alloy using an induction casting machine. DMLS specimens were manufactured from Co-Cr powder under an inert atmosphere. Zirconia specimens were milled from zirconia blanks and sintered according to the prescribed cycle. All bonding surfaces were air-abraded and ultrasonically cleaned before veneering.

During metal ceramic layering, metal specimens were degassed to form an oxide layer and then received two thin opaque coats followed by dentin porcelain. Zirconia specimens received a compatible dentin porcelain. A standardized veneer measuring 5 mm in diameter and 3 mm in height was produced for every specimen.

For shear bond testing and failure analysis, the veneered specimens were embedded in acrylic resin blocks to a level

immediately below the core-ceramic junction. A universal testing machine with a 50-kN load cell applied force adjacent to the interface at a crosshead speed of 1.0 mm/min until fracture. Shear stress was calculated as load in newtons divided by bonded area in square millimetres. Fractured surfaces were examined under a stereomicroscope and classified as adhesive, cohesive or mixed [5]. The study used 25 MPa as the minimum acceptable metal-ceramic bond-strength benchmark referenced to ISO guidance [6].
Data were analysed using IBM SPSS software version 20.0 (IBM SPSS, IBM Corp., Armonk, NY, USA). Descriptive statistics were reported for each group along with one-way analysis of variance to assess overall differences, followed by Tukey post-hoc testing for pairwise comparisons. P value of ≤ 0.05 was considered statistically significant.

RESULTS

Table 2 and Figure 1 present the descriptive and inferential findings. The DMLS group demonstrated the highest mean shear bond strength (33.491 ± 7.682 MPa), followed by the zirconia group (27.816 ± 10.427 MPa) and the metal group (26.973 ± 4.018 MPa). Although the DMLS group showed comparatively higher bond strength values, the difference among the three groups was not statistically significant (F = 2.05, p = 0.148).

Table 2. Shear bond strength by core material and overall ANOVA

Core material	Mean (MPa)	SD	95% CI Lower Bound-Upper Bound	F value	p value
Zirconia	27.81	10.42	20.357-35.275		
DMLS	33.49	7.68	27.996-38.986	2.05	0.148
Metal	26.97	4.01	24.099-29.848		

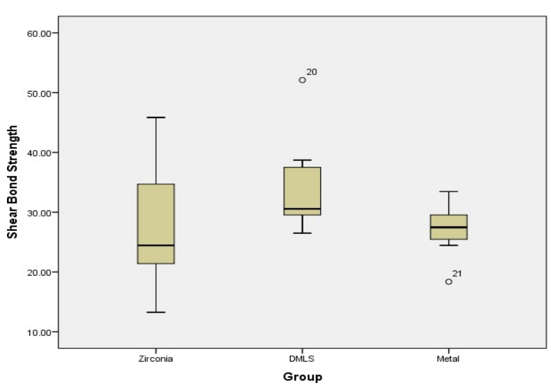

Figure 1. Mean shear bond strength of layered veneering ceramic to the three core materials

Table 3. Tukey multiple pairwise comparisons of shear bond strength

Reference Group	Comparison Group	Mean Difference	p value	95% CI Lower Bound-Upper Bound
Zirconia	DMLS	-5.675	.254	-14.3561-3.0061
	Metal	.843	.969	-7.8381-9.5241
DMLS	Zirconia	5.675	.254	-3.0061-14.3561
	Metal	6.518	.169	-2.1631-15.1991
Metal	Zirconia	-.843	.969	-9.5241-7.8381
	DMLS	-6.518	.169	-15.1991-2.1631

Table3 shows the Tukey multiple pairwise comparison revealed that none of the intergroup differences in shear bond strength were statistically significant. The comparison between zirconia and DMLS groups showed a mean difference of −5.675 MPa (p = 0.254), while the comparison between zirconia and cast Co-Cr groups showed a mean difference of 0.843 MPa (p = 0.969). The DMLS group compared with the cast Co-Cr group demonstrated a mean difference of 6.518 MPa (p = 0.169). Evaluation of the fractured specimens revealed that mixed type failure was the most common mode of bond failure in all three groups, with no statistically significant difference in failure patterns among them.

DISCUSSION

The present in-vitro study evaluated and compared the shear bond strength of veneering ceramic bonded to three different core materials: zirconia, direct metal laser sintering (DMLS) cobalt–chromium alloy, and conventional cast cobalt–chromium alloy.
The success and longevity of fixed prosthodontic restorations depend largely on the integrity of the bond between the veneering ceramic and the underlying core material. The core provides structural support, whereas the veneering ceramic contributes to aesthetics and translucency.
The higher mean shear bond strength observed in the DMLS group of current study may be attributed to the microstructural characteristics produced by the selective laser melting process. DMLS fabricates metal frameworks through a layer-by-layer approach, resulting in a rougher surface morphology that enhances micromechanical retention between the metal framework and veneering ceramic. The increased surface irregularities allow

improved interaction between the ceramic and the underlying framework, contributing to enhanced bonding performance.

Similar observations were reported by Akova et al., who compared laser-sintered and cast base-metal alloys and found that laser-sintered alloys exhibited comparable or slightly higher bond strength values due to enhanced surface roughness and mechanical interlocking [7]. Li J et al. evaluated porcelain bonding to cobalt-chromium alloys fabricated using casting, milling, and selective laser melting techniques and reported that selective laser melting produced bond strength values comparable to or higher than conventional casting methods, suggesting that additive manufacturing technologies can provide reliable metal–ceramic bonding [8].

