ECRONICON OPEN ACCESS

EC DENTAL SCIENCE

Research Article

Shear Bond Strength of Feldspathic and Heat-Pressed Ceramics to Co-Cr Alloy and Zirconia Specimens

Filippatos Gerasimos[1]*, Sarafianou Aspasia[2], Kourtis Stefanos[3] and Tripodakis Aris Petros[4]

[1]Department of Fixed Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece

[2]Assistant Professor, Department of Fixed Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece

[3]Associate Professor, Department of Fixed Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece

[4]Professor Emeritus, Department of Fixed Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece

***Corresponding Author:** Filippatos Gerasimos, Department of Fixed Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Greece.

Received: November 11, 2020; **Published:** February 27, 2021

Abstract

Aim: The aim of the present study was to investigate the shear strength of the bond between feldspathic and heat-pressed ceramic on Co-Cr alloy and zirconium substrate.

Materials and Methods: For the experimental procedure 54 disk-shaped specimens were fabricated from a metal alloy and zirconium, that served as substrates. Group A included 27 Co-Cr alloy specimens fabricated with SLM Technique while Group B included 27 CAD/CAM zirconium specimens Subgroups corresponding to the veneering material (feldspathic and glass-ceramic) were created within each group.

The bond strength between the substrate and the veneering material and the ultimate strength were measured.

Results and Conclusion: Within the limitations of this study the following could be concluded:

- The shear bond strength of various veneering materials on metal alloy and zirconium was mainly influenced by the type of substrate.
- The shear bond strength values of feldspathic ceramic on the metal alloy were superior compared to all other combinations.
- The higher shear bond strength values were noted for the combination of feldspathic porcelain on metal alloy, with statistically significant differences to glass ceramic materials on the same substrate.
- Feldspathic porcelain also showed increased shear bond strength on zirconium substrate compared to glass ceramic materials.
- The shear bond strength values of the two tested glass ceramic materials differed significantly either on metal or on zirconium substrate.

Keywords: *Shear Bond Strength; Heat-Pressed Ceramics; Co-Cr Alloy; Zirconia Specimens*

Introduction

All-ceramic fixed dental prostheses are increasingly used as an alternative to porcelain-fused-to-metal due to their enhanced esthetics and biocompatibility [1,2]. Zirconia is a promising material in cases where esthetics and strength are important [3], mainly due to its increased flexural (700 - 1.200 MPa) and fracture (7 - 10 MPa), strength, hardness, chemical stability [4], favorable optical properties [4,5] and biocompatibility. Zirconia frameworks are designed and milled through CAD/CAM and the layering technique is commonly used for veneering them with porcelain. Chipping of the veneering ceramic is one of the most commonly encountered clinical problems with zirconia restorations [6-8]. (8 - 10% at 2 yrs compared to 4 - 10% at 10 yrs for PFM restorations).

Despite the widespread use of all-ceramic materials, metal ceramic restorations are still considered as the gold standard [1,9] in the practice of fixed prosthodontics. Mechanical retention between porcelain and roughened alloy surface, as well as chemical bonding through the oxide layer are the main constitutes of the metal-ceramic bond. The coefficients of thermal expansion of alloy and ceramic must be compatible in order to minimize residual tensile stresses at the interface.

The traditional technique of layering dental porcelain on the metal framework leads to excellent esthetic results. It is, however, time consuming and the method of heat pressing has been advocated as an alternative approach [10-12]. This technique requires a final contour wax-up model on the framework to be invested under heat-pressed vacuum with pressable ceramics. Heat pressing can also be applied for veneering ceramic on the sintered zirconia frameworks.

Aim of the Study

The aim of the present study was to investigate the shear strength of the bond between ceramic and heat-pressed ceramics on metal or zirconium substrate. The working hypothesis was that the shear bond strength would be similar.

Materials and Methods

Materials and specimen fabrication

For the experimental procedure disk-shaped specimens were fabricated from a metal alloy and zirconium, 5 mm in diameter and 3 mm in thickness according to ISO 9693-1999 that served as substrates. A total of 54 specimens were fabricated and were divided in two Groups according to the substrate material. Subgroups corresponding to the veneering material were created within each group. The ceramic veneering in all specimens was 15 mm in thickness.

