Original Article

Evaluation and comparison of shear bond strength of porcelain to a beryllium-free alloy of nickel-chromium, nickel and beryllium free alloy of cobalt-chromium, and titanium: An *in vitro* study

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Abstract

Aims: The aim of this study was to evaluate and compare the shear bond strength of porcelain to the alloys of nickel-chromium (Ni-Cr), cobalt-chromium (Co-Cr), and titanium.

Materials and Methods: A total of 40 samples (25 mm × 3 mm × 0.5 mm) were fabricated using smooth casting wax and cast using Ni-Cr, Co-Cr, and titanium alloys followed by porcelain buildup. The samples were divided into four groups with each group containing 10 samples (Group A1–10: sandblasted Ni-Cr alloy, Group B1–10: sandblasted Co-Cr alloy, Group C1–10: nonsandblasted titanium alloy, and Group D1–10: sandblasted titanium alloy). Shear bond strength was measured using a Universal Testing Machine.

Statistical Analysis Used: ANOVA test and Tukey's honestly significance difference *post hoc* test for multiple comparisons.

Results: The mean shear bond strength values for these groups were 22.8960, 27.4400, 13.2560, and 25.3440 MPa, respectively, with sandblasted Co-Cr alloy having the highest and nonsandblasted titanium alloy having the lowest value.

Conclusion: It could be concluded that newer nickel and beryllium free Co-Cr alloys and titanium alloys with improved strength to weight ratio could prove to be good alternatives to the conventional nickel-based alloys when biocompatibility was a concern.

Keywords: Base metal alloys, cobalt-chromium, nickel-chromium, porcelain, shear bond strength, titanium

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INTRODUCTION

Dental casting alloys have been in extensive use in the field of dentistry for the fabrication of fixed prosthesis, majority of them being base metal alloys. Before the deregulation of the price of gold in the United States in the early 1970s, gold-based alloys were virtually the only type of alloy used for fixed prostheses. Later, in the early 1980s, fluctuations in the price of gold and the need for superior modulus and

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strength spurred the development of alternative alloys.[1] Scores of base metal alloys came into the market in the following years, and the dental profession is still staggering under the weight of the decision as to which if any of these materials can be used safely.[2]

Nickel-chromium (Ni-Cr) castings were introduced for crowns, bridges, and partial denture frameworks because of the lower cost of nickel compared with gold. However, many adverse reactions were reported with the use of these alloys and the metal most frequently responsible for an allergic response was nickel.[3] As per the toxicity data, nickel and beryllium were found to be positive animal carcinogens. Allergic and toxic responses were reported along with systemic changes in metabolic process in some cases. Beryllium grindings and casting fumes were found to cause conjunctivitis, dermatitis, and bronchitis.[4-10]

Later, cobalt-chromium (Co-Cr) alloys were developed in response to fears about possible toxic effects of alloys containing nickel and beryllium.[11] The absence of nickel in the composition of these Co-Cr castings, in combination with the low metal ion release rates, made them a viable alternative to patients sensitive to nickel.[12]

Titanium was discovered in the late 1700 s. The excellent corrosion resistance and biocompatibility of these alloys made them specially attractive for hypersensitive patients.[3]

With increased awareness about the health hazards of elements such as nickel and beryllium, more emphasis needed to be placed on use of these alloys for prosthodontic restorations.

Due to the high prevalence of porcelain chipping, increasing the importance of shear bond strength between metal and porcelain,[13,14] and in search of an alloy with the maximum compatibility with widely-used porcelain, the current study was planned. This study aimed to evaluate and compare the shear bond strength of a beryllium-free Ni-Cr alloy, a nickel and beryllium free Co-Cr alloy, and a titanium alloy.

MATERIALS AND METHODS

The alloys and porcelain used in this study were Ni-Cr alloy (Wiron 99-Bego), Co-Cr alloy (Lithecast), titanium alloy (Tilite-Talladium), and porcelain powder and liquid (IPS Classic-Ivoclar Vivadent, Schaan/Liechtenstein).

Preparation of metal specimens

A total of 40 metal specimens were fabricated using rectangular wax patterns [Figure 1] obtained from smooth