Vafaee et al. compared cobalt-chromium alloys fabricated using selective laser melting and conventional casting methods and found no statistically significant difference between the two fabrication techniques, although the laser-sintered group showed slightly higher mean values [5]. These findings support the present study, where DMLS demonstrated the highest mean shear bond strength but did not show statistically significant superiority compared with zirconia and conventional cast metal frameworks.

The zirconia group in the present study showed moderate shear bond strength values (27.81 ± 10.42 MPa) with greater variability compared with the metal groups. Zirconia–ceramic bonding differs from metal–ceramic bonding because zirconia does not form a strong oxide layer capable of establishing chemical bonding with porcelain. Instead, the bonding mechanism mainly depends on micromechanical retention and compressive stresses generated during porcelain firing cycles. The increase in variation seen in the zirconia group may be due to the differences in bonding mechanisms.

Choi et al. compared the shear bond strength of veneering porcelain with both zirconia and metal–ceramic core materials and found that zirconia had clinically acceptable bond strength values, but had higher variation than the metal–ceramic systems [9]. They concluded that the bonding of zirconia is dependent on various factors such as surface treatment, thermal compatibility and veneering techniques.

Surface treatment is an important factor in enhancing zirconia framework bonding. In a study reported by Santos et al., they reported that the bond strength between zirconia cores and veneering ceramics was enhanced by surface modifications with CNC milling and composite interlayers [10]. The present study employed standardized surface preparation methods, which could have been a reason for the acceptable bond strength observed for zirconia.

The mean shear bond strength of the conventional cast Co-Cr group was 26.97 ± 4.01 MPa, however this was not statistically different from the other groups. In restorative dentistry, metal–ceramic bonding has been regarded as one of the most predictable bonding methods. The metal to porcelain bond is accomplished by a combination of oxide layer formation, mechanical interlocking, and compressive stresses created during the firing cycles of the porcelain.

De Melo et al. investigated the shear bond strength of various ceramic systems with various metal alloys and found satisfactory bond strength between the base metal alloys (nickel-chromium and cobalt-chromium) and veneering ceramics, which is suitable to be used in porcelain fused to metal (PFM) restorations [11].

The findings of the present study are also similar to the work of Lee et al., who have compared the porcelain bonding with mill-able alloys and traditional castable alloys. They claimed similar shear bond strength values between various fabrication techniques indicating that the modern manufacturing techniques can provide the same bonding performance as the traditional casting methods [6]. These results are in line with the current study, in which no significant differences were found between the zirconia, DMLS and the conventional metal groups.

Several factors affect the bonding of core materials: chemical bonding, mechanical retention, surface characteristics, wettability and thermal compatibility of the core and veneering ceramic. Anusavice says that metal–ceramic bonding happens through chemical bonding, mechanical interlocking, compressive forces due to thermal compatibility and secondary van der Waals forces. The most common way of chemical bonding is the creation of an oxide layer on the metal surface during porcelain firing. This layer of oxide reacts with ceramic material and plays an important role in bond strength [12].

The thickness and durability of the oxide film are important in successful bonding, O'Brien said. A thin oxide layer may not give sufficient bonding, while a thick oxide layer may lead to a weak and brittle interface that will impair the longevity of the restoration [13]. Craig and Powers reported that surface roughness helps to improve mechanical retention and bonding between metal and ceramic materials [14].

To achieve better ceramic bonding, surface treatment methods like airborne particle abrasion, preoxidation, bonding agents, degasification, and mechanical retention are employed [15]. Külünk et al. showed that the adhesion of metal–ceramic is significantly enhanced with the use of aluminum oxide particles in air abrasion, due to the formation of micro-retentive areas that facilitate porcelain penetration [16].

The failure patterns of ceramic restorations are influenced by a number of factors such as interfacial defects, chemical bonding, mechanical retention, thermal stresses, and fatigue loading. O'Brien categorized the porcelain–metal bond failures as being adhesive, cohesive or mixed failures [13]. Adhesive failure is separation between porcelain and core material, cohesive failure within the porcelain/core material and mixed failure is a mixture of both characteristics [9].

DMLS frameworks are shown to have enhanced mechanical retention because of the rough surface created during the layer-by-layer creation of the framework. Akova et al. have reported that laser-sintered frameworks demonstrate improved characteristics of mechanical interlock and exhibit better bonding properties, which leads to better values of bond strength and cohesive ceramic fractures [7].

The present study was carried out in in-vitro conditions, and this may not fully reflect the oral cavity environment. However, the factors of saliva, temperature changes, pH changes, and masticatory forces were not properly simulated. The findings may not be generalizable because of the limited sample size, materials tested and standardized testing conditions used. Larger sample sizes and longer clinical follow-ups are recommended for further research.

CONCLUSION

Based on the limitations of this in-vitro study, no statistically significant differences were found among the shear bond strength of veneering ceramic to conventional cast Co-Cr, DMLS Co-Cr, and zirconia core materials. Although the DMLS group exhibited the highest mean shear bond strength, followed by zirconia and cast metal. The failure pattern in all groups that was seen most frequently was mixed failure, this failure mode was considered adequate bonding between core Materials and veneering Ceramic. The results indicate that DMLS and zirconia frameworks may be reliable alternatives to the traditional cast metal frameworks for veneered restorations. There is a need for more long-term clinical studies and fatigue testing with larger cohorts to confirm the results and confirm clinical applicability..

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