Group A

Group A included 27 metal specimens fabricated with Selective Laser Melting Technique (SLM) using a Co-Cr basic alloy (ST 272 SG, Sint-Tec, (Selective Laser Melting PM 100, Phoenix Dental Systems, Clermont-Ferrand, France). For the fabrication of the metal specimens in Group A a wax-pattern was fabricated to the corresponding dimensions and was scanned at a ScanWax 21 device (Dentona Ag, Germany) to achieve a digital prototype. The digital prototype was imported to an SLM device (Selective Laser Melting, PM 100 Dental System, Phenix Systems, Clermont-Ferrand, France) to fabricate the metal specimens of SLM group. The SLM device was equipped with a 500 w Yb - Fibez laser and it was capable of selectively laser melting across a controlled (XY) - axis. The power of a dental Co - Cr alloy (ST. 272SG, SINT - TEC Co, Riom, France) was applied to the metallic base of SLM device and was selectively laser melted upwards in successive layers.

The 27 specimens were devised in 3 subgroups, each including 9 specimens.: In the first subgroup (A1) the specimens were covered with heat pressed ceramic IPS In Line POM, Ivoclar Co, Liechtenstein). In the second subgroup (A2) the metal substrate was covered with heat-pressed glass ceramic (X3, Noritake Co, Japan In the third subgroup (A3) specimens were covered with feldspathic porcelain (Initial, GC Co, Japan). In all specimens the opaque layer was applied.

Group B

Group B included 27 specimens with zirconium base (substrate) fabricated with the CAD/CAM technique (Zir CAD, Ivoclar Co, Liechtenstein). The 27 specimens were divided in three subgroups of 9 specimens. In the first subgroup (B1) the specimens were covered with heat-pressed glass-ceramic mass IPS Emax ZirPress (Ivoclar Co, Liechtenstein). In the second subgroup (B2) heat-pressed glass ceramic Cerabien CZR (Noritake Co, Japan) was applied. On the specimens of the third subgroup(B3) feldspathic ceramic was applied. (Initial ZR, GC Co, Japan). All veneering procedures were accomplished following exactly the manufacturer's instructions. The groups and subgroups of the specimens with the abbreviations that were used are shown in table 1. The composition of the substrate materials and the ceramic materials for veneering are reported in table 2.

Base materials					
	Material	Fabrication	Manufacturer	Code	N
Group A	Co-Cr alloy	SLM	SINT-TEC (Sin Tec Co)	SLM	27
Group B	Zirconium	CAD-CAM	IDSE max ZirCAD (Ivoclar Co)	ZRC	27
Veneering materials for metal specimens (Group A)					
Subgroup A1	Glass-ceramic	Heat press	IPS inline Pom (Ivoclar Co)	POM	9
Subgroup A2	Glass-ceramic	Heat press	Ex-3 (Noritake Co)	XPN	9
Subgroup A3	Feldspathic ceramic	Fusion	INITIAL (GC Co)	IGC	9
Veneering materials for zirconium specimens (Group B)					
Subgroup B1	Glass-ceramic	Heat press	IPS E-max ZirPress (Ivoclar Co)	ZIP	9
Subgroup B2	Glass-ceramic	Heat press	Cerabien CZR (Noritake Co)	CZR	9
Subgroup B3	Feldspathic ceramic	Fusion	IBITIAL ZR (GC Co)	ZGC	9

Table 1: *Groups and subgroups of specimens.*

Base materials		
Group A	SINT-TEC (metal alloy)	Co - 62% Cz - 29% Mo - 5,5% Si <1% Mn <1% Fe <1%
Group B	IPS E max Zir CAD (Zirconium)	$Zr0_2$ 88 -95 % $Y_2 0_3$ 4,5 - 7% $Hf0_2$ 5% $Al_2 0_3$ 1%
Veneering materials		
Subgroup A1	IPS In-line POM (Ivoclar Co)	$Si0_2$ 50-65% $Al_2 0_3$ 8-20% $NC_2 0$ 4-12% $K_2 0$ 7-13%
Subgroup A2	EX-3 (Noritake Co)	Not provided
Subgroup A3	Initial (GC Co)	Not provided
Subgroup B1	IPS E-MAX Zir Press (Ivoclar Co)	$Si0_2$ 57-62% $Al_2 0_3$ 12-16% $NC_2 0$ 7-10% $K_2 0$ 6-8% CaO 2-4% $Zr0_2$ 1,5-25% $P_2 0_5$ 1-2%
Subgroup B2	CERABIEN ZR (Noritake Co)	Not provided
Subgroup B3	Initial – Zr (GC CO)	Not provided

Table 2: *Composition of the base (substrate) and the veneering materials B. Shear Bond strength.*

Shear bond strength

For the shear bond strength, the specimens were mounted in a Tensometer 10 device (Monsanto Co, Akron, OH, USA) where the bond strength between the substrate and the veneering material was investigated. The crosshead was set on the interface at a head cross speed of 1 mm/min. The ultimate strength (shear loading up to fracture) was calculated in MPa by dividing the recorded strength of fracture in Newtons by the surface of the interface.

