

Original Article

Investigation of the effect of bonding factors on strength of porcelain bond to soft metal alloys after application of thermal cycle

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ABSTRACT

Background: The chemical bond between the metal and the porcelain component is likely to fail in metal-porcelain restorations. This is due to the thick oxide layer that Cr–Co alloys create. This study aimed to investigate the effect of metal conditioner on controlling the oxide layer formed on the surface of the Sintron alloy and the strength of the metal–porcelain bond.

Materials and Methods: In this *in vitro* study, 33 samples were divided into three groups based on surface treatment ($n = 11$). In all three groups, an oxide layer was created. In the first group, Shofu metal conditioner, in the second group, metal conditioner of Creation, and in the third group, no metal conditioner was applied. All samples were then subjected to 3000 heat cycles between 5° and 55°C with a stop time of 5 s. The specimens were then placed in a universal testing machine for shear bond testing. A force was applied between the alloy and the porcelain by a 5 kN load cell at the speed of 1 mm/min until a fraction occurred. Intergroup comparison was made by the one-way analysis of variance followed by the Tukey's multiple comparisons test ($\alpha = 0.05$).

Results: The mean shear bond strength of the first group was 34.93 MPa and the mean shear bond strength of the second group was 31.37 MPa. The mean shear bond strength of the first and the second group was significantly higher than the third group (23.37 MPa) ($PV < 0.001$).

Conclusion: The use of metal conditioners between ceramill Sintron alloy and porcelain (Vita VMK MASTER) led to increasing the bond strength.

Key Words: Chromium alloys, dental porcelain, metal conditioner, shear strength

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INTRODUCTION

Porcelain-fused-to-metal system is the most common indirect restoration in dentistry.^[1] Precious and nonprecious metal alloys are used in this regard. Noble alloys used in the infrastructure of these restorations have an excellent bond to the porcelain, good mechanical properties, and high biocompatibility. However, due to the high price of these alloys, their uses are limited.^[2]

Nickel–chrome alloys, which were cheaper than gold, were firstly introduced for partial veneers, bridges, and custom frames. However, many adverse reactions have been reported following the use of these alloys. Nickel in particular has played a major role in causing these reactions.^[3] Nickel and beryllium alloys are carcinogens in animals.^[4,5] Toxic and allergic

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reactions and issues in metabolic processes have been reported in some cases.^[6,7] Beryllium vapors from metal spills can cause conjunctivitis, dermatitis, and bronchitis.^[8,9] Cobalt–chromium (Co–Cr) alloys were later developed to eliminate the toxic effects.^[10-12]

Among nonprecious alloys for metal-porcelain restorations, Co–Cr alloys have become very popular due to their good mechanical properties, such as high coefficient of elasticity, resistance to permanent deformation, and low toxicity.^[13-15]

The half-life of metal-porcelain restorations depends on various factors, including the bond strength between porcelain and the underlying metal structure.^[16] Proper oxidation of the metal surface is required for a stable bond between the metal alloy and porcelain to prevent the porcelain from denaturation.^[17] Nonprecious metal alloys are easily oxidized, and a thick oxide layer is formed on the alloy during porcelain production. The high thickness of the oxide layer causes problems in the bond between the porcelain and the alloy due to the formation of cracks inside the oxide layer.^[18] To solve this problem, attempts have been made to modify the components of the metal alloy^[19] or methods of preparing the alloy surface, such as degassing,^[20] increasing the firing temperature of the porcelain opaque layer,^[21] and the use of abrasives.^[22]

The durability of restorations can also be affected by intraoral conditions, such as the chewing cycle and temperature changes that occur with food intake.^[16] To make laboratory conditions more similar to clinical conditions, some laboratory studies have used a combination of mechanical and thermal cycles.^[23-25] In general, during mechanical cycles, a force is repeatedly applied to the specimens that mimic the chewing cycles,^[26] while in the thermal cycle, sudden and extreme thermal changes are applied to mimic the oral condition.^[27] Another way to reinforce the bond between alloy and porcelain is to use bonding agents (metal conditioners).^[28]