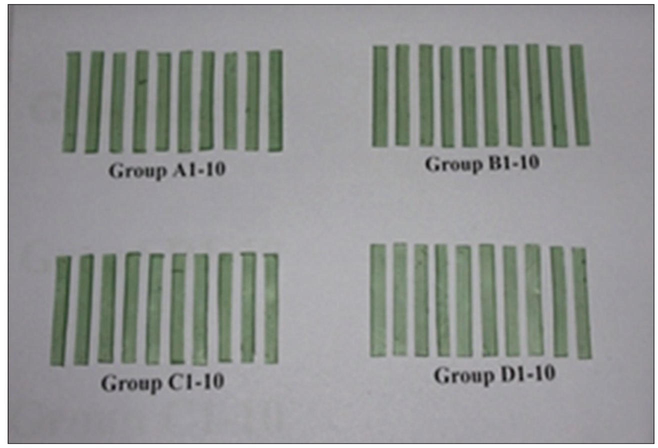


Figure 1: Wax pattern for casting

casting wax (Glattes Gusswachs-Bego, Germany) sheets of 0.5 mm thickness. Dimensions of wax patterns were kept slightly more than required dimension of castings, i.e., 25 mm × 3 mm. Thickness of wax patterns remained the same, i.e., 0.5 mm, as the smooth casting wax sheets used to make wax patterns were of that thickness only. Ni-Cr and Co-Cr specimens were invested with a phosphate-bonded investment material. For titanium specimens, a silica and phosphate free, alumina and magnesia based investment was used.

All specimens obtained after the casting procedure were finished and polished to the desired dimension of 25 mm × 3 mm × 0.5 mm [Figure 2]. Dimensional accuracy was checked using a digital Vernier caliper as shown in Figures 3 and 4.

The specimens were divided into four groups with each group containing 10 specimens.

- Group A1–10: Sandblasted Ni-Cr alloy
- Group B1–10: Sandblasted Co-Cr alloy
- Group C1–10: Nonsandblasted titanium alloy
- Group D1–10: Sandblasted titanium alloy.

All metal specimens, except Group C1–10, were sandblasted with aluminum oxide (110 mm) for 10 s from 2 cm distance, at 2 bar pressure, and 45° angulation approximately. Specimens were then cleaned in an ultrasonic cleaner for 10 min followed by oxidation as per the manufacturer's instructions.

Application of porcelain on metal specimens

Porcelain (IPS Classic-Ivoclar Vivadent) buildup was done on approved specimens in the central 8 mm portion of the metal castings leaving 8.5 mm on either side and to a thickness of 1 mm uniformly [Figures 5 and 6] which was followed by firing as per the firing schedule of the manufacturer. The dimensional accuracy of all the specimens was checked using the digital Vernier caliper. The specimens were later subjected to testing under a Universal Testing Machine [Figure 7].

RESULTS

All the 40 specimens were subjected to a shear bond strength test at a crosshead speed of 1 mm/min. Specimens were placed on a jig which had been fabricated to secure the specimens in a fixed position to standardize the angulation of load applied by the chisel-ended rod. A load was applied by a centrally located chisel-ended rod at an angle of 45° to the specimens. The load was applied till fracture occurred and the force output at fracture was divided by the bonding surface area to obtain the results in N/mm^2 or megapascals (MPa).

Group B samples presented with the highest mean shear bond strength value, and the values for all groups decreased in the following order: Group B > Group D > Group A > Group C [Graph 1].