Statistical analysis

The mean bond strength values and the standard deviation were analyzed statistically using the IBM-SPSS 25 software. The data were subjected to one- and two-way ANOVA and in Categorical Regression (CATREG). Following the non- parametric tests Mann - Whitney and Kruskal - Wallis were applied as the corresponding criteria of homogeneity of variation were not fulfilled. The least accepted level of statistical significance was p < 0,05.

Results

The experimental design with the combinations and the coding of the subgroups is shown in table 3.

Subgroup	Material combination	Coding
A1	Metal- Glass- ceramic	POM
A2	Metal -Glass- ceramic	XPN
A3	Metal- Feldspathic ceramic	IGC
B1	Zir-Glass-ceramic	ZIP
B2	Zir-Glass-ceramic	CZR
B3	Zir Feldspathic ceramic	ZGC

Table 3: *Combinations and subgroups of specimens.*

The data were first analyzed using the Kolmogorof-Smirnof tests to verify the normality of the distribution (Table 4).

Combination	Kolmogorov - Smirnov3			Shapiro - Wilk		
	Value	df	sig.	Value	df	sig.
ZGC	,219	9	,200*	,916	9	,359
IGC	,152	9	,200*	,975	9	,930
ZIP	,171	9	,200*	,938	9	,557
POM	,176	9	,200*	,926	9	,445
CZR	,143	9	,200*	,947	9	,656
XPN	,238	9	,150	,949	9	,674

Table 4: *Normality tests for the variable "shear bond strength".*
**Lowest limit of statistical significance, a. Lilliefors correction.*

As it can be noted regarding the dependent variable "Shear bond strength" showed no statistically significant differentiation from the normal distribution, both in Kolmogorof- Smirnof and the Shapiro-Wilk tests.

One-way ANOVA

The recorded values for the shear bond strength of the various combinations were subjected to one-way-ANOVA (Table 5). The combination metal substrate to feldspathic ceramic (IGC) showed the highest values (60.91 Mpa, SD 20.01) while the lowest value was recorded for the group XPN, combination of metal to glass ceramic (27.01 Mpa, SD 7.25).

The data were subjected to Levene's test of Homogeneity of Variances (Table 6). As it can observed, no statistical significance was noted so it was possible to proceed to the One-way-ANOVA (Table 7).

Shear bond strength (MPa)								
	N	Mean	SD	SE	95% Confidence Interval.		Min	Max
					Lower limit	Upper limit		
ZGC	9	42.9100	12.87408 a	4.29136	33.0141	52.8059	28.70	67.17
IGC	9	60.9133	20.01098 a	6.67033	45.5315	76.2951	26.04	90.72
ZIP	9	28.8911	12.48833 a	4.16278	19.2917	38.4905	10.08	44.94
POM	9	31.1578	16.69174 b	5.56391	18.3274	43.9882	10.95	58.07
CZR	9	38.9422	10.13403 b	3.37801	31.1525	46.7319	26.53	58.09
XPN	9	27.0133	7.25389 a	2.41796	21.4375	32.5892	12.89	37.31
Total	54	38.3046	17.61655 a	2.39731	33.4962	43.1130	10.08	90.72

Table 5: *Shear-bond strength values in various base-veneer combinations.*

Homogeneity of variance test					
		Levene Statistic	df1	df2	sig.
Bond Strength (MPa)	Based on Means.	2,383	5	48	,052
	Based on Median	1,500	5	48	,207
	Based on Medians and with adjusted df	1,500	5	33,844	,216
	Based on trimmed Means	2,296	5	48	,060

Table 6: *Homogeneity of variance test for the variable 'bond strength' for various base- veneer combinations.*

One way ANOVA for Bond Strength (MPa)					
	Sum of squares	df	Mean Square	F	Sig
Between groups	7199,592	5	1439,918	7,473	,000
Intra subject	9248,571	48	192,679		
Total	16448,163	53			

Table 7: *One-way ANOVA for the various base-veneer combinations.*

From the ANOVA a statistically significant difference was noted (F = 7.473, p = .000 « 0.05) among the various combinations. Some combinations showed very close values while other showed intense differences. A Post Hock multi comparison (Bonferroni tests) was performed to note the differences between the combinations detail (Table 8).

It is obvious that the IGC combination (metal alloy with feldspathic porcelain) shows statistically significant differences with all other combinations except ZGC (zirconium with feldspathic porcelain). On the other side the ZGC combination had no statistical significance difference with the rest combinations.