The most frequent issue with metal-ceramic restorations is the fracture of veneering porcelain and its chipping from metal-ceramic restorations.^[29] Due to the frequency of porcelain chipping from metal-ceramic restorations according to recent clinical studies, the importance of shear bond strength between metal and porcelain has increased.^[30] However, previous studies have not reached a certain solution to this issue. Hence, this study was designed

to investigate and compare the effect of two different metal bonds on the shear strength of metal–porcelain bonds while the oxide layer exists on the alloy surface. The null hypothesis was that the two tested metal bonds do not affect the shear bond strength of metal–porcelain bonds.

MATERIALS AND METHODS

Study procedure

This *in vitro* study was approved in research and ethics committee of Isfahan (NO: 50545). In the present *in vitro* study, Co–Cr metal alloy (Sintron – Soft Metal, Amann Girrbach) was used. According to the manufacturer's instructions, 33 disk-shaped samples with a diameter of 10 mm and a thickness of 2.5 mm were milled by CAD/CAM machine (IMES-ICORE 340). The bonding surface of the metal samples was polished with silicon carbide paper with a particle size of 400 nm under heavy cooling. Then, the bonding surface of the samples was subjected to airborne-particle abrasion by 110 alumina particles at a pressure of 4 bar for 10 s with a distance of 5 mm from the nozzle of the device and an angle of 45° to the sample surface. Ultrasonic purification was then performed using isopropyl alcohol (70%), and the samples were allowed to dry at room temperature. Then, the samples were subjected to the oxidation process [Figure 1] under the recommended conditions in the furnace (Koosha Fan Pars Model: Auto term 300) at 910°C for 20 min.

In the center of the sample's surface, which was subjected to airborne-particle abrasion, a 5 mm diameter area was created by covering the rest of the sections with adhesive tape to limit the porcelain

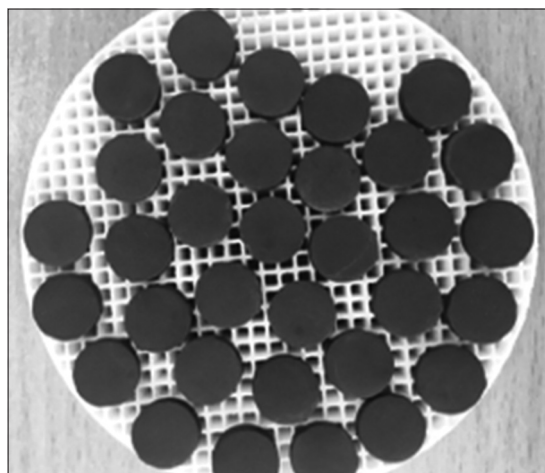


Figure 1: Samples after oxidation procedure.

curing area and applying a thin layer of metal conditioner. Then, the adhesive tape was removed, and the metal conditioner, which was applied on the alloy surface, was placed in the oven and cooked according to the instructions presented in Table 1.

After cooking the metal conditioner, the adhesive tape was placed on other areas of the sample surface except for the part where the metal conditioner was applied. APEC (Asia-Pacific Economic Cooperation) porcelain (Vita VMK Master) was then applied to the conditioner and cooked. Dentin porcelain was mixed with distilled water according to the manufacturer's instructions. A mold made of compressed plastic with a diameter of 5 mm and a height of 1.5 mm was placed on the APEC porcelain. Then, the mold was removed and porcelain was cooked. Finally, the porcelain went under a glazing process to complete the sample production process. The process was the same for all samples, and the only difference between the samples was in the type of applied metal conditioner. Accordingly, the samples were divided into three groups as follows:

- Group 1: Eleven samples having oxide layers and application of metal conditioner type Shofu (Japanese)
- Group 2: Eleven samples having oxide layers and application of metal conditioner type Creation (USA)
- Group 3: Eleven samples having oxide layers but without applying any metal conditioners.