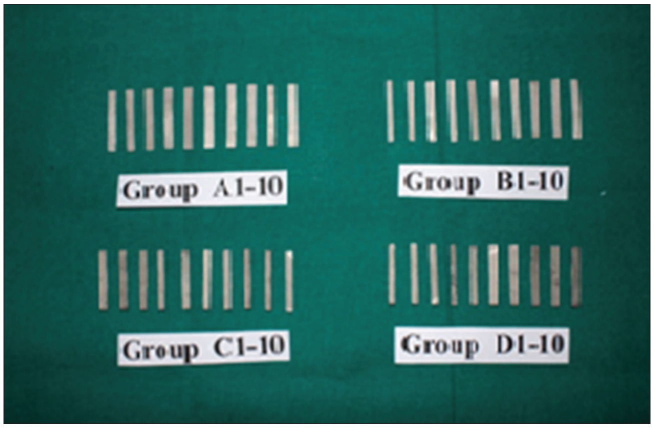


Figure 2: Finished and polished specimens

Figure 4: Crosschecking width of casting using digital vernier Caliper

Figure 6: Porcelain buildup on castings

Figure 3: Crosschecking length of casting using digital vernier Caliper

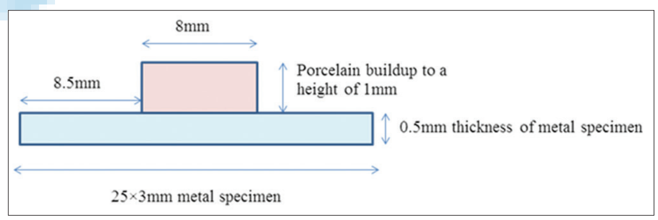


Figure 5: Line diagram showing porcelain buildup on metal specimens

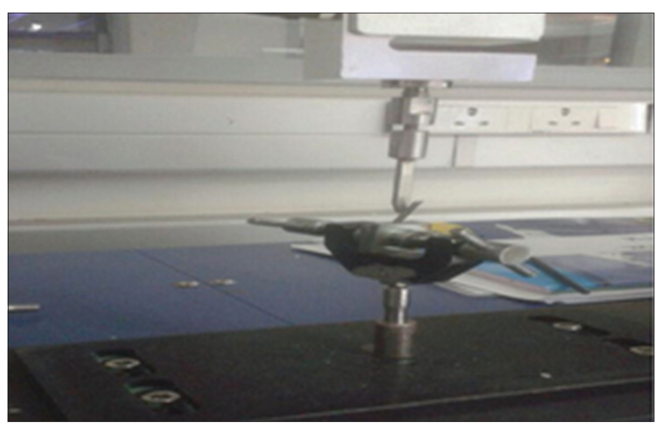
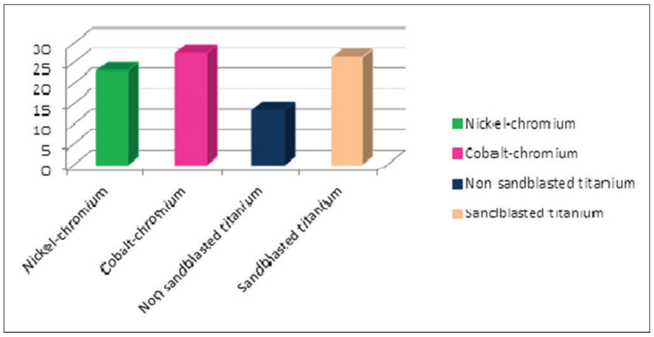


Figure 7: Testing for shear bond strength



Graph 1: Comparison of mean shear bond strength values of all four groups

One-way ANOVA was used to evaluate the shear bond strength between Groups A, B, C, and D [Table 1] and the difference in bond strength was found to be highly significant ($P = 0.000$).

Tukey's honestly significance difference *post hoc* test for multiple comparison [Table 2] revealed highly significant difference in the shear bond strength of nonsandblasted titanium group and all the other three groups ($P = 0.000$). A significant difference was found between sandblasted Ni-Cr and Co-Cr groups ($P = 0.49$). However, the difference in shear bond strength of sandblasted titanium group with sandblasted Ni-Cr ($P = 0.824$) and Co-Cr groups ($P = 0.270$) was not significant.

Table 1: Difference in shear bond strength between the four groups using ANOVA test

Groups	*N*	Mean	Standard Deviation	95% Confidence Interval for Mean		F	*p*
				Lower	Upper		
Group A	10	22.8960	3.35297	20.4974	25.2946	26.561	0.000*
Group B	10	27.4400	4.16222	24.4625	30.4175		
Group C	10	13.2560	4.28331	10.1919	16.3201		
Group D	10	25.3440	3.07975	22.1409	26.5471		

*Highly significant

Table 2: Tukey's HSD Post-Hoc Test for Multiple comparisons

Groups	Mean Difference	*p*
Group A		
Group B	-4.54400	.049 (S)
Group C	9.64000	.000 (HS)
Group D	-1.44800	.824 (NS)
Group B		
Group A	4.54400	.049 (S)
Group C	14.18400	.000 (HS)
Group D	3.09600	.270 (NS)
Group C		
Group A	-9.64000	.000 (HS)
Group B	-14.18400	.000 (HS)
Group D	-11.08800	.000 (HS)
Group D		
Group A	1.44800	.824 (NS)
Group B	-3.09600	.270 (NS)
Group C	11.08800	.000 (HS)

DISCUSSION

The metal and porcelain must have similar coefficients of thermal expansion, and metal must have a slightly higher value to avoid undesirable tensile loading at the interface.[15] All of the metals tested in this study were considered thermally compatible with the porcelain as purported by the manufacturers.

The alloys used in this study had the following coefficients of thermal expansion (25°C–500°C): Wiron 99 (Ni-Cr) 13.8; Lithecast (Co-Cr) 14.74; Tilite (Talladium, Titanium alloy) 13.2; and Ivoclar Classic 12.6 ± 0.5 (2 firings).

Apart from thermal compatibility, alloy selection was influenced by biocompatibility. Ni-Cr and Co-Cr alloys used in this study are beryllium free. As per the manufacturers, the titanium alloy used also has composition in compliance with ADA Guidelines and ISO-9000 for Cast dental alloys.

Many studies have shown that beryllium-containing Ni-Cr alloys demonstrated better castability and higher ceramometal bond strength values. Some other elements such as aluminum, niobium, and molybdenum also contributed to the castability of an alloy. The importance of beryllium present in Ni-Cr alloys has also been emphasized upon in porcelain-metal bonding. It has also been stated that beryllium acts as a reducing agent for nickel and chromium oxides and limits their improving the bond strength.[16-19]

Using beryllium-free alloys therefore might raise questions about the castability and bond strength of these alloys to porcelain. Hence, this study aimed at determination of the shear bond strength of beryllium-free alloys so that they could be put to good use in case of patients allergic to nickel and beryllium.