Two-way ANOVA

Following the One-way -ANOVA a two-way ANOVA was performed to investigate the main source of variation of the two variables, "base" and "veneer" (Table 9).

		Mean Difference			95% Confidence interval	
(1) Group	**(J) Group**	**(i-J)**	**Stand Error**	**sig.**	**Lower limit**	**Upper limit**
ZGC	IGC	-18.00333	6.54351	,125	-38.2178	2.2111
	ZIP	14.01889	6.54351	,559	-6.1955	34.2333
	POM	11.75222	6.54351	1,000	-8.4622	31.9666
	CZR	3.96778	6.54351	1,000	-16.2466	24.1822
	XPN	15.89667	6.54351	,284	-4.3178	36.1111
IGC	ZGC	18.00333	6.54351	,125	-2.2111	38.2178
	ZIP	32.02222*	6.54351	,000	11.8078	52.2366
	POM	29.75556*	6.54351	,001	9.5411	49.9700
	CZR	21.97111*	6.54351	,023	1.7567	42.1855
	XPN	33.90000*	6.54351	,000	13.6856	54.1144
ZIP	ZGC	-14.01889	6.54351	,559	-34.2333	6.1955
	IGC	-32.02222*	6.54351	,000	-52.2366	-11.8078
	POM	-2.26667	6.54351	1,000	-22.4811	17.9478
	CZR	-10.05111	6.54351	1,000	-30.2655	10.1633
	XPN	1.87778	6.54351	1,000	-18.3366	22.0922
POM	ZGC	-11.75222	6.54351	1,000	-31.9666	8.4622
	IGC	-29.75556*	6.54351	,001	-49.9700	-9.5411
	ZIP	2.26667	6.54351	1,000	-17.9478	22.4811
	CZR	-7.78444	6.54351	1,000	-27.9989	12.4300
	XPN	4.14444	6.54351	1,000	-16.0700	24.3589
CZR	ZGC	-3.96778	6.54351	1,000	-24.1822	16.2466
	IGC	-21.97111*	6.54351	,023	-42.1855	-1.7567
	ZIP	10.05111	6.54351	1,000	-10.1633	30.2655
	POM	7.78444	6.54351	1,000	-12.4300	27.9989
	XPN	11.92889	6.54351	1,000	-8.2855	32.1433
XPN	ZGC	-15.89667	6.54351	,284	-36.1111	4.3178
	IGC	-33.90000*	6.54351	,000	-54.1144	-13.6856
	ZIP	-1.87778	6.54351	1,000	-22.0922	18.3366
	POM	-4.14444	6.54351	1,000	-24.3589	16.0700
	CZR	-11.92889	6.54351	1,000	-32.1433	8.2855

***Table 8**: Post-Hoc multiple comparisons for the Bond Strength values of various base-veneer combinations (Bonferroni test).*
**: Statistical significance at 0.05 level.*

As it can be seen in table 9 the variable "base" shows no statistically significant differences regarding the shear bond strength (F = 0.542, df = 1, p = 0.465 » 0.05). On the other side for the variable "veneer" statistically significant differences were noted (F = 13.176, df-2, p = 0.000 « 0.05) with increased observed power for this test (1- β = 0.996). The interaction of the two independent variables also showed statistically significant differences (F = 5.236, DF = 2, p = 0.009 « 0.05) but just acceptable value for the observed power (1-β = 0.808).

Source	Type III Sum of squares	df	Mean of square	F	sig.	Non centrality parameter	Observed power^b
Corrected model	7199,592^a	5	1439,918	7,473	,000	37,366	,998
Intercept	79231,211	1	79231,211	411,209	,000	411,209	1,000
Base	104,361	1	104,361	,542	,465	,542	,111
Veneer	5077,589	2	2538,794	13,176	,000	26,353	,996
Base * Veneer	2017,642	2	1008,821	5,236	,009	10,472	,808
Error	9248,571	48	192,679				
Total Error	95679,374	54					
Corrected Error	16448,163	53					

Table 9: *Two-way-ANOVA for the dependent variables "shear-bond-strength" for the two independent variables: "base" and "veneer".*

a: R square = .438 (Adjusted R square = .379).

b: Calculated with alpha = .05.

For a more detailed investigation a post-Hock multiple comparison was also performed to verify if the Mean bond strength recorded for the feldspathic porcelain - named "porcelain " in the table (Initial, GC Co) differed significantly from the rest values (Table 10). As it can be seen from the table the Mean bond strength differed significantly from the rest Mean values for both glass ceramics Noritake and Ivoclar (p = 0.000 « 0.05). On the other side the difference between the Means of the glass ceramics (Noritake and Ivoclar) was not statistically significant (p = 0.526 > 0.05).