All samples were subjected to a thermal cycle. Each sample was immersed in ionized water for 3000 cycles at 55.5°C. It remained stationary for 1 min at each temperature and the transfer time from one temperature to the next was 30 s.

The samples were placed in an autopolymerizing resin in the universal testing machine (k-21046, Walter + bai, Switzerland) for transverse strength testing. To perform this test, a 5 kN load cell at a speed of 1 mm/min was used until a fraction occurred [Figure 2]. The force was

applied parallel to the bonding surface of the samples between the alloy and the porcelain [Figure 3]. Shear bond strength (MPa) was obtained using the following formula:

$$\text{MPa} = \text{Maximum force (N)} / \text{bonding surface (mm)}$$

Statistical analysis

Kolmogorov-Smirnov and Levene tests were used to check the normality and the homogeneity

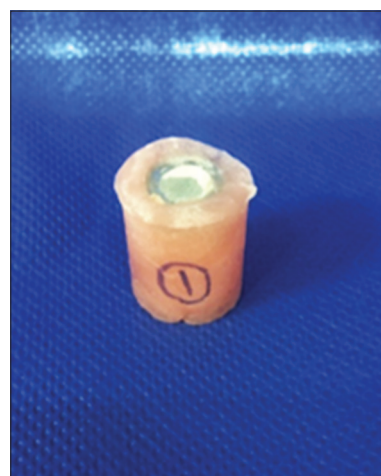


Figure 2: A sample after shear bond testing and separation of porcelain from metal.

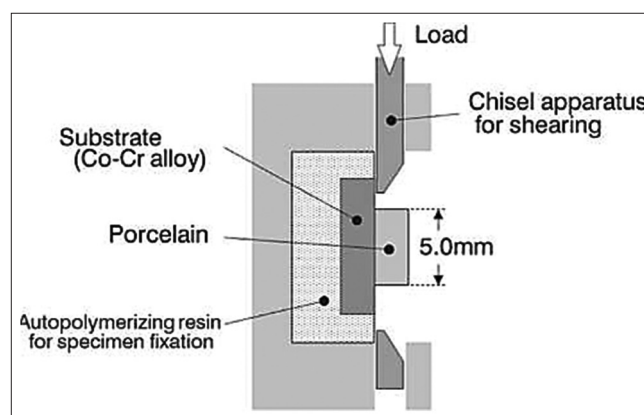


Figure 3: Applying a shear force parallel and close to the bonding surface of the samples between the metal and the porcelain.

Table 1: Cooking program for metal conditioners and porcelains according to manufacture's instructions

Material	Predrying temperature (°C)	Drying time (min)	Heating rate (°C/min)	Firing temperature (°C)	Holding time (min)
Shofu metal bond	500	5	60	960	1
Creation alloy bond	550	6	80	980	1
Opaque	500	5.38	80	950	1
1 st dentin	500	7.49	55	930	1
2 nd dentin	500	7.38	55	920	1
Glazing	500	5.15	80	920	1

of data, respectively. The one-way analysis of variance (ANOVA) was used to evaluate the interaction of various alloy surface modification methods on shear bond strength, and Tukey’s supplementary test was used to determine the statistical differences after the ANOVA test ($\alpha = 0.05$).

RESULTS

Data analysis of the present study indicated that the mean shear bond strength value was significantly different among the three study groups.

Table 2 shows the mean, standard deviation, minimum, and maximum shear strength of samples. According to Tukey’s tests, statistically significant differences were obtained for the shear strength between C and MSh samples ($P = 0.001$), C and MC samples ($P = 0.018$), and MSh and MC samples ($P = 0.405$).