Haag and Nilner wrote a systematic review on bonding between titanium and dental porcelain. With respect to the effect of surface treatment of titanium on its bond strength with porcelains, they found that sandblasting could be regarded as the most efficient surface treatment to obtain maximum bond strength. They also found that bond strength increased with an increase in aluminum oxide particle size. The analysis of all the parameters used in assessing the bond strength between metal and porcelain confirmed that the bond was strongest in the surface sandblasted using 110 μm and 250 μm aluminum oxide particles.[20]

Based on different studies conducted, 110 μm aluminum oxide particle size was decided for sandblasting of all the alloys as they gave the highest bond strength values.[20-26]

The air-abrasion for Tilite alloy was done using Talladium's Brazilian (reddish-brown) aluminum oxide particles sized 110 μm using a pressure range of 65–85 psi as recommended by the manufacturer.

The mean shear bond strength values for the Groups A1–10, B1–10, C1–10, and D1–10 were 22.8960, 27.4400, 13.2560, and 25.3440 MPa, respectively. The sandblasted Co-Cr alloy had the highest and nonsandblasted titanium alloy had the lowest bond strength value. Only sandblasted Co-Cr and sandblasted titanium alloy met the ISO standards for metal-ceramic dental restorative systems, i.e., a shear bond strength value of more than 25 MPa.[27]

The mean bond strength value of Wiron 99 obtained in this study was more or less similar to the results obtained by other authors.[28-30] Nieva *et al*. in their study compared the bond strength of Co-Cr and titanium-based alloys to different ceramics after different surface treatments. They found that sandblasting produced the best results with both alloys and that the bond strength of Co-Cr alloys in general was higher than that of titanium alloys.[13]

Similarly, de Melo *et al*. studied the shear bond strength of Ni-Cr and Co-Cr alloys to porcelain and found that there were no significant differences in the shear bond strength of alloys tested. The alloy Wiron 99 presented with mean bond strength of 63.0 ± 13.5 MPa. Highest mean bond strength was seen with the Co-Cr alloy IPS d. SIGN, 71.7 ± 19.2 MPa.[31]

However, these results were conflicting with the results obtained in other few studies.[32-34] The difference could be attributed to difference in alloy and porcelain compositions, variations in sample size, and difference in the testing methodology.

According to John McLean, apart from beryllium, aluminum, niobium, and manganese, alloying additions could be made to base metal alloys to control the formation of thick layer of chromium oxide at higher temperatures which improves the bonding of metal to porcelain. Some other trace elements which improve the adhesion of oxide to metal are zirconium and silicon.[35]

Based on these findings, the presence of 6% molybdenum, 1% manganese, and 1% silicon and the highest chrome content, i.e., 29% among the three alloys, in Lithecast could be one of the reasons why Lithecast Co-Cr alloy presented with the highest bond strength values. Thermal coefficient compatibility was also an important factor as demonstrated in the study by de Melo.[31]

Bruggers *et al*. studied the role of manganese in alloy-porcelain bonding. They found that during oxidation of manganese containing alloys, spinels were formed which adhered strongly to substrate alloy and retarded excessive oxidation which favored a strong alloy-porcelain chemical bond. The presence of manganese in Lithecast could thus be a factor increasing its bond strength.[36] Manganese was not present in Wiron 99 or the Tilite alloy used in this study.

The lower bond strength values observed with Wiron 99 alloy, similarly, could be attributed to the absence of silicon and manganese in the alloy.

The highly significant difference between Groups C and D suggested that sandblasting with 110 μm aluminum oxide particles drastically improved the shear bond strength of titanium alloys.

Therefore, based on the results obtained, Tilite alloy and the Lithecast alloy can be successfully used with the porcelain system (Ivoclar Classic) used in this study and will be beneficial for hypersensitive patients. However, the compatibility of Ni-Cr alloy (Wiron 99) and porcelain (Ivoclar Classic) used in this study still is questionable and needs further research.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions could be drawn.

1. Nickel and beryllium free Co-Cr alloy (Lithecast) and more biocompatible titanium alloy (Tilite) can prove to be good alternative to Ni-Cr alloys in case of hypersensitive patients
2. Sandblasting significantly improved the bond strength of titanium alloy (Tilite) with porcelain (Ivoclar Classic)
3. Ni-Cr alloy (Wiron 99) and nonsandblasted titanium (Tilite) alloy did not meet the ISO standards for shear bond strength
4. Further studies are required to assess the compatibility of Ni-Cr alloy (Wiron 99) and the porcelain used in this study (Ivoclar Classic).

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Conflicts of interest

There are no conflicts of interest.

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