		Mean difference (I-J)	Std Error	sig.	95% Confidence Interval	
(!) Veneer	(j) Veneer				Lower limit	Upper limit
Porcelain	Ivoclar	21.8872*	4.62696	,000	12.5841	31.1903
	Noritake	18.9339*	4.62696	,000	9.6308	28.2370
Ivoclar	Porcelain	-21.8872*	4.62696	,000	-31.1903	-12.5841
	Noritake	-2.9533	4.62696	,526	-12.2565	6.3498
Noritake	Porcelain	-18.9339*	4.62696	,000	-28.2370	-9.6308
	Ivoclar	2.9533	4.62696	,526	-6.3498	12.2565

Table 10: *Post Hoc multiple comparisons of means of bond strength for various veneering materials (LSD tests).*

Based on observed Means

*: Mean difference was statistically significant at 0.05 level.

Categorical regression

From the previous statistic tests it was noted that in this experimental procedure the veneering ceramic material had a more important influence on the shear bond strength than the base (metal or zirconium substrate. The Categorical regression analysis was performed to determine with more precision to which extent the independent variables (base, veneer) affect or "predict "the values and the variation of the independent variable (shear bond strength).

The specific model of Categorical Regression showed acceptable percentage of explained variation (multiple R = 0,534, $R^2 = 28.5\%$ or $R^2 = 0.285$). And in table 11 statistical importance was noted ($F_{3i}5_0 = 6.641$, p = 0.001 « 0.05).

ANOVA					
	Sum of squares	**df**	**Mean Square**	**F**	**sig**
Regression	15,386	3	5,129	6,641	,001
Residual	38,614	50	,772		
Total	54,000	53			

Table 11: *Total estimation of the statistical significance of the specific model of regression.*
Dependent variable: Shear Bond Strength (MPa) Predictors: Base, Veneer.

In table 12 it is shown that the statistical factor β of the independent variable "base" was low and not statistically significant (F = 0.618, df = 1, ρ = 0.436 » 0.05) while the Beta factor (β) of the independent value "veneer" was high with statistically significant difference (F = 28.998, df = 2, p = 0.000 « 0.05). From this data it is shown that the shear bond strength is affected mostly from the factor "veneer.

Standardized Coefficients					
	Beta	**Bootstrap (1000) Standard Error Estimate**	**df**	**F**	**Sig**
Base	,061	,077	1	,618	,436
Veneer	,530	,098	2	28,998	,000

Table 12: *Beta (β) factors of the specific model of categorical regression.*
Dependent values: Shear bond strength (MPa).

In table 13 the values for the importance of the two affecting factors is reported. As it can be noted, the variable "veneer" contributes 98,7% (0,987) to the total explained variation while the factor "base" contributes by 1,3% (0,013). Based on the above mentioned it can be stated that it is the veneering material that mainly influence the noted shear bond strength.

Correlations and Tolerance						
	Correlations			**Importance**	**Tolerance**	
	Zero order	**Partial**	**Part**		**After transformation**	**Before transformation**
Base	,061	,072	,061	,013	1,000	1,000
Veneer	,530	,531	,530	,987	1,000	1,000

Table 13: *Correlations and tolerance of the specific model.*
Dependent variable: Shear bond strength (MPa).

Discussion

The purpose of this study was the investigation of the shear bond strength of various ceramic veneering materials on metal and zirconium substrate. The bond of feldspathic porcelain on metal alloys has been the reference point in prosthetic restorations. On the other side the use of zirconium frameworks is rapidly expanding in the daily practice. The main problem that has been observed is the chipping of the veneering material from the substrate [11,13-16].

In the present study two different substrates (bases) were used, base-metal alloy and zirconium, and were veneered both with feldspathic and heat-pressed glass ceramic. The bond strength was measured in shear test in six different combinations [17-19].

The shear bond was selected as it offers certain advantages compared to other tests, as three-point-bending test, four-point bending test, biaxial flexure test or micro tensile bond strength [20-23]. For the shear bond strength standardized specimens (simple in fabrication) are required and it is possible to rank different products according to the bond strength values. On the other side some disadvantages have also been reported for this test including possibly increased Standard Deviation, occurrence of non-uniform interfacial stresses and a possible influence of specimen's geometry on the measured values [24,25].

Regarding the surface treatment of the substrate material a possible affection on the bond strength has been reported. For this reason, no surface treatment was applied on the bonding surfaces in the present study.