Tables 3 and 4 compare the mean shear bond strength of the test materials between groups using the one-way ANOVA and pairwise comparison using Tukey’s honest significant difference *post hoc* test.

Figure 4 shows the mean shear bond strength within the three groups. The mean shear bond strength was significantly different between the three groups.

DISCUSSION

The most important metal–porcelain bonding mechanisms in PFM (Porcelain Fused to

Metal) restorations are van der Waals forces, micromechanical bonding forces, and chemical bonding. To establish a chemical bond between the two components, electrons must be transferred between the crystalline part of the porcelain and the metal oxide. The presence of an oxide layer is necessary to strengthen the bond between the metal and the porcelain. Where the coupling part is made of noble metals, due to the fact that these metals do not oxidize, small amounts of base and nonprecious metals (usually indium and tin) are added to the alloy, which forms an oxide layer during the firing process. On the other hand, when in these restorations, the coupling is made of base alloys, a thick oxide layer is formed, which leads to fracture during porcelain firing processes and can reduce the bond strength.^[31]

In the present study, we investigated the bond strength between the metal and the porcelain in PFM restorations with chromium–cobalt alloys when/when not using metal conditioners. Both metal conditioners had a significant effect on increasing the bond strength compared to the control group.

A metal conditioner is usually a paste, powder, or liquid that is mixed together. In titanium metal restorations, it has been suggested to use metal conditioner for bonding to porcelain, but in Cr–Co metal restorations, the manufacturer’s instruction is different for various kinds of ceramics. Metal conditioners of different brands have different chemical compositions, which makes them have different effects on the metal–porcelain bond. However, almost all kinds of metal

Table 2: Mean, standard deviation, minimum, and maximum shear strength of samples

Groups	Shear strength					
	Mean	n	SD	Minimum	Maximum	SEM
C	23.37	11	5.61	15.61	30.68	1.69
Msh	34.93	11	6.57	24.92	49.40	1.98
Mc	31.36	11	6.99	19.07	40.75	2.10
Total	29.89	33	7.92	15.61	49.40	1.37

C: Samples without metal conditioner; Msh: Samples with Shofu metal conditioner; MC: Samples with creation metal conditioner; SEM: Standard error of mean; SD: Standard deviation

Table 3: Analysis of variance

Source of variation	Sum of squares	df	Variance	F	P
Between groups	762.059097	2	381.029548	6.31	0.005
Within group	1810.165	30	60.3388333		
Total	2572.2241	32	80.382003		

Tukey’s HSD *post hoc* test

Bartlett’s test for equal variances: $\chi^2(2)=1.6660$; $P>\chi^2=0.435$. HSD: Honestly Significant Difference

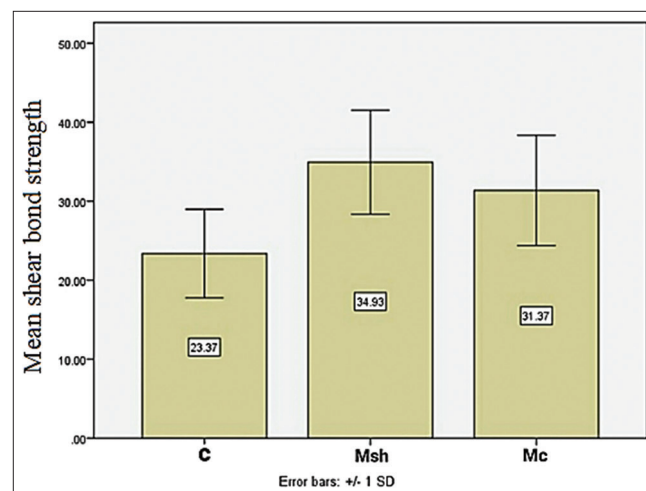


Figure 4: Mean shear bond strength (MPa) between the three groups. C: Samples without metal conditioner; Msh: Samples with Shofu metal conditioner; MC: Samples with Creation metal conditioner; SD: Standard deviation