Zirconium as a base material for fixed dental restorations has high mechanical strength (flexural strength 900- 1200 MPa, fracture toughness 9 - 10 MPa) and has been advocated for the fabrication of fixed restorations. In restorations with zirconium framework fracture has been reported with frequency 6 - 15% [26-28]. However, the most common problem in the clinical practice is the chipping of the veneering material, usually feldspathic porcelain [29]. The frequency of chipping is increased compared to metal ceramic restorations and this may be attributed to a weakness in the zirconium-ceramic bond.

On the other side the shear strength of ceramic materials was 20, 88 MPa while the corresponding value for metal ceramic was 24, 57 MPa without statistically significant difference [29]. The results of the present study are in accordance with the above-mentioned findings and zirconium can be considered as a reliable substrate for dental restorations.

Long term clinical trials have reported failures in metal ceramic restorations in 2, 7-5, 5% with follow-up 10 - 15 years [30]. Clinical trials with zirconium- based restorations have shown failures of the veneering ceramic 6 - 15% in a period of 3 - 5 years [31], while the corresponding failure rates for metal-ceramic restorations was significantly lower reaching up to 4% [27,31].

The shear bond strength for metal ceramic has been reported ranging from 54 to 71 MPA, values similar to results of the present study [32,33]. On the other side the exact bonding mechanism between zirconium and ceramic veneering material is not completely known in detail. Three factors however seem to significantly affect the created bond: The wetting of the zirconium substrate from the ceramic material, the chemical bond and the micro-mechanical retention/interaction.

For these reasons, an alternative clinical solution has been presented recently namely the use of feldspathic and glass ceramic materials for the veneering of zirconium frameworks. It was the aim of this study to investigate the bond strength of the veneering materials on zirconium and metal alloy substrate.

In the present study the values of shear bond strength in metal alloy specimens veneered with feldspathic porcelain were superior to all other combinations. Feldspathic porcelain also showed high shear bond strength values when combined to zirconium substrate. A possible reason for this finding may be the ability of feldspathic porcelain to withstand a combination of residual, thermal and mechanical stress [26-29].

The relation of thickness between the substrate and the veneering material may also affect the bond strength as it may "guide" the failure initiation site in bilayered ceramic discs with a relatively strong framework and a weak ceramic veneer [30-33].

Turk., *et al*. [34] reported inferior bond strength of zirconium-ceramic combination compared to metal ceramic restorations when heat-pressed glass ceramic was used as veneering material. Similar findings were also reported in other *in-vitro* studies [35-37]. On the other side, Abrisham., *et al.* [29] found no statistically significant difference between metal and zirconium substrate in shear bond strength of layered restorations [34-37].

In the present study higher values of bond strength were found in layered feldspathic restorations compared to glass ceramic but increased bond strength was found for the metal substrate. The results are in accordance with the findings of Guess., *et al*. [8] where shear bond strength was found 9, 4-12, 5 MPa and was also found reduced compared to metal ceramic.

Comparing the different values of various veneering materials on zirconium substrate in the present investigation, higher values were found for the feldspathic porcelain compared to glass ceramics. This result is in accordance with the study of Ishibe., *et al*. [38] where values of 21.34 - 40.41 MPa were found compared to values of 30.03 - 47.18 MPa for feldspathic porcelain [14].

Similar differences were found for the metal substrate where the bond strength values of feldspathic porcelain were superior to the corresponding values of glass ceramics. This finding however was in contrast with the results of Farzin., *et al*. where glass ceramic materials showed improved bond strength of glass ceramics [21].

Ishibe., *et al*. found statistically significant differences among glass ceramic materials of various brands after heat-pressing on metal alloys while no statistically significant difference was found between feldspathic porcelain and glass ceramic materials [14].

No statistical differences were found between the bond strength of heat-pressed and conventional ceramic [16,25]. In an *in-vitro* study [11] where the bond strength was investigated in crowns, higher fracture values (45%) were found for the traditional technique compared to heat- pressed ceramic [16-25].

Sivankutty reported higher shear bond strength values for the layering technique [26] (40, 3 MPa) compared to the heat press technique (29, 3 MPa). In the study of Khmaj., *et al*. only specimens fabricated with heat-pressing failed under the important limit of 25 MPa [17].

On the other side, high bond strength of heat pressing materials has been shown in some studies. Farzin., *et al*. [21] reported higher bond strength (56,52 ± 4,97 MPa) of glass ceramic materials compared to the conventional technique (48,29 ± 6,02 MPa).

Regarding the quality of the bond achieved between zirconium and veneering materials, Henriques., *et al*. [19] found less imperfections and lower reduction of the bond strength values after mechanical and thermal fatigue in specimens fabricated with heat pressing compared to the layering technique.

Focusing on the limitations of the present study the following should be noted: The specimen fabrication that was done according to the ISO specifications is a geometric analogue of a restoration without achieving exact mimicking of a clinical restoration. Additionally, for the layering technique only the dentin layer was applied in order to achieve a homogenous veneering with a standardized thickness.

The variety of materials and testing methods in the different studies does not allow a direct comparison of the reported results further *in-vitro* studies are needed to verify the results of this study which should be confirmed by long-term clinical trials.

Conclusion

Within the limitations of this study the following could be concluded:

- The shear bond strength of various veneering materials on metal alloy and zirconium was mainly influenced by the type of substrate.
- The shear bond strength values of feldspathic ceramic on the metal alloy were superior compared to all other combinations.
- The higher shear bond strength values were noted for the combination of feldspathic porcelain on metal alloy, with statistically significant differences to glass ceramic materials on the same substrate.

- Feldspathic porcelain also showed increased shear bond strength on zirconium substrate compared to glass ceramic materials.
- The shear bond strength values of the two tested glass ceramic materials differed significantly either on metal or on zirconium substrate.

Acknowledgments

The authors thank sincerely Professor Dr. G. Heliades, Chairman of the Department of Biomaterials in the Dental School of the National and Kapodistrian University of Athens and Associate Professor Dr. S. Zinellis in the same Department for their precious help and guidance in this research.

Bibliography

1. Christensen RP and Ploeger BJ. "A clinical comparison of zirconia, metal and alumina fixed-prosthesis frameworks veneered with layered or pressed ceramic: a three-year report". *Journal of the American Dental Association* 141.11 (2010): 1317-1329.
2. Kelly JR., *et al.* "Ceramics in dentistry: historical roots and current perspectives". *The Journal of Prosthetic Dentistry* 75.1 (1996): 18-32.
3. Zarone F., *et al.* "From porcelain-fused-to-metal to zirconia: clinical and experimental considerations". *Dental Materials* 27.1 (2011): 83-96.
4. Akin H., *et al.* "Shear bond strength of resin cement to zirconia ceramic after aluminum oxide sandblasting and various laser treatments". *Photomedicine and Laser Surgery* 29 (2011): 797- 802.
5. Akin GE., *et al.* "Surface roughness and bond strength of zirconia posts to a resin cement after various surface pretreatments". *Photomedicine and Laser Surgery* 33 (2015): 246-251.
6. Bonaudo D., *et al.* "Single-session implant supported chairside restoration of tooth 35 with a titanium / zirconia abutment and an all-ceramic crown using an immediate-loading protocol". *International Journal of Computerized Dentistry* 12.2 (2009): 147-157.
7. Donovan TE. "Porcelain-fused-to-metal (PFM): alternatives". *Journal of Esthetic and Restorative Dentistry* 21.1 (2009): 4-6.
8. Eliasson A., *et al.* "A clinical evaluation of cobalt-chromium metal ceramic fixed partial dentures and crowns: A three-to seven-year retrospective study". *Journal of Prosthetic Dentistry* 98.1 (2007): 6-16.
9. Guess PC., *et al.* "Shear bond strengths between different zirconia cores and veneering ceramics and their susceptibility to thermocvcling". *Dental Materials* 24 (2008): 1556-1567.
10. Anusavice KJ. "In: Phillips' science of dental materials, 11th edition., W.B. Saunders, Philadelphia (2006): 621-654.
11. Sola-Ruiz MF., *et al.* "Post-fatigue fracture resistance of metal core crowns: press-on metal ceramic versus a conventional veneering system". *Journal of Clinical and Experimental Dentistry* 7.2 (2015): e278-e283.
12. Dong JK., *et al.* "Heat-pressed ceramics: technology and strength". *The International Journal of Prosthodontics* 5 (1992): 9-16.
13. De Backer H., *et al.* "Long-term results of short-span versus longspan fixed dental prostheses: an up / to 20-year retrospective study". *The International Journal of Prosthodontics* 21 (2008): 75-85.