Table 4: Comparison of the mean shear bond strength of the test materials using one-way analysis of variance and pairwise comparison using Tukey Honestly Significant Difference *post hoc* test

Sample	Contrast	SE	Mean difference	Tukey (95% CI)	P
Msh versus C	11.47364	3.312204	3.46	3.308154-19.63912	0.004
Mc versus C	8.013636	3.312204	2.42	-0.1518456-16.17912	0.055
Mc versus Msh	-3.46	3.312204	-1.04	-11.62548-4.705482	0.555

C: Samples without metal conditioner; Msh: Samples with Shofu metal conditioner; MC: Samples with creation metal conditioner; SE: Standard error; CI: Confidence interval

conditioners reinforce the junction between the metal and the porcelain by chemical bonding. The main elements of both metal conditioners used in this study were Si and Ti. Studies have shown that the silica element in the metal conditioner compound absorbs metal oxides that form on the metal surface during porcelain, the cooking process.^[32] Ti also acts as an oxygen scavenger in its composition and plays an important role in preventing the formation of an oxide layer on the metal surface during the cooking process, since cracks, formed inside the oxide layer, endanger the bonding.^[18,32,33]

According to the results of the present study, metal conditioners that have Si and Ti in their chemical composition increase the strength of the metal–porcelain bond and control the thickness of the oxide layer.

In previous studies,^[34] metal conditioners were gold-based and made for gold alloys, or that tungsten was the main component. Tungsten does not have a significant role in controlling oxide layer thickness, and its role is to prevent the oxide layer from being washed by APEC porcelain and make the oxide layer hard and impermeable.

In some studies on titanium alloy restorations, it has been concluded that the use of metal conditioners on a metal surface that has already undergone the airborne-particle abrasion process increases the bond strength between the metal and the porcelain due to the significant wettability of the metal surface.^[33] A characteristic of the present study was surface treatment and airborne-particle abrasion of the samples. The use of metal conditioners may also be more effective for Cr–Co metals if subjected to airborne-particle abrasion, but confirmation of this hypothesis requires further investigation in future studies.

A study by Yoo *et al.*^[35] examined the claims of metal conditioner manufacturers that these materials are coefficient of thermal expansion (CTE) balancing agents and confirmed that if Cr–Co and porcelain

are selected in a way that their CTEs are not compatible, the higher bond strength will be obtained in the group that used metal conditioner. The bond strength between the metal and the porcelain in PFM restorations, according to ISO 9693, is higher than 25 MPa and the mean bond strength obtained is lower than this value in the group that did not use metal conditioner. Therefore, it is likely that the use of metal conditioner is essential in restorations with metal base (specifically in this study, soft metal chrome cobalt alloy).

Another factor that influences the success of porcelain-metal restorations is the resistance of the metal–porcelain bond to thermal, mechanical, and chemical stresses in the mouth. In this study, the simulation of thermal stresses in the mouth by placing samples in thermal cycles has been performed. Totally, 3000 thermal cycles were applied to the samples, which is approximately equivalent to 2.5 years.^[25]

There are many methods for measuring the bond strength, the best of which is the shear test, flexural 3 points, and flexural 4 points. The shear test was chosen because it exerts a force on the area of the initial contact between the metal and the porcelain and, unlike flexural tests, the coefficient of elasticity of the metal does not affect the result.^[36]

The present survey was limited to the lack of complete simulation of the oral environment regarding sample shape and other characteristics and difficulty in accessing different brands of metal conditioners. Therefore, it is recommended for future studies resemble oral conditions more accurately. It is also suggested to investigate the effect of both airborne-particle abrasion and metal conditioners together on bond strength.

CONCLUSION

According to the results of this study and considering the limitations, the use of Creation (USA) and Shofu (Japanese) metal conditioners to increase

the bond strength between Ceramill Sintron and porcelain (Vita VMK Master) was approved.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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