14. Ishibe M., *et al.* "Shear bond strengths of pressed and layered veneering ceramics to high-noble alloy and zirconia cores". *Journal of Prosthetic Dentistry* 106 (2011): 29-37.
15. Stawarczyk B., *et al.* "Load-bearing capacity and failure types of anterior zirconia crowns veneered with overpressing and layering techniques". *Dental Materials* 27 (2011): 1045-1053.
16. Venkatachalam B., *et al.* "Ceramic pressed to metal versus feldspathic porcelain fused to metal: a comparative study of bond strength". *The International Journal of Prosthodontics* 22 (2009): 94-100.
17. Khmaj Mr Khmaj AB., *et al.* "Comparison of the metal-to-ceramic bond strengths of four noble alloys with press-on-metal and conventional porcelain layering techniques". *Journal of Prosthetic Dentistry* 112.5 (2014): 1194-1200.
18. Choi JE., *et al.* "Pressed ceramics onto zirconia. Part 1: Comparison of crystalline phases present, adhesion to a zirconia system and flexural strength". *Dental Materials* 27 (2011): 1204-1212.
19. Henriques B., *et al.* "Shear bond strength of a hot pressed Au-Pd-Pt alloy-porcelain dental composite". *The Journal of the Mechanical Behavior of Biomedical Materials* 4 (2011): 1718-1726.
20. Beuer F., *et al.* "High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings-a new fabrication mode for all-ceramic restorations". *Dental Materials* 25 (2009): 121-128.
21. Farzin M., *et al.* "Evaluation of Bond Strength of Pressed and Layered Veneering Ceramics to Nickel- Chromium Alloy". *Journal of Dentistry* 16.3 (2015): 230-236.
22. Holden JE., *et al.* "Comparison of the marginal fit of pressable ceramic to metal ceramic restorations". *Journal of Prosthodontics* 18 (2009): 645-648.
23. Giordano Ra. "Dental ceramic restorative systems". *Compendium of Continuing Education in Dentistry* 17 (1996): 779-782.
24. International Organization for Standardization. ISO Standard 9693-1. Dentistry compatibility testing part 1: metal ceramic systems. ISO. Geneva, Switzerland (2012).
25. Schweitzer Dm., *et al.* "Comparison of bond strength of a pressed ceramic fused to metal versus feldspathic porcelain fused to metal". *Journal of Prosthodontics* 14.4 (2005): 239-247.
26. S Sivankutty. "Evaluation of Shear Bond Strength at Ceramo Metal Interface of Metal Ceramic Restorations Fabricated With 'Press on Metal' And 'Conventional Layering Techniques' - An Invitro Study". *Journal of Dental and Medical Sciences* 9.2 (2018): 42-47.
27. Guazzeto M., *et al.* "Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II". *Dental Materials* 20 (2004): 449-456.
28. Fahmy NZ and Salah E. "An in vitro assessment of a ceramic-pressed- to- metal system as an alternative- to conventional metal ceramic systems". *Journal of Prosthodontics* 20 (2011): 621-627.
29. Abrisham S., *et al.* "Shear Bond Strength of Porcelain to a base metal compared to Zirconia Core (2017).
30. Tinschert I., *et al.* "Lifetime of alumina and zirconia ceramics used for crown and bridge restorations". *Journal of Biomedical Materials Research* 80 (2007): 317-321.

31. Augstin Panadero R., *et al.* “Zirconia versus metal: a preliminary comparative analysis of ceramic veneer behavior”. *The International Journal of Prosthodontics* 25 (2012): 294-300.

32. Al-Shehri SA., *et al.* “Influence of lamination on the flexural strength of a dental costate glass ceramic”. *Journal of Prosthetic Dentistry* 76 (1996): 23-28.

33. Isgro G., *et al.* “The influence of the veneering porcelain and different surface treatments on the biaxial flexural strength of a heat-pressed ceramic”. *Journal of Prosthetic Dentistry* 90 (2003): 465-473.

34. Turk AG., *et al.* “Effect of different veneering techniques on the fracture strength of metal and zirconia frameworks”. *The Journal of Advanced Prosthodontics* 7 (2015): 454-459.

35. Abhuselib MN., *et al.* “Microtensile bond strength of different components of care veneered all-ceramic restorations”. *Dental Materials* 22 (2006): 857-863.

36. Ansong R., *et al.* “Fracture toughness of heat-pressed and layered ceramics”. *Journal of Prosthetic Dentistry* 109 (2013): 234-240.

37. Subash M., *et al.* “Evaluation of shear bond strength between zirconia core and ceramic veneers fabricated by pressing and layering techniques: In vitro study”. *International Journal of Pharma and Bio Sciences* 7 (2015): 612-615.

38. Ishibe M., *et al.* “Shear bond strengths of pressed and layered veneering ceramics to high-noble alloy and zirconia cores”. *Journal of Prosthetic Dentistry* 106 (2011): 29-37.

Volume 20 Issue 3 March 2021